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Research paper

System-Wide Analysis of the Plastics Value Chain in Indonesia: The Five Levels of Information

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Abstract

This study examines the complex challenges of achieving a circular plastics value chain in Indonesia. Applying the systems-based approach of Complex Value Optimisation for Resource Recovery (CVORR), the study highlights the importance of understanding the dynamic interconnections between natural, social, economic, and political subsystems. The analysis reveals that rather than purely technical or financial, the barriers to circularity lie also in institutional frameworks, norms and power structures, that govern how resources are managed. Addressing these systemic lock-ins requires coordinated and inclusive strategies. These include strengthening regulatory frameworks to support infrastructure investment and innovation, advancing policy reforms and shifting societal norms. Achieving the adoption of such holistic, system-wide interventions is the only pathway to supporting Indonesia's vision to transition to a circular plastics economy; a transformation that must be driven by human agency and underpinned by strong political will. This approach, if effectively implemented, will provide a robust foundation for far-reaching environmental, economic, technical and societal benefits.

Keywords: System Analysis · CVORR · Indonesia · Circular Plastics Value Chain · Systemic Interdependencies · Plastic Pollution Prevention

1. INTRODUCTION

Assessing the complex, multidimensional value of material, component and product value chains — including both positive and negative impacts across the environmental, economic, social, and technical domains — in a sustainable circular economy (CE) context requires a systems-based approach (Iacovidou et al., 2017). Although a clear definition for such approaches is currently lacking, their importance in holistically evaluating the interplay of various factors is widely acknowledged within the global community (Yalçın & Foxon, 2021).

Despite ongoing efforts to develop tools for systemic assessments, many fall short of capturing a comprehensive understanding of resource and waste management systems (Khan & Kabir, 2020, Zhang et al., 2021). This is because existing approaches often focus on the most immediate or visible problems, neglecting the broader systemic inefficiencies that drive these issues (Iacovidou et al., 2021). For example, water companies may apply restoration technologies in rivers to preserve biodiversity without addressing the root causes of water pollution (Li et al., 2022, Md Anawar & Chowdhury, 2020). Similarly, local authorities may implement food

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waste collection programmes to meet regulatory targets without adequately employing communication strategies for educating residents, leading to program failures (Pickering et al., 2020). In the plastics sector, the introduction of biobased biodegradable plastics, intended to solve environmental pollution problems - has unintended consequences that are not fully understood (Gerassimidou et al., 2021). Likewise, the proliferation of disposable vape pens to address health concerns has created a hazardous waste stream, posing multifaceted challenges for waste management and regulatory enforcement (Main et al., 2024). These examples exemplify the need for a systems-based approach; one that provides holistic, evidence-based insights into how various dimensions fit within ecological, economic, regulatory, technological, and cultural contexts to promote circularity. The CVORR (Complex Value Optimisation for Resource Recovery) approach was developed specifically to address this need (Iacovidou et al., 2020).

CVORR offers a structured methodology for identifying the root causes of systemic inefficiencies and optimising multidimensional value recovery in alignment with CE objectives. It achieves this by pinpointing key intervention points and conducting their sustainability assessment, ultimately leading to system optimisation (Iacovidou et al., 2017). The CVORR's methodology encompasses three progressive stages: 1) the core stage, which establishes a baseline analytical tool; 2) the intermediary stage, which involves system evaluation, and 3) the final stage, which supports system refinement and optimisation. Together, these stages provide a comprehensive understanding of how multidimensional value is created, destroyed, and distributed across resource and waste management systems (Iacovidou et al., 2020). In this context, the term 'management system' refers to the entire value chain, from production to end-of-life fate (otherwise known as end-of-life management), acknowledging that each phase consists of multiple processes. However, for the sake of clarity and simplicity, it is often presented as a straightforward production-consumption-management system.

The CVORR baseline analysis—the core stage of the methodology—comprises five key steps. Key to this step-process is a conceptual analysis of the system's structures, dynamics, and drivers. This analysis is guided by the Five Levels of Information (5LoI) framework (Iacovidou et al., 2020). which explores the interconnections between five sub-systems that represent the internal, inherently interlinked components, or 'gears', that shape the behaviour and functioning of a resource system or value chain, within specific cultural, spatial, and temporal contexts. Through analysis of these sub- systems, CVORR's 5LoI provides a deeper understanding of systemic complexity, exposing inefficiencies, persistent linear patterns and underlying structural barriers, or 'lock-ins', to circularity. This insight informs the identification of LoI-specific interventions - technical, infrastructural, policy, economic and communication-based – that are critical for enabling sustainable transitions. Ultimately, this approach strengthens efforts to close material loops effectively and sustainably (Iacovidou et al., 2021).

The present study aims to demonstrate the necessity of employing the CVORR's 5LoI framework to uncover the lock-ins that hinder progress towards circularity, using the Indonesian plastics value chain as a case study. The selection of this case study is informed by three years of research under the Plastics in Indonesian Societies (PISCES) project that investigated the barriers to plastic pollution prevention and circularity. Over the past decade, Indonesia's economic growth has led to rising living standards and its transition to a middle-income nation (Arisman & Fatimah, 2023), which has contributed to a significant rise in plastic consumption. As of 2018, plastics represented approximately 15% of the total waste generated in Indonesia (NPAP, 2022, SYSTEMIQ, 2021b),less than half of which is effectively managed by municipal waste management systems (Patton & Li, 2021). This ineffective management posed and continues to pose, mounting risks to the environment, climate, public health, and the overall sustainability of Indonesia's future economic development (Arisman & Fatimah, 2023), demanding a shift from the current economic model.

Given Indonesia's extensive geographical spread, diverse population densities, and uneven resource distribution, analysing the plastics value chain is imperative to tackling pollution and promoting circularity (Becerra, 2021). A deep understanding of systemic inefficiencies in the Indonesian plastics value chain is currently lacking, preventing an accurate diagnosis of the underlying issues that govern plastic waste mismanagement and associated pollution, which in turn hinders the development of coordinated and effective interventions. This presents a challenge in creating a circular plastics economy. Using the CVORR's 5LoI framework aims to address this gap and assess the interconnected complexities of the Indonesian plastics value chain. The research objectives focus on gaining a deeper understanding of the intertwined nature of the natural, social, economic and political sub-systems to grasp and address the root causes of plastic pollution effectively and provide valuable insights for transitioning Indonesia towards a circular plastics economy.

The paper is structured as follows: Methodology (Section 2) details the CVORR approach and the 5LoI framework. Results (Section 3) presents the system analysis findings for Indonesia's plastics value chain based on the 5LoI framework. Discussion (Section 4) highlights key considerations for advancing a more sustainable plastics system, followed by Conclusions (Section 5), which summarize the main outcomes and implications of the study.

2. METHODOLOGY

The study employs CVORR's baseline analytical tool. The tool is specifically developed to unpack the complexities governing materials, components and products (MCPs) value chains, and identify inefficiencies, structural barriers, blind spots and levers of change to advance sustainable circularity.

2.1 Description of the Tool and Analytical Procedure

The baseline analytical tool comprises five steps, as shown in Figure 1. Step 1 involves defining the scope and goals of the analysis. Step 2 sets the main objectives and establishes system boundaries, forming the foundation for system depiction. The system analysis begins in Step 3 with a Material Flow Analysis (MFA), which outlines the system's boundaries, material stocks, flows, and the key processes associated with these flows. MFA is described as a *"systematic assessment of the flows and stocks of materials within a system defined in space and time"* (Brunner & Rechberger, 2016), p.1984. Step 4 involves identifying and quantifying monetary flows to support stakeholder mapping, a crucial step in understanding activities within the value chain, including their coordination and management, structure and drivers.

Following Step 4, is a detailed stakeholder analysis, using the Mendelow matrix to provide valuable insights into the governance and dynamics within the value chain (Cuofano 2023, Mendelow, 1991). This analysis reveals how contextual factors, value-adding activities, stakeholder interactions, and network dynamics are shaped by the system's processes and values. The baseline analysis concludes with Step 5, which involves applying the 5LoI framework. Although detailed results from the MFA and stakeholder analyses are presented in forthcoming publications, their absence here does not detract from the 5LoI-based analysis. On the contrary, this demonstrates the adaptability of CVORR's baseline analysis to different needs and its capacity to deliver comprehensive, layered systemic analysis.

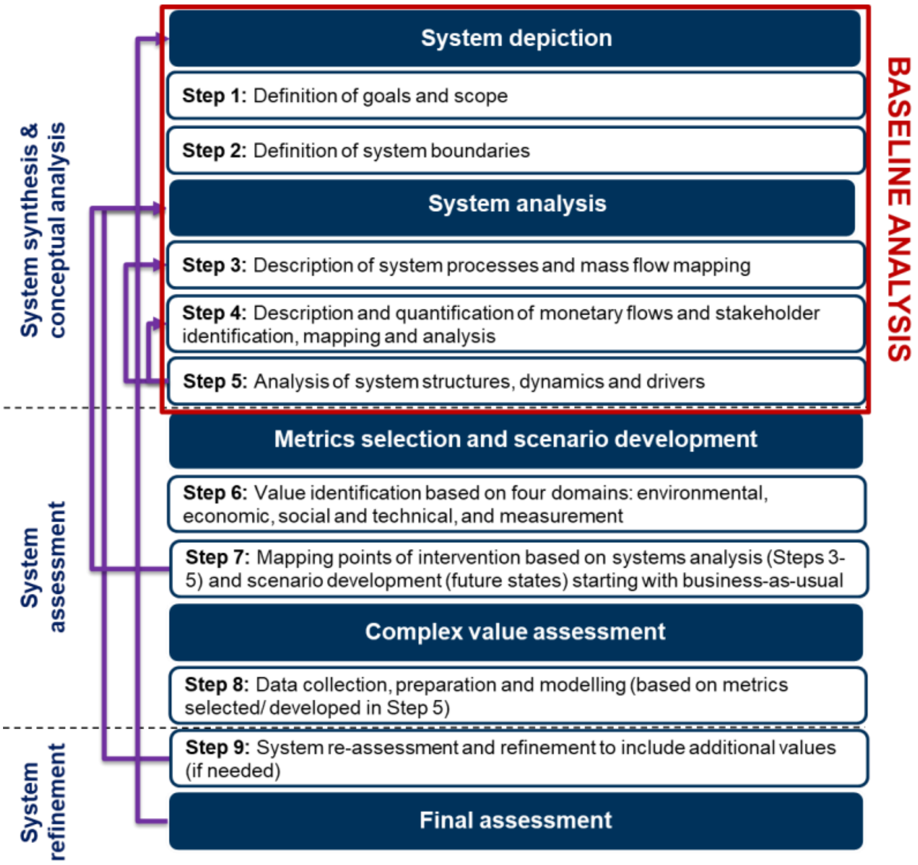


Figure 1. The CVORR Approach. Adopted (Iacovidou et al., 2020)

The 5LoI framework includes: 1) the natural environment and provisioning services, 2) infrastructure, technology, and innovation, 3) the regulatory and political landscape, 4) market and business activities, and 5) consumer/end-user behaviour. These five levels (or sub-systems) are deeply interconnected, meaning that changes at one level influence the entire system. Practical experience has shown that a systematic approach starting from the innermost level of 'Natural Environment and Provisioning Services' (1st level) and progressing outward to 'Human Behaviour, Needs, and Practices' (5th level), is the most effective (**Figure 2**). This is because the natural environment is the foundation of any resource recovery system, shaping behavioural patterns, that, in turn, influence service provision and drive production and consumption dynamics. This approach enhances our understanding of the interconnections within the system and facilitates the formulation of targeted, evidence-based recommendations to advance sustainable circularity.

As illustrated in **Figure 2**, each level of information within the framework offers distinct and valuable insights into how materials, components, and products (MCPs) are managed across both upstream and downstream parts of the value chain. This layered perspective enables a structured analysis of the relationships between levels, facilitating the robust identification of structural barriers that reinforce linear practices and hinder circularity. Such systemic lock-ins often stem from institutional, economic, technological, or social constraints, thereby limiting the system's capacity for transformative change towards circularity.

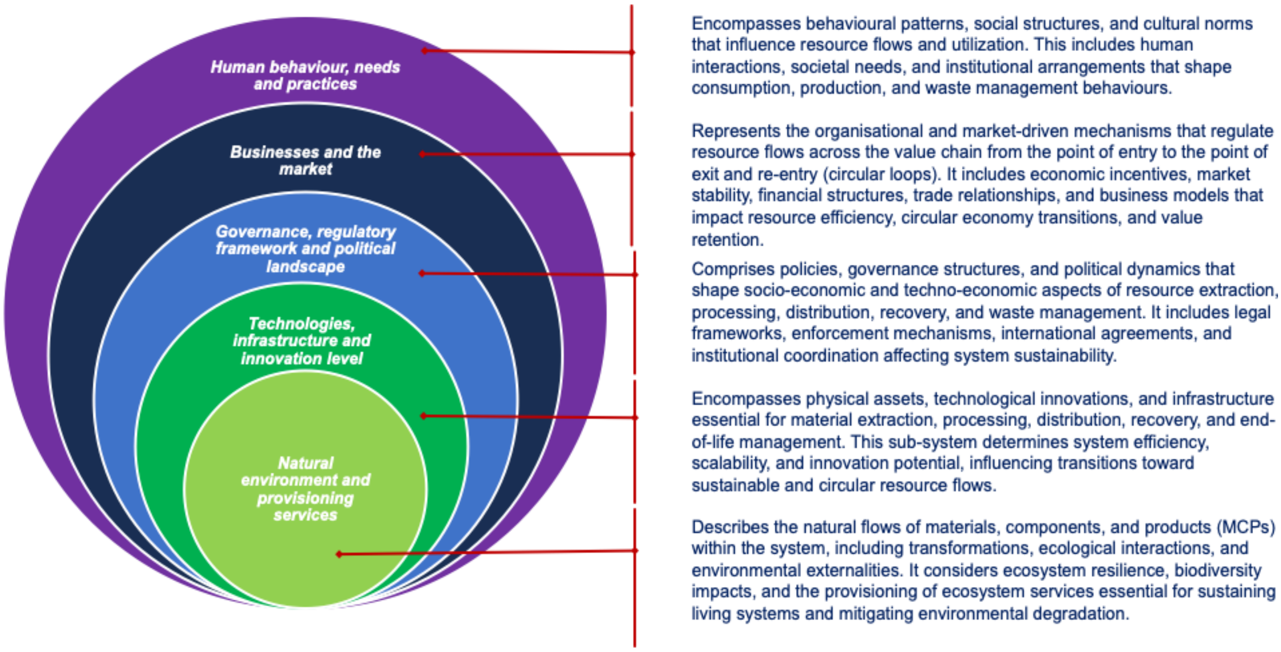


Figure 2. The 'Five Levels of Information' (5LoI). A conceptual approach to understanding the dynamics, drivers and barriers of resource recovery systems. Source: (Ebner & Iacovidou, 2021)

Table 1 outlines the checklist associated with each level of the 5LoI framework, providing implementation guidelines on the types of evidence required for data collection and the key research questions that need to be addressed at each level.

Table 1. Implementation Checklist of the 5LoI Framework. Adapted by (Iacovidou, 2021)

Sub-system	Checklist	Guidance
Natural environment and provisioning services	*Define the following:* • *MCPs flows and their cyclical ability* • *MCPs attributes (e.g., composition, design, recyclability, degradation potential)* • *Service linked to distribution, disposal and management MCPs* • *Impact of MCPs on ecosystem(s)/ecosystem services*	*Include in your description:* • *The sources, pathways and fate of MCPs from the point of entry to the point of exit* • *Use Guidance Template 1&2 (Supplementary Material) to detail MCPs properties, including functionality, structure and their influence on production, consumption and management.* • *The services supporting MCP supply, distribution and post-consumption management.* • *The environmental, economic, social and technical impacts of MCP-related activities involved in the production, consumption and management, on community, natural environment and ecosystem services, and infrastructure (e.g., damages).*

Technologies, infrastructure and innovation level	*Define the following:* • *Identify MCPs production and processing infrastructure (only within the system boundaries)* • *Identify MCPs collection and management infrastructure* • *Waste management protocols* • *Ongoing innovation initiatives supporting circularity*	*Include in your description:* • *Details on the location, capacity and efficiency of MCPs manufacturing infrastructure, including technical capacity and regional coverage* • *Details on collection coverage and the location, size/capacity of waste management infrastructure. Specify the technology types, and their advancement level* • *Waste facilities performance, including reject rates and recovery efficiency* • *Financial incentives, and policy-driven innovation strategies (e.g., alternative technologies and waste valorisation)*
Governance, regulatory framework and political landscape	*Define the following:* • *Key government structures and their regulatory role* • *Level of policy enforcement* • *Policies and policy instruments associated with MCPs management* • *Governance challenges and decision-making procedures*	*Include in your description:* • *National and international regulations governing MCPs production, consumption and management* • *Regulatory effectiveness, enforcement mechanisms and institutional capacity to ensure compliance with regulations* • *Policy targets, instruments and incentives (e.g., subsidies, taxation) and institutional capacity that drive MCPs circularity* • *Political barriers to achieving sustainability targets, including vested interests, corruption, vvvtransparency and governance constraints*
Businesses and the market	*Define the following:* • *Market trends that drive the supply and demand for MCPs* • *MCPs design and standardisation requirements* • *Businesses commitment to meeting common goals and targets* • *Market stability and price volatility at production and management* • *Investment in infrastructure, workforce and technology*	*Include in your description:* • *Design specification of products that serve multinational markets, branding strategies, reputation, marketability* • *Product design trends and businesses willingness to adopt sustainable practices* • *Compliance with regulations and exploitation (greenwashing) of policy instruments and incentives that drive sustainability* • *Price fluctuations and their effects on MCP value chains (import/export dependencies). Specify secondary market stability for repaired, refurbished, repurposed, recycled MCPs* • *Financial mechanisms supporting corporate investments in new technologies and infrastructure, training and capacity building*

Human behaviour, needs and practices	*Define the following:* • *Consumer perception of MCPs provision, consumption/use and disposal* • *Consumer waste management behaviour and service* • *accessibility* • *Societal attitudes, beliefs and cultural norms*	*Include in your description:* • *Consumer purchasing habits, trends, and behaviour shifts* • *Acceptance and participation in waste management services* • *Public awareness and access to information and inclusivity (asymmetry of information provided)* • *Barriers to behavioural change, including education gaps and the role of media in shaping perceptions and behaviour (social, mass, and direct communication)*

Each level of the 5LoI framework informed the types of research questions (**Table 1**) used for structuring our approach to literature searching and discussions in workshops, ensuring that the gathered information was relevant to the analytical framework.

2.2 Application And Case Study

The 5LoI framework is employed in Indonesia, allowing empirical validation of its analytical capabilities. Indonesia is selected as a case study due to its ongoing efforts to address plastic pollution, a challenge exacerbated by rapid economic growth and rising plastic consumption, and its status as a focal area of research under the PISCES project. These factors have placed immense strain on the country's waste management systems, which remain inadequate and underdeveloped. Consequently, there is an urgent need for effective circular economy strategies to improve resource recovery and mitigate environmental impacts. Strengthening Indonesia's resource recovery and waste management infrastructure, not only supports its national sustainability goals but also positions the country as a potential model for other nations facing similar challenges, highlighting the urgency of implementing systemic, sustainable solutions.

2.3 Data Collection and Integration

A mixed-methods approach is employed, combining primary and secondary data sources to enhance analytical depth and reliability. Primary data was collected through a series of personal communications with stakeholders in the plastics value chain, as well as workshops organised in the context of the PISCES project. These interactions allowed for direct insights into the challenges and opportunities faced by participants, fostering a participatory approach to data collection. Secondary sources included a comprehensive review of peer-reviewed literature and grey literature, including government databases, and relevant reports from various national and international organizational stakeholders. This examination provided foundational knowledge and context, enabling the identification of existing frameworks and strategies in plastic management.

The following steps are employed to ensure a robust analysis:

1. **Integrating Theory with Data through Triangulation:** To enhance methodological robustness, we employed data triangulation and cross-referencing from multiple sources. By systematically integrating both primary and secondary data, we ensured greater validity in our findings and strengthened the reliability of the insights generated. This approach aligns with established research methodologies that emphasise the convergence of multiple data streams to mitigate bias and enhance analytical depth.
2. **Aligning Data Collection with the Analytical Framework**: To establish a clear connection between data and the analytical framework, we used the structured checklist presented in **Table 1** that guided the data collection process. Each level of information is analysed using specific descriptive elements that define the underlying sub-systems, ensuring transparency and replicability in analysing complex value chains.

2.4 Limitations and Future Refinements

Recognising the evolving nature of systems-based analysis, this study acknowledges potential limitations, including data availability constraints and model simplifications. While our approach enables a comprehensive understanding of the natural, social, economic, and political sub-systems affecting plastic management, it is essential to acknowledge potential biases and limitations. For instance, the reliance on self-reported data from stakeholders may introduce subjective interpretations of issues, while the selection of specific workshops may not represent the full spectrum of perspectives within the value chain. To mitigate these biases, we employed data triangulation and cross-referencing from various sources to enhance the validity of our findings.

Additionally, while the CVORR 5LoI framework offers a comprehensive analytical approach, its application in this study is solely focused on assessing Indonesia's broader plastic value chain. Consequently, our findings may not fully capture regional and local variations in waste management practices and associated impacts. Differences in governance structures, economic priorities, and cultural contexts can lead to diverse outcomes that require further investigation. Additionally, certain critical dimensions influencing plastic pollution, particularly those shaped by local stakeholders, including government bodies, local communities, and the private sector, as well as other context- specific factors, such as cultural norms and practices, and the prevalence of the informal recycling sector, may be underrepresented. Within the CVORR framework, these aspects are typically addressed through a detailed stakeholder analysis, which falls outside the scope of this study but is examined in a separate work currently under submission. Future research will focus on refining the 5LoI framework through expanded datasets and stakeholder engagement to enhance accuracy and applicability.

3. RESULTS

This section examines the key drivers behind plastic production, consumption and management while also highlighting the barriers that hinder plastic circularity within the Indonesian plastics value chain, using the implementation checklist of the 5LoI framework within the CVORR approach (**Table 1**). This comprehensive, systemic analysis reveals critical areas where targeted interventions are essential to enhance circularity in the plastics value chain. These are aligned with the Indonesian government's broader efforts to promote circularity and achieve its sustainability goals.

Each level of the 5LoI framework is presented in dedicated subsections following the same order, allowing for a focused examination of the sustainability dimensions related to the specific challenges and opportunities identified during the analysis.

3.1 First LoI: Natural Environment and Provisioning Services

3.1.1 Plastic Flow, Attributes and Cyclical Ability

The total mass (based on the production, imports and exports) of plastic MCPs placed on the market is estimated at 11.3 million tonnes (Mt) (Fig.3). The Indonesian Aromatic and Plastic Olefin Association (INAPLAS) reported that in 2019 Indonesia's plastic consumption per capita was 23 kg per person per year (IPEN, 2022a), whereas (Ratnawati et al., 2020) reported that from 2020 to 2024 the annual plastic consumption was 40 kg per person per year. At the polymer level, the main types of plastics produced and consumed in Indonesia are PP, PE, polystyrene (PS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC). Polyolefins (i.e., PE and PP) and PET account for the largest types of plastic consumed.

According to the Statistics Research Department, based on data from 2020, plastic packages consumed within households in Indonesia were estimated at 3.3 Mt (Statistica, 2021). This estimate comprises packages of detergent, cleaning and personal care products (5.2%), food (28.3%), beverages (29.7%) and other household products (36.8%) (Statistica, 2021). The food and beverage packaging sector is the biggest plastic user in Indonesia, which is responsible for 65% (IPEN, 2022a) to 80% (Ratnawati et al., 2020) of the total national plastic consumption. All plastic packaging is of *low intended functionality* as they are designed for short-term or single-use applications, offering specific properties that last for a defined period—typically days, weeks, or months. It is also of *low perceived value* as they are disposable, low-cost, and of minimal importance, while its transformation is rapid and occurs primarily during the *use-life stage* (see *Supplementary Material for further details on intended functionality and perceived value, Annex A*). Indonesia's sachet-based economy, which provides products in small, multi-layered plastic-aluminum packaging, further complicates the functionality and value of plastic packaging (IPEN, 2022a).

While vital for low-income consumers (NPAP, 2020b), sachets have low recyclability and contribute significantly to plastic waste (Rinasti et al., 2022, USAID, 2022), making up 16% of environmental plastic pollution (Patton & Li, 2021). Sachet plastic waste is the most prevalent type found along Indonesian riverbanks (Cordova et al., 2024) and beaches (Cordova et al., 2022). The predominant types of sachets used in the country are those for food and snack packaging, followed closely by packaging for toiletries (Cordova et al., 2023). Unlike rigid plastic packaging like bottles and food containers, which are easier to recycle and are collected more frequently, sachets are not prioritised by formal or informal recycling systems (GIG, 2020, NPAP, 2020b). Sachet waste, often composed of low-value, multi-layered plastics, presents unique difficulties that render it less appealing for formal and informal recyclers (Posadas, 2014). These issues are exacerbated by the socio-economic conditions and operational dynamics of the informal recycling sector, which is frequently marginalized and lacks formal recognition and support.

3.1.2 Services Linked to the Disposal and Management of Plastic Waste

Solid waste management (SWM) provisioning services in Indonesia face significant challenges due to inadequate infrastructure, weak law enforcement, illegal disposal practices, and local geographic and climate factors (GIG, 2020, Lestari & Trihadiningrum, 2019, UN-ESCAP, 2021, World Bank, 2021), leaving large amounts of post-consumer plastic waste uncollected. In many areas, households and small commercial businesses have no choice but to litter or burn waste in open spaces, often near residential areas (NPAP, 2020b). The Indonesian government's efforts to expand and diversify SWM infrastructure across the nation fall short due to the lack of substantial capital investment and a sustainable funding model for waste collection operational costs – either through centralised tax revenue, enforced retribution fees, or municipal budget allocation. These issues restrict cities to short-term solutions offering limited financial returns (GIG, 2020, NPAP, 2020a, Rimantho et al., 2023, UNCRD, 2016). Rapid urbanisation, population growth, and limited resources add further strain, resulting in widespread open dumping, burning, and the accumulation of plastic waste in the environment (Sembiring & Nitivattananon, 2009).

Over 160 million Indonesians lack access to waste collection, and 40% of the 142 million urban residents have no SWM services (NPAP, 2020a, World Bank, 2021). Most mismanaged plastic waste (72%) comes from medium-sized cities and rural regions (IPEN, 2022a, NPAP, 2020b, Patton & Li, 2021), where 85% of plastic waste goes uncollected (World Bank, 2021). These communities often lack the financial and technical resources for effective SWM, making government support essential for progress (Patton & Li, 2021, SYSTEMIQ, 2021a). Remote coastal areas generate less waste but are more vulnerable to pollution due to limited waste services, seasonal storms, and high transportation costs (Phelan et al., 2020). For example, nearly half the waste in remote coastal communities in southern Sulawesi and Flores leaks into the ocean, worsened by ocean currents carrying additional debris (Phelan et al., 2020).

3.1.3 Impact of Plastic Waste on Ecosystem(S)/Ecosystem Services

Impacts on ecosystems: Indonesia is a major source of marine plastic pollution, with approximately 83% originating from land-based sources (World Bank, 2021). This causes extensive pollution in coastal areas (Purba et al., 2019, Syakti et al., 2017), sediments (Alam et al., 2019, Manalu et al., 2017), water surface (Alam et al., 2019, Syakti et al., 2017) and deep sea (Cordova & Wahyudi, 2016). A study of nine river outlets in Jakarta Bay found plastics made up 59% by abundance and 37% by weight of total debris, with Styrofoam and plastic wrap being the most prevalent types (Cordova & Nurhati, 2019).

In 2018, clean-up activities of coastal beaches in Indonesia found 57,589 marine debris items, of which 63% were single-use plastics (SUPs) (NPAP, 2022). Flexible plastics, such as bags, sachets, and wrappers, are responsible for around three-quarters of plastic leakage (Ismawati et al., 2022, NPAP, 2020a). The Ministry of Environment and Forestry reported that 10 billion plastic bags, equivalent to 85 kt, enter the environment annually (Ratnawati et al., 2020) with severe consequences for marine ecosystems and waterways. Several major Indonesian rivers, including the Brantas, Ciliwung, Citarum, Progo, Solo, and Serayu, rank among the world's 20 most polluted rivers (FairPlanet, 2023, Ratnawati et al., 2020). In 2018, only 3% of the Citarum River met environmental quality standards (IPEN, 2022a), with an estimated 108.77 tonnes of plastic waste entering annually (Rinasti et al., 2022).

In 2019, about 3.2 Mt of plastic waste polluted Indonesia's coastal waters (Patton & Li, 2021), much of it originating from rivers in Java, Sumatra (M. R. Iskandar et al., 2024), and tourist islands (Sea-Circular, n.d.,). These macroplastics eventually degrade into microplastics, worsening long- term contamination and threatening marine life (Silva Filho & Velis, 2022), particularly their growth, health, reproduction, survival and feeding patterns (Kershaw & Rochman, 2015). Moreover, microplastics were detected in 93% of fish species sold in Jakarta, the capital city (Nurhasanah et al., 2024), and 55% of fish species sold in Makassar, the largest city in eastern Indonesia (Rochman et al., 2015), raising concerns about microplastic ingestion and its unknown human health consequences (Barreiros & Raykov, 2014, Lavers et al., 2019).

Impacts on communities: Coastal communities and tourism, which employ 13 million Indonesians, rely heavily on healthy marine ecosystems (GIG, 2020). However, marine plastic pollution is causing significant economic harm, with annual losses estimated at USD 14 billion due to damaged fisheries and reduced tourism (GIG, 2020, Ratnawati et al., 2020). This pollution affects the livelihoods of 3.7 million people dependent on fisheries and over 100 million Indonesians who rely on fish as a dietary staple (NPAP, 2020b). Fishers have also reported reduced catches, attributing the decline to increasing plastic waste on beaches (Patton & Li, 2021). Fishing, seaweed farming, and tourism are all significantly affected by plastic waste in these regions (Patton & Li, 2021, Phelan et al., 2020).

Landfills near residential areas pose additional risks, as wastewater can seep into farmlands, hindering crop growth (USAID, 2022). Around 40% of landfills in Indonesia are open dumps, increasing the risk of water contamination from leachate infiltrating groundwater (Kurniawan et al., 2024). The discharge of leachate from landfills has led to a significant increase in the presence of microplastics, with a three-fold rise observed in these contaminants (Nurhasanah et al., 2021). Open dumpsites also endanger waste pickers with potential injuries and disease transmission and expose both wildlife and livestock, like cows, to plastic ingestion while they forage for food. As a result, communities heavily reliant on healthy land and marine ecosystems for livelihoods are particularly vulnerable to the impacts of plastic pollution through multiple pathways, including food chain contamination, groundwater and soil contamination (Phelan et al., 2020).

The widespread open burning of plastic waste significantly exacerbates air pollution by releasing greenhouse gases, particulates, and heavy metals like lead and chromium, which inadvertently affect communities (NPAP, 2020b). In 2017, Indonesia emitted 9.4 Mt of CO2 equivalent and 5,600 t of particulates from plastic burning (NPAP, 2020b), posing significant health risks, such as cancer and cardiovascular diseases (Cogut, 2016, GIG, 2020). Additionally, open burning poses immediate physical risks such as burns, inhalation of toxic fumes to individuals and their communities and food chain contamination. Open burning of plastic waste releases toxic chemicals like dioxins, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), short-chain chlorinated paraffin (SCCPs) and perfluoro-octane sulfonate (PFOS) (Petrlik et al., 2019). For instance, in areas like Tropodo and Bangun, where plastic waste is burned, eggs tested revealed dangerously high levels of dioxins and PFOS, posing serious health risks (Petrlik et al., 2019). High dioxin concentrations have also been found in chicken eggs in villages near burning sites (IPEN, 2022a). Notably, PVC burning is known to emit dioxins linked to hormonal and reproductive issues (Zhang et al., 2015).

Impacts on infrastructure: Plastic debris significantly increases the risk of flooding by blocking drainage systems, as seen during the 2020 Jakarta floods (GIG, 2020). The accumulation of plastic waste in drainage networks obstructs water flow, leading to localised flooding (GIG, 2020). The 2018 floods impacted over 1.5 million Indonesians (NPAP, 2020b). Seasonal factors exacerbate this issue, with plastic waste leakage rising 2-3 times during the rainy season compared to dry periods, as rainfall mobilises waste left in the environment (Rinasti et al., 2022, World Bank, 2021). Cities like Jakarta, Makassar, and Balikpapan have installed trash racks and traps to remove floating plastics from waterways. The implementation of river trash booms - specifically designed to intercept and capture plastic and other debris as it flows down the rivers - can significantly reduce the volume of litter reaching coastal regions, effectively preventing it from entering the sea by as much as tenfold compared to areas lacking such mitigation strategies (Cordova & Nurhati, 2019). However, these measures are insufficient to prevent waste-related blockages (Shuker & Cadman, 2018). To address this, the Indonesian government has committed up to USD 1 billion annually for cleaning up waterways and seas (Sea-Circular, n.d.,). Littered plastic waste plays a significant role in the blocking of waterways and subsequent flooding creates negative health impacts from diarrheal diseases as well as those transmitted by mosquitos that include malaria, dengue, Japanese encephalitis and Chikungunya. These disproportionally impact infants and children as well as those on low incomes.

Figure 3 summarises the critical causes of plastic pollution in Indonesia, attributing it to significant challenges related to plastic overconsumption and ineffective solid waste management, which lead to illegal disposal practices. These issues contribute to widespread plastic pollution, severely impacting the natural environment and the ecosystem services it provides, ultimately affecting the livelihoods of local communities.

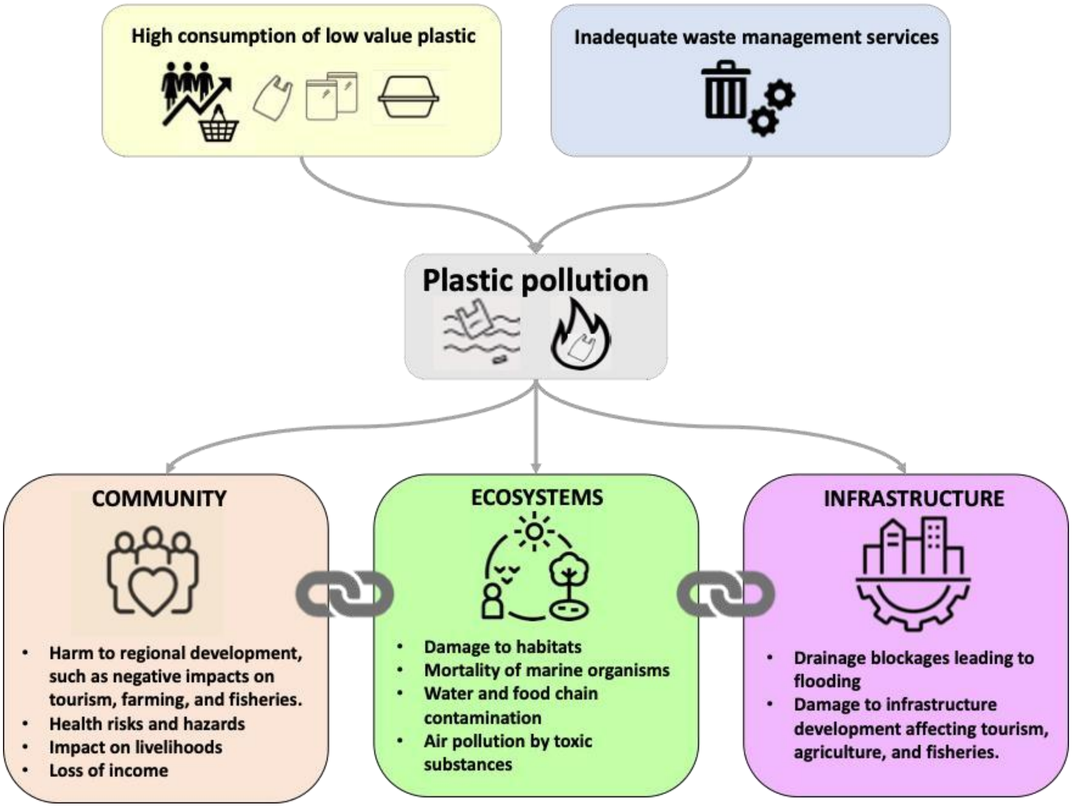


Figure 3. First LoI of the Indonesian plastics value chain as a system

3.2 Second LoI: Technologies, Infrastructure and Innovation Level

3.2.1 Plastics Production and Processing Infrastructure (Only Within the System Boundaries)

Indonesia's annual domestic production of virgin polymer resins is estimated at 2.3 Mt, accounting for 32% of its demand, while 17% (i.e., 1.2 Mt) is produced from secondary plastic materials (with ca. 914 kt sourced domestically and 320 kt imported) (IPEN, 2022a). The remaining 51% are imported from other countries, e.g., Singapore, Japan, and South Korea (IPEN, 2022a).The development of the petrochemical and polymer industry has attracted special attention from the government due to its capital-, technology-, and energy-intensive nature providing raw materials for almost all sectors such as plastic, textile, pharmaceutical, agriculture, etc. (IPEN, 2022a). Manufacturers, including PT Chandra Asri, still rely on obsolete naphtha-based processes, posing hindrances to modernization. Economic constraints and a lack of know-how further impede technological upgrades impacting large-scale equipment replacement (USAID, 2022). **Table 2** provides details on the current infrastructure upstream of the plastics value chain in Indonesia.

Table 2. Overview of the Current Existing Infrastructure Upstream of the Plastics Value Chain in Indonesia. Adapted from: (IPEN, 2022a)

Value chain stage	Industry type	No. of companies	Raw materials input	Product output
Production	*Petrochemicals industry (upstream)*	*4*	*Petroleum sources (e.g., naphtha and condensate)*	*Olefins, aromatics, paraffins*
	Petrochemical industry (mid-stream)	*4 (constitute 99.4% of total production)*	*Olefins, aromatics, paraffin*	*Butanol, Butene-1, Ethylene dichloride, MTBE, PTA, Raffinate-1, Styrene, Vinyl chloride*
	Polymer (Petrochemical) industry (downstream)	*10 (constitute 88% of total plastic resin production)*	*Vinyl chloride, styrene, ethylene, glycol, etc.*	*Resins (PE, PP, PVC, PET, rPET, ABS, Polyester, acrylic acid, 2-ethyhexanol)*
	Plastic manufacturing industry	*1,581 (380 large, 1,200 small-medium*	*Resins*	*Plastic MCPs*

The production capacity of the petrochemical/polymer industry may significantly impact the imports of raw plastic materials (i.e., resins), as Indonesia has the potential to become one of the largest polymer producers in Asia. In 2019 Indonesia occupied the 8th position out of 13 countries in polymer production in the Asia-Pacific region (Kameke, 2022). Currently, there are about 1,581 plastic manufacturing companies in Indonesia the majority of which are located in Java and Sumatra (IPEN, 2022a). The development of the plastics manufacturing industry has received special attention from the national government due to its important role in the economic activity of the country (IPEN, 2022a).

The most prevalent plastic manufacturer is the packaging industry covering from 36% (Ratnawati et al., 2020) to 56% of total plastic manufacturing (IPEN, 2022a). The food and beverage manufacturing sector is the major plastic producer and user in Indonesia, as nearly 60% of plastics produced and imported are used within this sector (Ratnawati et al., 2020), contributing about 5% to the GDP in 2022 (Nurhayati-Wolff, 2023). This industry, especially the FMCG companies, contributes considerably to plastic pollution, indicating the need for consumer goods producers, to accelerate and expand their actions on mitigating the plastic pollution issues (Tearfund, 2020).

3.2.2 Plastic Waste Collection and Management Infrastructure

Indonesia's waste management sector comprises both formal and informal recycling systems, though the infrastructure supporting the informal recycling sector's (IRS) activities remains largely undocumented (IPEN, 2022a). Formal waste management is primarily overseen by local governments and small private waste haulers, with significant differences between rural and urban areas. In rural regions, waste management is often the responsibility of village authorities, while urban areas typically feature large-scale operations controlled by city or regency authorities (SYSTEMIQ, 2021b).

Currently, solid waste management (SWM) programs primarily target urban areas, while waste collection and management in rural, coastal, and river communities is largely unaddressed (NPAP, 2020b). The major challenges for the Indonesian government in addressing plastic pollution and promoting circularity are the provision of adequate infrastructure, the technological maturity of existing systems, opportunities for innovation across the plastics value chain and a lack of reliable end markets for the use of recycled material at a country level (addressed in the 4LoI). **Table 3** provides details on the current infrastructure downstream of the plastics value chain in Indonesia.

Table 3. Overview of the Current Existing Infrastructure Downstream of the Plastics Value Chain in Indonesia. Adapted from: (IPEN, 2022a)

Value chain stage	Industry type	No. of companies	Raw materials input	Product output
Production	*Petrochemicals industry (upstream)*	*4*	*Petroleum sources (e.g., naphtha and condensate)*	*Olefins, aromatics, paraffins*
	Petrochemical industry (mid-stream)	*4 (constitute 99.4% of total production)*	*Olefins, aromatics, paraffin*	*Butanol, Butene-1, Ethylene dichloride, MTBE, PTA, Raffinate-1, Styrene, Vinyl chloride*
	Polymer (Petrochemical) industry (downstream)	*10 (constitute 88% of total plastic resin production)*	*Vinyl chloride, styrene, ethylene, glycol, etc.*	*Resins (PE, PP, PVC, PET, rPET, ABS, Polyester, acrylic acid, 2-ethyhexanol)*
	Plastic manufacturing industry	*1,581 (380 large, 1,200 small-medium*	*Resins*	*Plastic MCPs*
Plastic waste collection and sorting	*Waste bank*	*11,500*	*Post-consumer waste*	*Sorted recyclable plastics*
	Temporary Waste Processing Site / 3R Centre (TPS3R)[1]	*923 (508 active, 323 not active and 92 with unknown status) - 934[2]*	*Post-consumer waste*	*Sorted recyclable plastics*
	Intermediate Transfer Facilities (TPST) (TPST) – more complex system than TPS3R[1]	*356 (208 active, 46 not active and 102 with unknown status)*	*Post-consumer waste*	*Sorted recyclable plastics*
Plastic waste recycling	*Recycling facilities*	*600 large and 700 small*	*Post-consumer plastics*	*Recycled plastic MCPs*
Plastic waste recovery	*Waste-to-Energy (WtE), facilities*	*2 plants*	*Post-consumer plastics*	*Energy*
Plastic waste disposal	*TPA*	*368[2] - 380[3]*	*Unsorted solid waste*	*Managed solid waste*
	Dumpsites[3]	*167-198[4] (open) and 188 (non-open)*	*Unsorted solid waste*	*Mismanaged solid waste*

[1]Source: (IPEN, 2022a); [2] Excluding formal open dumpsites (World Bank, 2021); [3]Source: (Ratnawati et al., 2020); [4]Source: (Ismawati et al., 2022)

Challenges in plastic waste management span regulatory barriers, stakeholder attitudes, funding limitations, infrastructure constraints, and a scarcity of expertise in advanced technologies (Arisman & Fatimah, 2023). An example lies in the traditional operations of waste banks, lacking technological integration to improve efficiency and manage substantial waste volumes (Khair et al., 2019). Key obstacles encountered by the recycling sector encompass the fluctuating prices of virgin plastic, inadequate segregation of waste at the household level, negative attitudes towards recycled goods, limited capacity of local authorities to establish efficient SWM systems, absence of incentives provided to support the recycling industry and of reliable local markets for the use of recycled materials (USAID, 2022). **Table 4** summarises the details of waste disposal, recycling facilities, and other key aspects of the Indonesian solid waste management (SWM) system.

Table 4. Characteristics of Waste Collection Infrastructure

Waste Management Category	Location	Key details
Waste Disposal Sites (TPAs)	*Mainly in mega and medium cities[1]*	*19 out of 42 regencies/municipalities have registered TPAs[2]* *130 TPAs operate beyond their designed capacities, and have a minimum lifecycle capacity of 10 years[2]* *Cover a total area of 4,585 hectares nationwide [3]* *25% of formal sites operate as sanitary landfills[1]* *>50% of TPAs reverted to open dumping since 2018 due to lack of funding and regulation enforcement[4]* *Contribute to plastic leakage (2-20% leakage depending on the landfill type) due to erosion[1]*
Material Recovery Facilities (MRF)	*Sub-districts throughout Indonesia via neighbourhood and community organizations*	*Capacity of 3-6 m³/day, serving around 1,000-1,600 residents[1]* *41-45% of MRFs are inactive or have an unknown status[4]* *Supported financially by the local governement[1]*
Temporary Disposal Sites (TPS)	*Sub-districts throughout Indonesia via neighbourhood and community organizations[5]*	*Reduce transport distance for trucks to landfills[6]* *Varying collection systems based on local characteristics such as accessibility, road width and resident willingness to pay for services[7]*
Waste Banks	*Sub-districts throughout Indonesia*	*Contribute 2% to recycling, requiring clients to sort at home[8]* *Generated USD 1.2 million in revenue in 2019, collecting 12,500 tonnes of recyclables, including 4,000 tonnes of plastic[9]*
Recycling Facilities	*Concentrated in Java (80-90%) with fewer facilities in North and South Sumatra [10]*	*Capacity of 2 Mt/year[11]* *11% of PET and polyolefins recycling[11]*
Recovery Facilities	*One in Surabaya and one in West Java[12,13]*	*Surabaya: capacity 2MW[12]* *West Java: processing 2,000 tonnes of waste daily[13]*

1(NPAP, 2020b); 2(World Bank, 2021); 3(KLHK, 2020); 4(SYSTEMIQ, 2021a); 5(UN-ESCAP, 2021); 6(IGES & CCAC-MSWI, 2019, USAID, 2022); 7(Shuker & Cadman, 2018); 8(APRILIA, 2021, IPEN, 2022a, Ratnawati et al., 2020); 9(Patton & Li, 2021); 10(NPAP, 2020b, USAID, 2022); 11(USAID, 2022); 12(GIG, 2020); 13(SAI, 2023).

Waste disposal sites: are landfills, known as Tempat Pemrosesan Akhir Sampah or Final Waste Processing Site (TPAs) (World Bank, 2021). The majority of these sites operate like controlled dumpsites and often as open dumps (Becerra, 2021, KLHK, 2020, World Bank, 2021) due to economic constraints, insufficient funding, lack of regulation enforcement and technical capacity (SYSTEMIQ, 2021a). TPAs are prone to severe erosion due to steep slopes and/or soil structure, increasing the risk of plastic waste leaking into the environment (World Bank, 2019). Landfills in Indonesia are typically situated near rivers or coastal regions, which increases the risk of plastic waste contaminating these environments (Nurhasanah et al., 2021). A notable incident is the Cipeucang Landfill landslide, which resulted in over 100 tonnes of plastic waste flowing into the Cisadane River in Banten (Post, 2020). Consequently, levels of microplastics and heavy metal contamination rose in the coastal area (Purbonegoro et al., 2024, Sulistyowati et al., 2023, Sulistyowati et al., 2022). The availability of land for new TPAs is restricted, and existing sites are overburdened (GIG, 2020). Many cities face landfill space shortages, and procuring new land is challenging due to community approval requirements (Ratnawati et al., 2020).

Material recovery facilities (MRF): In most MRFs, the cost of sorting plastic exceeds the revenue gained from selling the sorted plastics, creating a significant gap (approximately twice the cost or more) (SYSTEMIQ, 2021a). This is due to informal activities, where high-value recyclable materials are largely collected, leaving a large fraction of residual waste mixed with plastics that has been rejected by the informal sector. This significantly affects the economics of formal MRFs (SYSTEMIQ, 2021a). Larger MRFs are cost-effective but may be less practical for an island nation like Indonesia (GIG, 2020). In contrast, smaller MRFs offer advantages such as reduced transport costs, the potential for affordable agreements with local providers, and closer ties with the informal sector (GIG, 2020). It is worth noting that MRF sizes in Indonesia differ from those in the Global North. For the sake of comparison, the largest MRF in the nation - the Balak MRF in Banyuwangi – stands at a capacity of 85 tonnes per day (ca. 35 kt per annum), which is smaller than the maximum capacity of many medium MRFs in the UK (20-50 kt per annum) (Monksleigh, 2023).

Temporary disposal sites (TPS): These sites are unevenly distributed among sub-districts, leading to inefficiencies (IGES & CCAC-MSWI, 2019, USAID, 2022). In many areas, the waste transportation to TPS is often managed by neighbourhood and community organizations, resulting in inconsistent waste container standards and inefficient collection due to the variable waste loading level and maintenance conditions of the containers (UN-ESCAP, 2021). In areas with difficult access, dumpsters are placed in accessible locations and emptied on a set schedule by district entities (Shuker & Cadman, 2018). In accessible areas, the collection is fee-based; the fee is collected by the head of the neighbourhood and community organizations (Shuker & Cadman, 2018).

Waste banks: Many communities operate waste banks (*Bank Sampah)* (IPEN, 2022a), as a means of monetising the economic value of post-consumer plastics (Patton & Li, 2021). Waste banks require their clients (i.e., consumers/end-users) to sort waste at home and often conduct additional sorting or plastic washing on-site to increase its value (Putri et al., 2018). They play a dual role by:
1) managing waste and 2) promoting local economic development by offering income and economic services such as banking options, savings, loans, and essential item purchases (Budiyarto et al., 2024, Prabawati et al., 2023). They effectively manage waste by engaging households, the primary waste generators in Indonesia (Budiyarto et al., 2024, Rimantho et al., 2023), reducing plastic waste leakage, improving source segregation, increasing material recovery as well as driving behavioural changes towards recycling at the community level (Budiyarto et al., 2024, IGES & CCAC-MSWI, 2019, Latanna et al., 2023, Rimantho et al., 2023, Rinasti et al., 2022). The government currently views waste banks as an effective method for SWM nationwide (Becerra, 2021). However, data on recyclable waste materials input by waste bank size is currently lacking, which limits our ability to assess their effectiveness as a comprehensive SWM option (Becerra, 2021). In recent years, waste bank numbers have surged, growing more than 600% between 2014 and 2018 (IPEN, 2022a). Sustainable operation for a waste bank requires around 28 tonnes of recyclables annually and a minimum of 247 households as customers monthly (IPEN, 2022a).

Recycling facilities: Indonesia's plastic recycling sector is primarily composed of small-medium facilities with limited technological advancement (NPAP, 2020b). Mechanical reprocessing is common due to challenges in implementing advanced methods like chemical recycling, which demand a more advanced technological landscape in terms of readiness, safety, and deployment progress (NPAP, 2020b). Though instrumental in promoting recycling, recycling facilities often struggle operationally due to inadequate plastic waste feedstock (USAID, 2022), the lack of waste collection infrastructure (APRILIA, 2021) and government support (IPEN, 2022a). Around 80% of collected plastics are cross-contaminated with organic waste (GIG, 2020). Because of poor quality, the utilization of post-consumer recycled plastic as feedstock in the plastic recycling industry is uncommon (USAID, 2022), due to recycled material quality-related challenges, such as tensile strength, tear resistance, and durability (USAID, 2022). Moreover, the economic viability of recycling plants depends on the scale of economies and the consistency of feedstock supply (NPAP, 2020b). However, the unpredictable revenue stream, influenced by variable plastic waste quantities and qualities, hinders growth (SYSTEMIQ, personal communication, 2022a).

Challenges in increasing recycling rates stem from the uneven distribution of recycling facilities, mainly concentrated in Java, which impacts the economic availability of recyclable materials in other regions (GIG, 2020, Ratnawati et al., 2020, WEF, 2020). Understanding Indonesia's recycling landscape is crucial (NPAP, 2020a), as transportation costs influence plastic waste pricing disparities between regions (USAID, 2022). Regional variations in pricing lead to economic inefficiencies in certain areas, hampering recycling systems beyond major urban centres (Patton & Li, 2021, USAID, 2022). For instance, rigid PET is valued at USD 0.34 per kg in Jakarta and slightly lower in Sumatra (USD 0.25 per kg) due to transportation expenses (USAID, 2022). Flexible plastics, already valued low in Java, are often not accepted in Sumatra and Kalimantan due to inadequate value to cover transport costs (USAID, 2022). In 2018, Unilever piloted chemical recycling for hard-to-recycle plastic products, such as sachets and multi-layers (GIG, 2020, IPEN, 2022a), but logistical, financial, and technical obstacles led to its discontinuation. Sachet packaging typically consists of a multilayer structure made up of polymers, including polyethylene, polyester, aluminium, and cast polypropylene (Driscoll & Rahman, 2020). The complex and varied nature of these multi-layered materials poses significant challenges for recycling, as separating and processing the individual components can be difficult (Cabrera et al., 2022, Kaiser et al., 2017). While initiatives for recycling certain plastics through chemical methods or energy recovery exist, their circular economy impact is constrained (USAID, 2022). Profitability challenges persist in recycling flexible plastic, necessitating high quantities for economically viable processes (USAID, 2022).

The private sector's limited involvement in the recycling industry has steered attention towards other technologies, such as Waste-to-Energy (WtE), which is viewed as an established solution to persistent waste challenges (UN-ESCAP, 2021). The WtE industry sector is gradually progressing in Indonesia (Becerra, 2021), with a growing focus on WtE projects as an alternative to landfills (GIG, 2020). The Indonesian government's National Action Plan outlines the need for WtE projects, including WtE plants (i.e., for electricity production) in 12 cities and Refuse-Derived Fuel (RDF) plants (i.e., used as fuel to power WtE facilities or cement industry) in 34 cities/regencies by 2025 (Ismawati et al., 2022). Until early 2020, Indonesia was without WtE facilities, although plans were in place (NPAP, 2020b). This is due to the government's concerns that WtE plants would create an infrastructural lock-in (high capacity) that would create a demand for large amounts of waste, preferably high in calorific content, to fulfil its purpose and deliver a return on investment (Ismawati et al., 2022). Instead, Indonesia's Corruption Eradication Committee or KPK (*Komisi Pemberantasan Korupsi*) recommends cities convert municipal waste into refuse-derived fuel (RDF), which can be sold to industries as a fossil fuel substitute (i.e., cement kilns or coal-fired power plants) (Ismawati et al., 2022). Cilacap City in Central Java Province serves as an example, utilising RDF as an alternative fuel source in a nearby cement factory (IGES & CCAC-MSWI, 2019).

While RDF production aims to address SWM, it is crucial to recognise that relying solely on RDF is not a comprehensive solution to plastic pollution issues (IPEN, 2022b). It also bears challenges in securing commitments from RDF end-users like cement kilns and power plants to switch from coal to RDF, compromising progress (APRILIA, 2021). Moreover, burning RDF can potentially create air pollutants, necessitating careful regulation to avoid risks to public health and the environment (IPEN, 2022b). Considering potential alternatives, investing the same amount of capital (approx. USD 6 million) in enhancing SWM systems and city landfills could offer more comprehensive benefits for addressing these challenges (IPEN, 2022b). Some key RDF projects in Indonesia can be found in the *Supplementary Material* (**Table B1**).

3.2.3 Ongoing Innovation Initiatives Supporting Circularity

There are various local initiatives aimed at addressing the plastic pollution problem across the plastics value chain in Indonesia (NPAP, 2022, Patton & Li, 2021). Examples of current innovations and initiatives for plastic waste management in Indonesia are detailed in *Supplementary Material* (**Table B2**). Key initiatives led by the business and government sectors that need to be highlighted include the following:

Packaging Recovery Organisation (PRO) systems: launched in August 2020, these systems serve as private sector co-funding mechanisms for SWM and promote the adoption of extended producer responsibility (EPR) (NPAP, 2020a). PRO initiatives help cover operational costs for SWM services and boost post-consumer packaging recycling (SYSTEMIQ, 2021a). In 2020, six major companies formed Indonesia PRO (IPRO) to manage producer responsibility through a voluntary take-back system for post-consumer packaging (Arisman & Fatimah, 2023, IPEN, 2022b, SYSTEMIQ, 2021b). Initially focusing on East Java and Bali, IPRO aims to expand its reach, though at present it remains limited (SYSTEMIQ, 2021b). Greater funding from producers is needed for plastic waste collection and sorting under EPR schemes, along with strong government oversight to ensure affordability and compliance (NPAP, 2022, SYSTEMIQ, 2021b). Challenges include fair contributions, levelling the playing field, and supporting smaller players (SYSTEMIQ, 2021b).

Public-Private Partnerships (PPP), or Kerjasama Pemerintah dengan Badan Usaha (KPBU): these partnerships involve collaborations between government and businesses to provide public waste infrastructure with shared risks (Ismawati et al., 2022, SYSTEMIQ, 2021a). A notable example is the 20-year partnership between Surabaya City and the waste management company PT Sumber Organik for a WtE plant, where the private sector funds the capital and operational costs of the facility and the public sector provides waste and tipping fees (SYSTEMIQ, 2021a). Ownership transfers to the public after the contract ends (SYSTEMIQ, 2021a). Supportive policies like Perpres No. 38/2015 encourage private sector involvement, with financial backing from organisations like the Indonesia Infrastructure Guarantee Fund (IIGF), Sarana Multi Infrastruktur (PT SMI), and Indonesia Infrastructure Finance (PT IIF) (GIG, 2018). However, the success of PPPs depends on clear scope, economic considerations, information sharing, organisational readiness, and innovation

(Prabawati et al., 2023). One important consideration of a PPP is when the facility is handed back at the end of the contract to ensure that the pre-requisite skills remain in place to both operate and maintain these facilities. Most importantly, there must be guaranteed operational expenditure (OPEX) funding that would make the private sector capital expenditure (CAPEX) viable. Without these considerations, critical infrastructure cannot be developed, and service delivery remains hindered, whereby stakeholders like waste banks risk being overexploited, potentially leading to program failures due to stakeholder reluctance to engage in PPP schemes (Prabawati et al., 2023).

Figure 4 presents an overview of the 2nd LoI that highlights the key limitations impacting the advancement of SWM infrastructure within Indonesia's plastics value chain, which contributes to infrastructural lock-ins. It also addresses the current state of existing SWM infrastructure and initiatives that have the potential to overcome these infrastructural challenges.

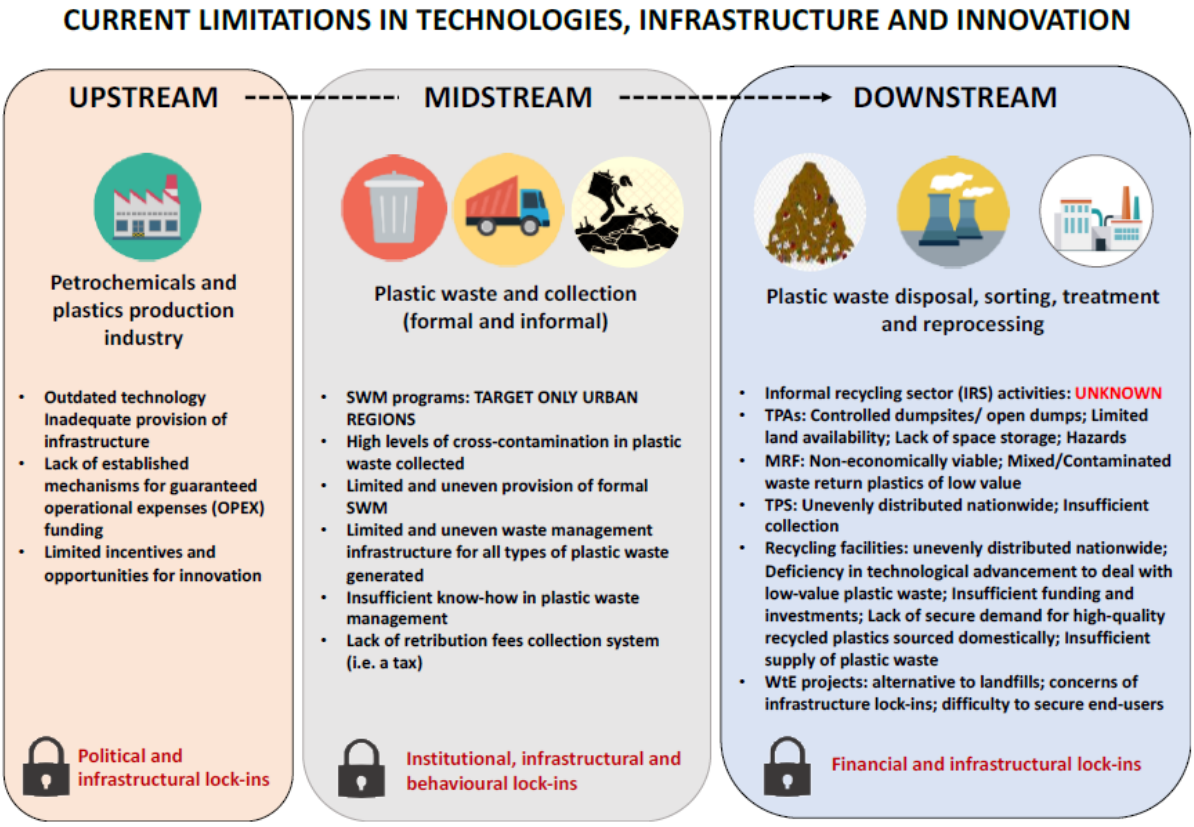


Figure 4. Second LoI of the Indonesian plastics value chain as a system. Note: TPA refers to waste disposal sites; MRF refers to material recovery facilities; TPS refers to temporary disposal sites; and WtE refers to waste-to-energy

3.2.4 Plastic Waste Management Protocols

The only plastic waste management protocol in the Indonesian context is the National Action Plan on Marine Debris (analysed in detail in **Section 3.3**). This plan sets an ambitious target to reduce marine plastic debris by 70% by 2025. It encompasses strategies for behavioural change, waste management improvements, funding mechanisms, law enforcement and policy reform and research and development initiatives. The latter, which is of relevance to this LoI, encourages innovation in materials and waste management technologies, however, its effective implementation is currently hampered by inadequate infrastructure, funding limitations, and the need for greater public awareness.

It is worth noting that a universal collection system could serve as a critical foundation for addressing numerous issues across the subsystems. This essential service intersects with challenges related to capital and operational costs and the acquisition of sustainable funding mechanisms to cover these. Improving the regulatory frameworks, developing clear investment models and supportive markets, and building institutional and technical capacity can address this challenge while simultaneously driving behaviour change. Establishing this system is just one of the key prerequisites needed to advance circularity efforts in Indonesia.

3.3 Third LoI: Regulatory Framework and Political Landscape

3.3.1 Key Government Structures and Their Regulatory Role

Indonesia faces significant challenges in its political landscape, hindering efforts to combat plastic pollution and promote a circular economy. The role of the national government is to regulate and monitor the entire supply chain of plastic MCPs, improve plastic waste management and increase transparency (Gerassimidou et al., 2022). The Indonesian government has implemented several programmes focusing on discouraging plastic consumption (mainly carrier bags), encouraging plastic waste source separation via the Waste Sorting Movement (Gerakan Pilah Sampah), and implementing recyclables collection. Furthermore, the MoEF has developed collaborations with institutions and local governments concerning marine plastic pollution to prevent and control environmental damage (Ratnawati et al., 2020).

The role of local government is to implement policies for plastic pollution prevention and provide services for the collection of household waste, including plastic waste. The local government needs to consider the local needs and, therefore, can play a crucial role in improving the plastic waste management system by creating a substantial partnership with community organisations, often forming their waste banks (Maryanti, 2017). Responsibilities vary across regions, with local governments managing household waste and waterway waste management handled by different departments in various cities (Shuker & Cadman, 2018). Clarifying roles across government levels is essential. Despite inter-ministerial linkages, overlapping roles hinder effective plastic waste management (Shuker & Cadman, 2018).

3.3.2 Governance Challenges and Decision-Making Procedures

Indonesia employs a hybrid national-local development political regime (Ratnasari et al., 2023), which results in waste management services suffering from regional disparities and resource shortages (IGES & CCAC-MSWI, 2019). This national-local policy dynamics results in slow implementation of national SWM policies, stemming from coordination gaps, insufficient emphasis on sustainable waste management in national policies, and local governments' limited understanding and application of policy coherence (Ratnasari et al., 2023).

Currently, waste collection operates through a decentralised model involving both formal and informal sectors (IGES & CCAC-MSWI, 2019). While these networks are effective in capturing large volumes of rigid plastic waste, they fall short of preventing plastic pollution caused by low- value flexible plastics, which are often left uncollected. This highlights the need for technical-based interventions upstream, which the plastic manufacturing industry must address, alongside infrastructural, policy and economic-based interventions downstream that prioritise waste collection responsibilities, capacity building, infrastructure development, funding plans, and enforcement based on local characteristics (Budiyarto et al., 2024).

Local waste management is also hampered by a lack of technical expertise and capacity (NPAP, 2020b), as well as frequent political, national and local leadership changes, which may lead to the disruption or rejection of SWM service provision (e.g., a program that starts with the support of one mayor (*Bupati*) might be rejected when the next one comes into office) (Latanna et al., 2023, SYSTEMIQ, 2021a). These changes, together with administrative reforms, also contribute to inconsistent SWM service provision, stakeholder confusion, resistance to change, and difficulties aligning different government structures and processes (IGES & CCAC-MSWI, 2019, Patton & Li, 2021). A more unified strategy combining national directives and local innovations is needed (IGES & CCAC-MSWI, 2019).

3.3.3 Level of Policy Enforcement

Enforcement of waste management regulations is weak (Kurniawan et al., 2024, USAID, 2022) due to unclear laws, insufficient professional training (Purba & Erliyana, 2020), limited inspections, and weak political will, leading to these practices becoming normalised (IGES & CCAC-MSWI, 2019, NPAP, 2020b). Political leaders often avoid imposing penalties due to limited waste management infrastructure, which makes enforcing bans on open dumping and burning politically challenging to maintain voter support (SYSTEMIQ, 2021a). Legal resistance, such as lawsuits against plastic bans in Bali, highlights the challenge of balancing regulation with industry interests (IPEN, 2022a).

Another critical issue in Indonesia's political landscape is the lack of regulatory compliance in many recycling plants, leading to neglected health and safety practices (APRILIA, 2021). To address this, Indonesia's Food and Drugs Administration (BPOM) issued safety standards for food-grade rPET plastics to guide recyclers (Ismawati et al., 2022), but more work is needed to improve safety and regulatory compliance across the recycling industry. The lack of local government capacity for law enforcement and standards induces a lack of confidence and increased risk to the private sector, and therefore, additional investment by credible businesses is prevented (Shuker & Cadman, 2018). Moreover, this challenge is compounded by a rigid bureaucratic system hindering effective policy implementation in SWM (Latanna et al., 2023).

3.3.4 Regulatory Framework and Policy Instruments Associated With Plastic Waste Management

To create an enabling environment for implementing a regulatory framework on plastic waste management, the Ministry of Environment and Forestry (MoEF), in collaboration with the Institute for Global Environmental Strategies (IGES), UNEP on Environmental Technologies (CCET), and Sustainable Waste Indonesia (SWI), developed the **'National Plastic Waste Reduction Strategic Actions for Indonesia.'** This initiative received support from Japan’s Ministry of Environment (Ratnawati et al., 2020).

Figure 6 outlines the timeline of key strategies and activities in plastic waste management, illustrating the significant evolution of the regulatory framework for SWM. Before 2008, efforts primarily focused on traditional end-of-pipe solutions (UNCRD, 2016). Between 2008 and 2015, the focus shifted towards adopting the 3R principles (Reduce Reuse and Recycle) and Extended Producer Responsibility (EPR) (UNCRD, 2016). Since 2015, the focus has moved toward advancing a circular economy and meeting the Sustainable Development Goals (SDGs) (UNCRD, 2016). However, Indonesia's ambitious waste management goals face challenges due to the country's unique geography, which complicates and increases the costs of waste management and plastic recycling (Patton & Li, 2021).

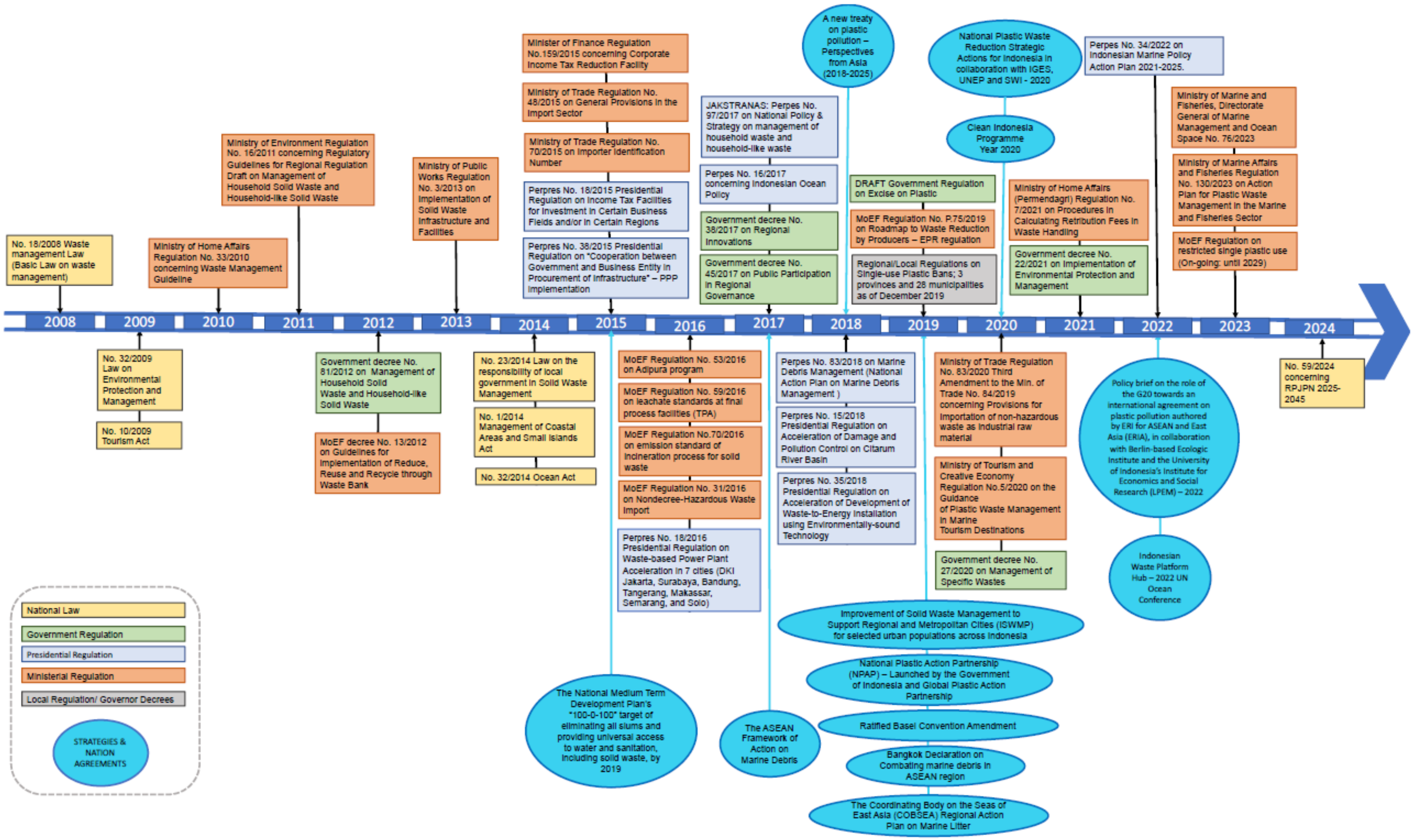


Figure 5. Timeline for Development of the Indonesian Regulatory Framework on Plastic Waste Management

Key regulations driving Indonesia's plastic waste management efforts include JAKSTRANAS (Perpres No. 97/2017), the National Action Plan on Marine Debris (Perpres No. 83/2018), the EPR Regulation (MoEF Regulation No. P.75/2019), and regional SUP bans. These regulations aim to achieve several targets by 2025: reduce marine plastic debris by 70%, reduce waste at the source by 30%, and increase waste treatment to 70% (SYSTEMIQ, 2021b). However, by 2020, MoEF reported only a 2.5% waste reduction. This could be attributed to poor governance as a result of deficiencies in the implementation and enforcement of existing SWM policies and regulations; financial capacity to provide and/or improve waste management infrastructure; befitting institutions to support efforts via education and awareness-raising mechanisms; strategic planning with a focus on the end-of-life of plastics; financing of resource recovery systems; and political will (UN-ESCAP, 2021). Despite having a broad regulatory framework (see *Supplementary Material,* **Table C1 and Figure 1**), Indonesia must strengthen and accelerate policy implementation practices (Sani & Fathurrahman, 2023) and strife for targeted policies for waste producers (Kurniawan et al., 2024). Without more active measures to curb plastic production and marine litter, the country risks missing its 2025 marine plastic debris reduction target of 70% (NPAP, 2022).

In 2019, Indonesia partnered with the Global Plastic Action Partnership to establish the National Plastic Action Partnership (NPAP), a platform for public-private cooperation with 230 members (WEF, 2020). NPAP launched the Multistakeholder Action Plan to reduce marine plastic waste by 70% by 2025 and transition to a circular economy for plastics by 2040. Key focus areas include policy, sustainable finance, research, innovation, and behaviour change (Sea-Circular, n.d.,). More details on NPAP's actions can be found in *Supplementary Material* (**Section C2**). Indonesia has also established national development plans to reduce plastic pollution and align with SDGs. Both mid-term and long-term development plans, including the National Medium-Term Development Plan (RPJMN 2020–2024) and the National Long-Term Development Plan (RPJPN 2005-2025) outline measures for SWM and introduce the RPJPN 2025-2045 to implement resource efficiency strategies, including the principles of 3R (see *Supplementary Material* **Section C3**).

Indonesia has also developed national strategies for integrated plastic waste management. Recently, the Indonesian government launched the Indonesian Biodiversity Strategy and Action Plan (IBSAP) 2025-2045, which encompasses five blue economy policies aimed at addressing various environmental issues, including plastic pollution. Key initiatives focus on cleaning marine plastic waste, reducing plastic generation, and establishing tracking systems for waste management (FAO, 2024). The IBSAP underscores the necessity of integrated approaches that consider the broader environmental impacts of plastic pollution. Additionally, the Indonesian Sustainable Consumption and Production (SCP) Strategy Framework for 2020-2030 promotes sustainable practices, emphasizing waste reduction, enhanced recycling, and achieving a "Waste-Free Indonesia 2025" (FAO, 2020). This strategy cultivates a circular economy with improved resource efficiency and stakeholder collaboration, positioning Indonesia as a potential exporter of high-quality recycled products.

Indonesia has also engaged in international agreements on marine plastic pollution, including the UN Convention on the Law of the Sea (UNCLOS), MARPOL, and the Basel Convention (Sea-Circular, n.d.,). The 2021 Basel Convention amendments on hazardous waste movements and disposal ban the export of mixed, unrecyclable plastic waste without the importing country's consent, improving global waste management (Sea-Circular, n.d.,). As an ASEAN member, Indonesia endorsed the Bangkok Declaration and the Action Plan for Managing Marine Debris in 2019 (Sea-Circular, n.d.,).

Furthermore, the Indonesian government has devised various policy measures and regulatory instruments to enhance the waste management system in the coming years, with major focus areas including the following:

Extended Producer Responsibility (EPR) Scheme: Indonesia introduced EPR in 2008 (SYSTEMIQ, 2021b), allowing industries to co-fund plastic waste management (NPAP, 2020b). However, detailed guidelines were lacking until the MoEF issued Regulation No. 75/2019 (NPAP, 2022, SYSTEMIQ, 2021b), holding producers (including, brand owners, manufacturers, importers, and retailers) responsible for reducing plastic waste through recycling, reuse, and redesign (USAID, 2022, Wang & Karasik, 2022). Based on this framework, producers are mandated to reduce waste production by 30% by 2029 (UN-ESCAP, 2021), aiming for a 2% annual increase in recycling rates (Ratnawati et al., 2020). Producers are required to promote sustainable practices (Wang & Karasik, 2022), take back post-consumer products for recycling (Patton & Li, 2021), connect to waste management systems like waste banks and sorting facilities, and report waste collection volumes to the MoEF (NPAP, 2021).

The EPR system is in its early stages and faces gaps in funding, enforcement, and reporting mechanisms (SYSTEMIQ, 2021a). Challenges include insufficient legal backing, voluntary compliance, lack of clear financing structures, and weak enforcement mechanisms, all of which hinder its effectiveness (Arisman & Fatimah, 2023, SYSTEMIQ, 2021b). For instance, while the regulation requires producers to develop waste management master plans and submit annual progress reports, based on self-reporting, the financing and enforcement mechanisms for these are not defined, leading to a perception of 'voluntary' compliance for companies (SYSTEMIQ, 2021b). Industry compliance is primarily achieved through voluntary corporate social responsibility (CSR) activities on an individual company basis that provides much lower levels of funding (SYSTEMIQ, 2021b). EPR implementation also has gaps in registration, reporting, and operational mechanisms, underscoring the necessity for a reliable reporting system, e.g., through the National Waste Management Information System (SIPSN) administered by the MoEF (NPAP, 2022). Although a waste information system for the implementation of the EPR scheme is in operation, it has to be improved in terms of information on collected and recycled plastic waste (NPAP, 2022).

Though the regulation encourages recycling, clarity on the engagement of the informal recycling sector that is central to waste collection is lacking (SYSTEMIQ, 2021b), which alongside infrastructure limitations, impedes progress (Arisman & Fatimah, 2023). Producers are encouraged to reduce waste before it reaches consumers and use more recyclable materials, but balancing these requirements across business sizes is a challenge (SYSTEMIQ, 2021b). Further concerns arise regarding the necessary transformations in value chains, especially for multi-layer plastic waste (SYSTEMIQ, 2021b), and the apprehension that a mandatory system may overwhelm the industry, indicating the need for a system that accommodates businesses of all sizes (SYSTEMIQ, 2021b).

Retribution Fees: Waste management in cities is primarily funded by household retribution fees, mainly collected by neighbourhood and community associations (APRILIA, 2021, GIG, 2018), usually through a door-to-door collection of cash payments (SYSTEMIQ, 2021a). This manual handling payment system complicates fee collection, with potential revenue leakage due to the lack of transparency and corruption, hindering the comprehensive service delivery (SYSTEMIQ, 2021a). Although a new regulation (No. 7/2021) aims to standardise fee collection and develop an efficient and consistent retribution fee payment system across Indonesia (NPAP, 2020b), challenges persist. In response to these issues, some cities are adopting digital payments or adding fees to utility bills to improve transparency, while others include these fees in utility bills, e.g., Perusahaan Listrik Negara (PLN), Indonesia's state-owned electric utility company, or PDAM for water charges (NPAP, 2020a). However, the latter is also challenging due to issues with transferring funds to different service providers. Still, retribution fees are too low to cover the cost of waste management operations (NPAP, 2020a), while waste levies are typically not imposed (APRILIA, 2021).

Adipura Program: The Adipura Program, led by MoEF, promotes enhanced waste management and cleanliness initiatives across 380 cities (Ratnawati et al., 2020). It monitors waste collection, treatment, and disposal, assessing cities on their performance. Self-reported data is evaluated by MoEF assessors and recorded in the SIPSN (Sistem Informasi Pengelolaan Sampah Nasional) (Ratnawati et al., 2020). Cities are categorized based on size (metropolitan, big, medium, small) and evaluated under five classifications ranging from the best (Class 1) to the worst (Class 5). Key data tracked include solid waste collection rates, at-source treatment rates, sorting facility treatment rates, and waste bank and informal collector collection rates (Ratnawati et al., 2020).

Single-Use Plastic (SUP) ban: Indonesia has implemented SUP bans in several provinces and cities, including plastic bags, cutlery, and styrofoam, resulting in significant reductions in plastic use (IPEN, 2022b). Regulation No. 75/2019 targets a complete phase-out of SUPs like plastic bags, straws, cutlery, food containers, foam/Styrofoam, and small packaging by 2030, with a focus on promoting reusable and recyclable alternatives (NPAP, 2022). In 2016, the MoEF implemented a paid plastic bag regulation (200 rupiah / 0.01 USD per bag) across 22 cities and one province (Becerra, 2021, GIG, 2018), resulting in a 25-30% reduction in plastic bag usage during a trial period of 3 months (Irianto et al., 2022). However, administrative challenges in managing the collected funds (Irianto et al., 2022), such as inadequate enforcement, limited private sector engagement, and ineffective pricing strategies, hindered the policy's national impact (Becerra, 2021). By the end of 2023, only a small percentage of cities (100 out of 514) and two provinces (Bali and Jakarta) have already issued local policies on waste reduction through bans and restrictions on SUPs (Cordova et al., 2024, 2023). An evaluation conducted by the Bali government, Alliance for Zero Waste Indonesia, and other stakeholders assessed the impact of the Bali Governor Decree No. 97/2018 banning SUPs in 2021. The evaluation showed a reduction of plastic bags at 51- 57%, a reduction of styrofoam for food packaging at 77-81% and of straws at 66-70%. In comparison, Jakarta saw a reduction of bags by 82% with a 42% reduction in households, 95% at shopping centres, 100% at supermarkets and 50% at traditional markets (IPEN, 2022).

Plastic Excise Tax: Discussions on a plastic excise tax began in 2020, proposing a fee of Rp 200 per plastic item (IPEN, 2022a, SYSTEMIQ, 2021b). The tax aims to fund waste management (SYSTEMIQ, 2021b) but faces opposition from the plastic producers and Fast-Moving Consumer Goods (FMCGs) industries, raised by industry associations, i.e., the Indonesian Plastic Industry Association (INAPLAS), due to concerns over its impact on profitability and jobs. Despite delays, the Ministry of Finance is exploring tailored excise rates based on plastic types and environmental impact (Patton & Li, 2021). The discussions on plastic excise taxes in Indonesia highlight the complex interplay between economic implications, environmental sustainability, and industry interests, essential for effective policy execution (IPEN, 2022a).

Overall, Indonesia's EPR, SUP bans, and excise tax efforts are hindered by regulatory gaps, industry opposition, and weak enforcement, but they mark significant steps toward reducing plastic waste.

Figure 5 summarises the key aspects underlined by the 3rd LoI. These include the regulatory framework for plastic waste management that has prompted essential policy measures aimed at enhancing the sustainability of the plastics value chain in Indonesia, as well as how the current political landscape obstructs the effective implementation of these policies. It reveals the challenges posed by regulatory lock-ins and their impact on progress.

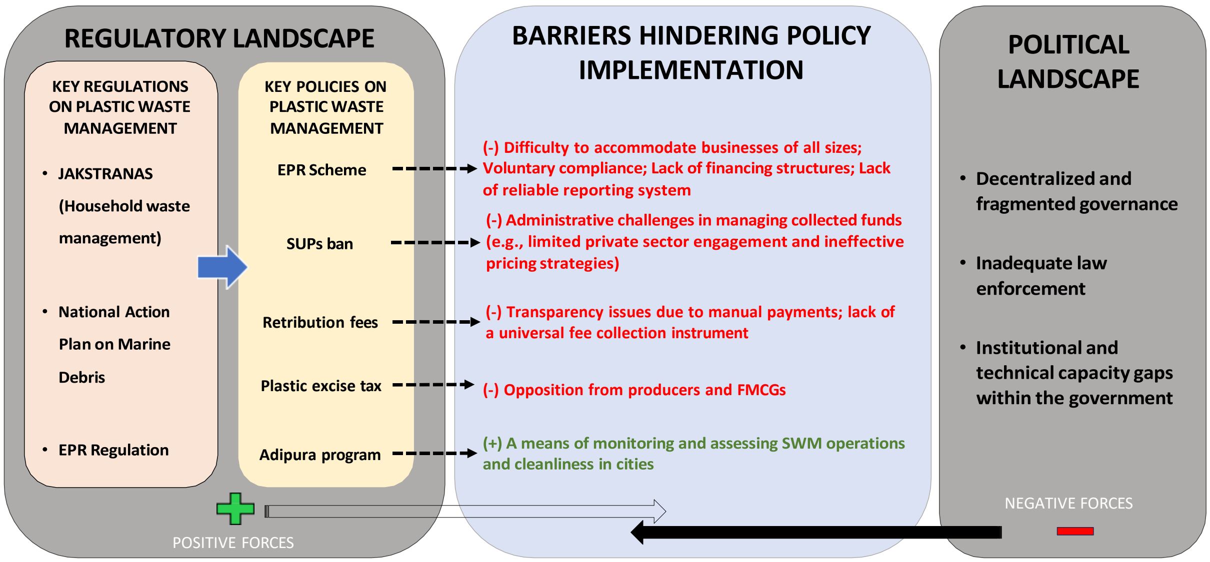


Figure 6. Third LoI of the Indonesian Plastics Value Chain as a System. Note: EPR refers to Extended Producer Responsibility; SUPs refer to single-use plastics; FMCGs refer to Fast-Moving Consumer Goods

3.4 Fourth LoI: Businesses Activities and The Market

3.4.1 Market Trends That Drive the Supply and Demand for Plastic and Plastic Waste

Upstream in the value chain

In Indonesia, the plastic industry has an annual production capacity of 5 Mt with the packaging sector being the largest driver of demand, valued at USD 9.6 billion in 2020. The Food and Beverage packaging sector is the major consumer, accounting for 65% of total plastic usage (USAID, 2022). Polyolefins are the most widely used plastics in packaging (Becerra, 2021), with high-density polyethylene (HDPE) leading the market at 46%, followed by polypropylene (PP) at 31%, polyethylene terephthalate (PET) at 12%, polyvinylchloride (PVC) at 11%, and polystyrene (PS) at 7% (USAID, 2022). The industry supports over 177,300 jobs, with more than 95% of plastic manufacturers based in Java and Sumatra (IPEN, 2022a). The plastic bag sector is particularly notable, consuming 6.5% of national plastic pellets and employing around 30,000 workers (IPEN, 2022a).

Indonesia's plastics supply chain includes both pellet producers and product manufacturers, with a high reliance on imported raw materials such as naphtha from Thailand and the Middle East (USAID, 2022) owing to limited domestic raw material availability, as local crude oil is prioritised for fuel (USAID, 2022). Consequently, approximately 40-50% of the petrochemicals used in plastic production are imported (Becerra, 2021). This dependency raises the costs for local products, making them less competitive compared to imports from countries like China and India (USAID, 2022). To address these challenges, the Ministry of Industry is investing USD 31 billion in petrochemical development projects to increase domestic production of ethylene, propylene, butadiene, PE, and PP (USAID, 2022). This investment aims to reduce reliance on imported petrochemicals and stimulate growth within the plastic industry (USAID, 2022). Additionally, the government's "Increased Use of Domestic Products" program aims to improve industrial efficiency, expand the use of local products, and boost global competitiveness (USAID, 2022).

Plastic is the cheapest and, in many cases, the most resource-efficient option for businesses, particularly FMCGs, due to its safety, reliability and cost-effectiveness (Patton & Li, 2021). Sachets have become particularly prevalent, as they are perceived to meet consumer needs based on social status (Patton & Li, 2021). This proliferation is driven by societal norms as well as business motivations. Affordability and accessibility are key elements in sachet marketing, making it suitable for low-income communities through widespread retail distribution and strong consumer demand (Singh et al., 2009, Sy‐Changco et al., 2011). Key factors that drive sachet market success include extensive retail networks, favourable cultural conditions, a higher perceived value among consumers, and packaging technology that offers convenience and reduces costs (Singh et al., 2009). The extensive network of retailers offering these products even in remote areas, drives their wide sachet distribution, increasing product preference and market reach (Sy-Changco et al., 2011). This enables fast-moving consumer goods (FMCG) companies to rise in popularity and preference, illustrating how they have adopted piecemeal retailing to create a growing sachet market (Pardesi et al., 2015, Sy - Changco et al., 2011).

Downstream of the plastics value chain

In Indonesia, plastic waste management involves both formal and informal recycling sectors. The informal sector, primarily driven by waste picker activities (GIG, 2020), plays a vital role in recycling by sorting plastic waste, which is then sent to recycling plants (IPEN, 2022a, SYSTEMIQ, 2021b). In contrast, municipal waste collections often end up in landfills due to insufficient sorting (GIG, 2020). Waste pickers face significant challenges, including low wages and unsafe working conditions (NPAP, 2020b). Similarly, formal waste collectors are often inadequately trained, which disrupts system continuity and efficiency (SYSTEMIQ, 2021a). Both sectors face funding constraints that impede investments and daily operations (USAID, 2022).

Waste banks (*Bank Sampah*): Despite the low contribution of waste banks to waste management at the national level, their contribution to employment is considerable (i.e., 163,128 people) with nearly half (49%) being women (IPEN, 2022a). Waste banks operate based on the market prices provided by the brokers or recyclers, which vary across the year by plastic type and location of origin, with rigid plastic waste earning higher values due to its chemical composition, viscosity, and melt flow index, compared to flexible plastics (USAID, 2022). However, waste banks may face fluctuations in sales due to buyer limitations on plastic waste purchases (Putri et al., 2018).

Informal Recycling Sector (IRS): This sector supports approximately 3.5 million informal waste workers and 115,000 junkshops in Indonesia (Kibumi, n.d.,). Waste pickers, known as "pemulung", and waste mobile traders, known as "rosokan", collect valuable plastic waste from streets, residential areas, and landfills to sell to middlemen or junkshops, referred to as "small pengempul", who further sort and clean the waste (USAID, 2022), before passing it on to aggregators or early processors, known as big pengepul, who prepare it for conversion into raw materials for the recycling industry (USAID, 2022). The activities of the IRS are not well-documented due to the sector's emphasis on confidentiality (Agunwamba, 2003; Hayami et al., 2007). Furthermore, the IRS faces significant challenges in collecting plastic waste, especially of low value, driven by a combination of factors such as material limitations, logistical hurdles, and economic considerations (Nikiema & Asiedu, 2022, Zahrah et al., 2024).

Recyclers at the early stages of the value chain face challenges due to fluctuating plastic prices and their inability to transfer VAT within the informal supply chain (NPAP, 2020a). Many recyclers are not tax-registered, which prevents upstream buyers from offsetting taxes and leads to lower prices for informal stakeholders (IPEN, 2022a). For example, a 10% price reduction for waste buyers can result in a 30-50% price drop for informal collectors (IPEN, 2022a). To alleviate this financial pressure, the Plastic Recycling Association (ADUPI) and the Indonesian Packaging Federation (IPF) have proposed VAT exemptions or sector-wide VAT payments from collection to recycling (IPEN, 2022a). In response, the Ministry of Industry is introducing fiscal incentives, including bank loans for small and medium recycling businesses, removing 10% VAT for the plastic recycling sector, and promoting the use of recycled plastic in industries to support recycling and expand waste collection efforts (USAID, 2022).

Plastic recycling: The plastic recycling industry in Indonesia employs over 177,000 workers (USAID, 2022) and is valued at USD 2.3 billion, with a projected annual growth rate of 7.1% from 2022 to 2030 (Kibumi, n.d.,). This sector primarily consists of small-scale enterprises that produce basic less technically demanding household items such as buckets, plastic bags, and brooms (USAID, 2022), although their end-product is typically pellets and flakes (GIG, 2020). Recycled plastic waste contributes 16% of the raw materials used in the upstream plastic industry (USAID, 2022). Major buyers of recycled plastic materials include large apparel companies and the automotive and aerospace industries, with some of the recycled plastics being exported to Europe, China, or Taiwan (GIG, 2020). However, it is worth noting that the plastic waste demand influences plastic waste pricing. As of present, rigid polypropylene (PP) cups are the most economically valuable (*personal communication*). In contrast, flexible plastics have very low value. Additionally, the price of plastic waste can vary by location; recycling centres are mainly located in Java, so transportation costs for delivering plastic waste from other islands to Java can make recycling economically inefficient in some areas (NPAP, 2020a). Transporting plastic waste involves upfront costs and requires a minimum volume, which can further impact its economic viability (NPAP, 2020a).

3.4.2. Businesses Commitment to Meeting Common Goals and Targets

From 2025 to 2040, sustainable SWM is projected to require USD 13.3 billion in capital and operational costs (including USD 1.5 billion for plastic recycling), with an annual operational need of USD 1.8 billion (NPAP, 2020b). National (APBN) and local government (APBD) budgets, through the Ministry of Public Works and Housing and the Ministry of Environment and Forestry (SYSTEMIQ, 2021b), fund SWM programs, as outlined in Perpres No. 83/2018 on Marine Debris Management, with a planned allocation of USD 1 billion (UN-ESCAP, 2021). Even though development banks such as the European Investment Bank (EIB) and the Asian Development Bank (ADB) are open to financing waste management projects in Indonesia, consistent revenue streams are essential for securing these investments (SYSTEMIQ, personal communication, 2022c). Additionally, the lack of widespread SWM collection, the variety of SWM technologies and the inconsistent quality of plastic waste pose challenges for financial institutions to invest in these projects (SYSTEMIQ, personal communication, 2022b, personal communication, 2022c).

The financing process for waste management projects is detailed in government documents known as the Blue and Green Books (NPAP, 2020a). The Blue Book includes 84 initiatives (SYSTEMIQ, personal communication, 2022a) eligible for external financing through loans and grants, while the Green Book contains 20-25 projects (SYSTEMIQ, personal communication, 2022a) endorsed by the government for funding within two years (AFD, 2018, Vidyaningrum, 2020). These books reflect the government's strategic vision for infrastructure development and budget planning (SYSTEMIQ, personal communication, 2022c). SWM projects that require government involvement undergo this approval process (SYSTEMIQ, personal communication, 2022c), with development banks typically requiring government participation to invest in such projects (SYSTEMIQ, personal communication, 2022b). However, the criteria for transitioning projects between the Blue and Green Books remain undisclosed to the public (SYSTEMIQ, personal communication, 2022a).

3.4.3 Market Stability and Price Volatility At Production And Management

The price of recycled plastics does not reflect production costs as it would in a perfectly efficient market (USAID, 2022). Instead, it is closely linked to the price of virgin plastics, which fluctuates with crude oil prices (USAID, 2022). Although production capacities and market fragmentation can affect the relationship between crude oil prices and recycled plastics (Angus et al., 2012), the low market price of virgin plastics makes them more competitive than recycled plastic resin. This fluctuation in plastic recycling prices impacts profitability for recyclers, causing the supply of recycled plastic to be less responsive to market price signals. Plastic material, component and product manufacturers often prefer to buy virgin plastic resins because they are cheaper, reducing demand for recycled plastics. Inadequate collection and sorting of secondary plastics lead to shortages, driving up prices and making recycled plastics less attractive to manufacturers due to their lower quality than virgin plastics (NPAP, 2020a). Plastic production companies generally enjoy higher profit margins than recycling companies, allowing them to endure greater declines in plastic resin prices, particularly because their input costs, such as crude oil and energy, move in tandem with these prices (Ebner & Iacovidou, 2021) (pg. 727).

Plastic waste trade: In 2018, Indonesia transitioned from a net exporter to a net importer of plastic waste due to China's market closure (NPAP, 2020b). Major trade partners, such as the Netherlands, Germany, and the US, have seen variations in trade values corresponding to these import volumes (IPEN, 2022a). Although plastic waste imports account for only about 3% of the country's total plastic waste generation, they represented 30% of Indonesia's recycling feedstock in 2018 (NPAP, 2020b). In 2020, Western European shipments constituted 57% of Indonesia's total imported plastic waste (IPEN, 2022a). Imported plastic waste occupies a significant portion of the recycling capacity, potentially reducing the capacity available for handling additional domestic waste (NPAP, 2020b). However, a substantial amount of imported plastic waste, between 30-50%, is mismanaged, often through dumping and open burning, while high-value plastics are informally recycled (IPEN, 2022a, Petrlik et al., 2019). East Java, and particularly areas where there is large-scale recycling, has become a key centre for importing and recycling foreign plastic waste, though much of this waste is non-recyclable and ends up turning communities into dumping sites (Petrlik et al., 2019).

Indonesian authorities have taken steps against illegal waste imports, enforcing waste trading policies (GIG, 2020, Petrlik et al., 2019). These measures include procedures for listing hazardous plastic waste under treaty control and requiring prior informed consent for the export of mixed or contaminated plastic waste, which allows importing countries to refuse shipments (Petrlik et al., 2019). Notably, Indonesia returned 19 waste containers to the UK in 2019 for non-compliance (GIG, 2020). However, there is no evidence of firm prosecutions related to illegal waste activities such as dumping or burning (GIG, 2020). Various stakeholders are discussing a roadmap to phase out plastic scrap imports and enhance recycling rates by developing infrastructure (Ismawati et al., 2022). The rationale behind national government control over the import of non-hazardous waste is to enhance national competitiveness and meet industrial demands (Ratnawati et al., 2020). Conversely, plastic waste exports (HS code 391590) have decreased since 2016 (IPEN, 2022a). Previously, Indonesia exported plastic waste to China and Hong Kong, but after China imposed waste import restrictions, exports shifted to Thailand, Malaysia, and Vietnam (IPEN, 2022a).

3.4.4 Investment In Infrastructure, Workforce and Technology

Major capital investments, such as new landfill construction and sorting centres, are usually supported by the national budget (APBN) (SYSTEMIQ, 2021b), whereas local government budgets (APBD) fund most formal waste collection, cleaning up waterways and disposal (APRILIA, 2021, SYSTEMIQ, 2021a), though private entities like Waste4Change, EcoBali, and Sumber Organik (managing the Surabaya landfill) also handle some waste operations (NPAP, 2020a). However, the local government's current funding is insufficient for comprehensive SWM coverage. Waste collection fees directed to APBD budgets are often diverted to operational expenses, such as salaries, rather than being dedicated to waste management services (NPAP, 2020a). APBD allocations for SWM typically range between 1- 4% (APRILIA, 2021), with most regions allocating less than 2% (GIG, 2018), despite technical guidelines provided by the Office of Public Works recommending 5-10% for effective SWM (UN- ESCAP, 2021). This is attributed to the fact that waste management is not categorised as a mandatory basic service by the national government, leading to low priority of waste sector development and financing by local government. Most of the APBD budget is spent on sectors like healthcare, education, and infrastructure (NPAP, 2020b). These constraints hinder effective local 3R (Reduce, Reuse, Recycle) programs (Becerra, 2021), with SUP bans also struggling due to weak enforcement and a lack of affordable alternatives (NPAP, 2022). Strengthening local governments' technical expertise and financial resources is essential for enforcing national waste laws (GIG, 2018).

Financing recycling: Investments and funding opportunities in beverage bottle recycling have been taking place in Indonesia, e.g., Unilever's USD 5.25 million for the production of 25,000 tonnes of food- grade rPET annually (IPEN, 2022a) and Indorama Ventures' USD 1.5 billion for recycling 750,000 Mt of PET by 2025 (IPEN, 2022a). These initiatives are supported by the first blue loan from the International Finance Corporation (IFC) amounting to USD 150 million, aimed at combating marine plastic pollution but have faced implementation challenges (IPEN, 2022a).

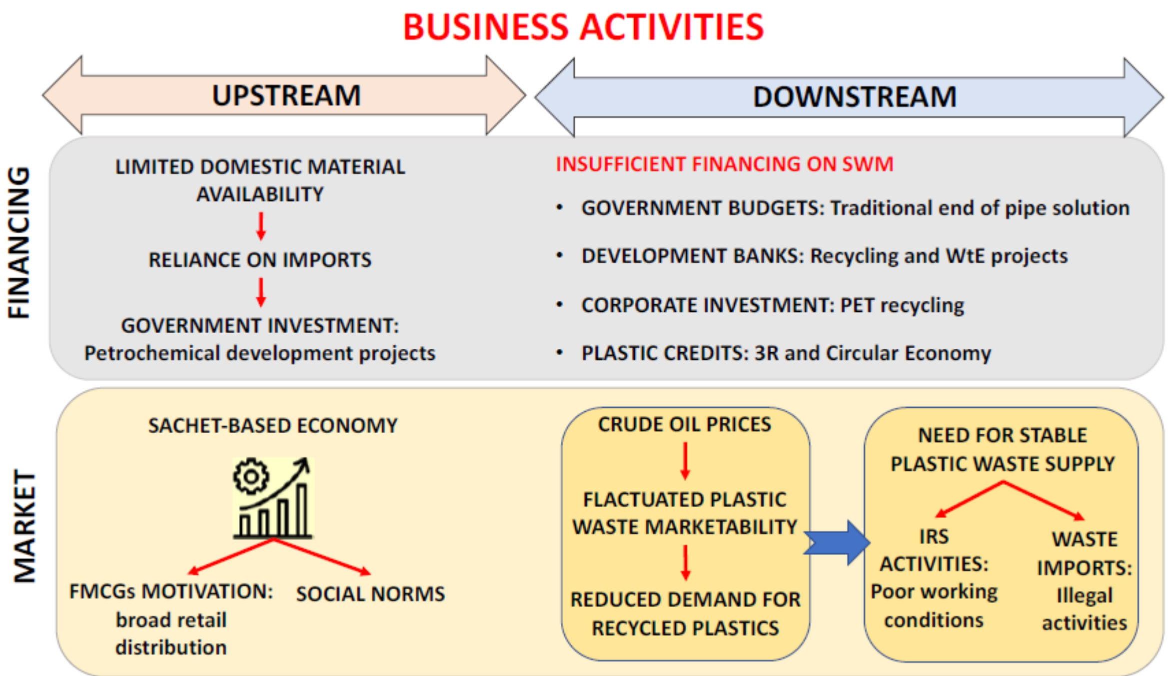
Financing WtE: Presidential Regulation Perpres No. 35/2018 aims to achieve 234 MW of power generation from WtE projects, with estimated construction costs ranging from USD 54 to 340 million, primarily funded by Indonesian investors (Ismawati et al., 2022). Development banks tend to finance waste projects, including well-established WtE systems that offer stable revenue streams through energy production (SYSTEMIQ, personal communication, 2022a). However, Indonesia’s Corruption Eradication Commission (KPK) has raised concerns about WtE projects, warning that they could impose a financial burden on national and local governments for the next 25 years, requiring an estimated USD
1.16 billion investment (Ismawati et al., 2022). This is particularly concerning as an established collection system is lacking, and measures to curb plastic production, reduce SUPs, and promote refill and reuse systems are gaining traction. Investments in WtE facilities must be carefully managed to avoid stranded assets resulting from a lack of widespread collection service and the prevention of increased recycling and reduction efforts.

One significant challenge for WtE projects is that Indonesia’s state-owned electricity company, PLN, which has a monopoly on power distribution, offers insufficient payments for electricity generated by WtE facilities, making these projects financially less viable than other energy sources (GIG, 2020). To address this issue, the national government needs to incentivize nearby industries to become energy off- takers from WtE facilities (GIG, 2020), relieving PLN of the obligation to purchase electricity (Ismawati et al., 2022). However, industries using RDF would need to assume the risks associated with RDF, as there are no quality assurance measures in place for its environmental and technical performance (Ismawati et al., 2022). Social acceptance is another challenge. For example, the RDF plant in Badung Regency faced protests from residents over unpleasant odours (Ismawati et al., 2022). Although the residents sought legal advice to challenge the plant, an assessor hired by Danone-Aqua, one of the plant's sponsors, reported that the facility met all necessary standards, paying little attention to the concerns of the local community (Ismawati et al., 2022).

The informal recycling sector (IRS), which is highly active in Indonesia, has also opposed WtE technology (Coca, 2022). The Indonesian Waste Pickers Union advocates for empowering waste pickers, who play a critical role in reducing plastic waste, and for expanding recycling and reuse systems, rather than investing in WtE infrastructure (Coca, 2022). However, WtE plants could process low-value and marine plastics, reducing costs for municipalities by lowering gate fees (GIG, 2020). To ensure the success of WtE projects, it is crucial to secure a long-term supply of feedstock without undermining separate collection and recycling efforts (Purba & Erliyana, 2020).

Financing EPR - Plastic Credits: As a concept tied to the EPR (SYSTEMIQ, 2021b), plastic credits have emerged as a market solution to drive sustainability through various credit types accounting mechanisms (ValueCred, 2021). Plastic credits are a concept similar to carbon credits and may refer to *Circular Credits, Social Plastic Collection Credits, Waste Collection Credits, Waste Recycling Credits, Ocean Bound Plastic Credits (OBP Credits),* and *Neutralization Certificates* (ValueCred, 2021). It is a new financial mechanism to incentivise plastic collection and recycling (SYSTEMIQ, 2021a), providing tradeable units to project developers involved in plastic waste collection or recycling (SCS, 2021). These credits can be bought by manufacturers, FMCGs, or intermediary organizations (Compliance Schemes and Purchasing Organisations), with the proceeds supporting the project's implementation, operation, and expansion (SCS, 2021). More details are provided in *Supplementary Material* **(Section D)**. Although not yet legally supported in Indonesia, they are being explored by the government (SYSTEMIQ, 2021a). However, further insights on the impact of plastic credits are needed to enhance understanding and adoption in the country's waste management system (SYSTEMIQ, 2021b).

Figure 7 illustrates an overview of the fourth LoI regarding business activities, including the financing landscape and market dynamic across the entire value chain of plastics in Indonesia. It highlights financial lock-ins upstream, stemming from limited material availability for plastic production, which leads to a reliance on imports and focuses investments on petrochemical-based projects. Meanwhile, downstream, there is inadequate financing for waste management infrastructure, primarily supported by government funding aimed at end-of-pipe solutions. Regarding the market dynamics, **Figure 7** shows that the plastics market operates as a sachet-based economy, while financial and institutional lock-ins hinder the broader marketability of recycled plastics.



Figure

Figure 7. Fourth LoI of the Indonesian Plastics Value Chain as a System. Note: FMCGs refer to Fast-Moving Consumer Goods; 3R refers to reduce, reuse, and recycling principles

Regarding *plastic design and standardisation requirements*, there are currently no specific plans available. However, NPAP's financing roadmap focuses on innovations to advance plastic management, in addition to supporting project development, filling funding gaps in city waste systems, and encouraging capital investment (NPAP, 2022). Therefore, changes in those aspects are due to be seen in the future.

3.5 Fifth LoI: Human Behaviour, Needs and Practices

Plastic pollution is largely driven by socioeconomic factors and human behaviours, making community engagement crucial to reducing its impact (Rinasti et al., 2022). Addressing plastic pollution, however, requires a systemic approach that goes beyond individual actions.

3.5.3 Consumer Perception of MCPs Provision, Consumption/Use and Disposal

Preferences for small-portion packaging, such as sachets, are shaped by affordability, convenience, and social norms (Oblea & Cabauatan, 2022, Phelan et al., 2020). This preference for sachet packaging is underscored by the PISCES research, which highlights that portion control, convenience, social acceptance, and buying frequency are driving these products' flow in the system. Efforts like campaigns targeting universities aim to shift purchasing habits, though awareness of plastic as a financial burden remains low (GIG, 2020, UN-ESCAP, 2021). Concerning disposal and waste management services, communities are aware that flexible plastics are of low perceived value due to their low monetary value and thus prefer to burn or dispose of them. This is not the case for rigid ones whose perceived value is high due to the monetary value attached to them. Additionally, the prevailing belief is that waste management services should come at no cost, as previous generations did not pay for them. This creates resistance to retribution fees and, coupled with a lack of political will to address this mindset, leads to stagnation in change.

However, the notion of value is further highlighted as a key driver for the implementation of community-based waste management systems, with which illegal disposal behaviour was significantly reduced (Sekito et al., 2013). Success stories like community-based systems in Surabaya (Trihadiningrum et al., 2017) and Semarang (Sekito et al., 2013) show that with proper guidance from community leaders and training activities, communities can significantly improve waste collection and segregation (Sekito et al., 2013, Trihadiningrum et al., 2017). These initiatives underscore the importance of continuous collaboration, and implementation of comprehensive strategies involving communication interventions (e.g., awareness-raising campaigns), design enhancements, and stakeholder participation to enhance education for sustainable waste practices (Appleby et al., 2024).

3.5.4 Consumer Waste Management Behaviour and Service Accessibility

There's often public misunderstanding about individual responsibility for plastic pollution (Patton & Li, 2021). Many view waste management as solely the government's duty, leading to reluctance to use services like waste banks (Latanna et al., 2023). Even when services exist, people may not use them due to infrequent pickups or fees, lack of awareness of available waste services, and non-uniform provisions (Fukuda et al., 2018), upcoming by WP4-PISCES). A PISCES survey found that awareness varies, even within the same community, people may choose not to use them, for example, if the service is seen as too infrequent (WP6-PISCES). This decision often depends on the convenience of alternative/improper waste disposal methods, such as open burning, which some communities encourage in a controlled manner, building dedicated burning points, highlighting that enforcement is an issue even within the local government itself (SYSTEMIQ, 2021a).

Inadequate services often lead citizens to litter or resort to improper waste disposal methods (Chaerul et al., 2014, GIG, 2020, Phelan et al., 2020, Safitri et al., 2014, World Bank, 2021). Specifically, PISCES research observed a negative correlation between waste collection services and the amount of waste openly burned; however, this was not the case for the usage of dumpsites, signifying that not all improper waste management behaviours can be simply substituted by the provision of waste collection service. It also revealed that education level had a negative correlation with openly burnt waste amounts, while age and income did not show significant associations (WP4-PISCES). Additional surveys showed that residents are more likely to participate in waste segregation when convenient services are available (Meidiana et al., 2021, Phelan et al., 2020, Safitri et al., 2014); as the lack of time, laziness, and impracticality can prevent it (Trihadiningrum et al., 2017). Factors like age, profession, participation in community activities, awareness of sustainable practices, household distance to waste banks, and familiarity with the 3R initiative are statistically significant in influencing individuals' inclination to engage in waste reduction through waste banks (Meidiana et al., 2021). This emphasizes that communication-based interventions are crucial to address behaviours that are not easily replaced by infrastructure (Meidiana et al., 2021).

Public awareness regarding waste management in Indonesia, including knowledge about available services, remains inadequate and enforcement within the governance structure needs to be strictly controlled (KLHK, 2020, Trihadiningrum et al., 2017, Wikurendra et al., 2024). A survey in Sulawesi found limited public understanding of plastic's harmful effects (Phelan et al., 2020), and 2018 data from the Indonesian Central Bureau indicated that only 28% of the Indonesian population exhibited a concern for proper waste disposal practices (Patton & Li, 2021). However, solely improving plastic literacy without enhancing waste management infrastructure may have limited effectiveness (Phelan et al., 2020).

3.5.5 Societal attitudes, beliefs and cultural norms

The perceptions around cleanliness and cultural beliefs are other barriers noteworthy to mention (upcoming by WP4-PISCES). Cultural beliefs, such as the superstition of burning a baby's diapers leading to negative spiritual consequences (due to the linkage of the baby's belongings with its soul) complicate waste management as it leads to diaper disposal in the river, though many dismiss these beliefs as outdated (upcoming by WP4-PISCES). This belief is not universally held; many communities now regard this as an old superstition and that it only applies to cloth diapers, not plastic ones; introducing an important element of perception around materials and their meaning that requires further research (upcoming by WP4-PISCES).

Indonesians have a strong connection to their environment and often feel overwhelmed by the visible effects of plastic pollution in their surroundings (GIG, 2020), though PISCES research, indicates that concerns for individual or community well-being often and the way this is impacted by their surroundings took precedence over environmental concerns regarding plastic pollution. This is also confirmed by (Schlehe & Yulianto, 2020) reporting that most individuals do not consider the general idea of nature to be very important; instead, they focus more on their immediate social surroundings and relationships (Schlehe & Yulianto, 2020). This could explain why practices such as open burning persist as a popular practice that prevents waste dispersion and deters animals and the perceived rate of illnesses despite the awareness of the harmful impacts of burning on the environment. However, there is still a strong connection to nature in Indonesia, and both social and environmental concerns can drive pro- environmental behaviours (Schlehe & Yulianto, 2020).

The gender perspective is also important to note in addressing human behaviour in Indonesia. Women play a central role in household purchasing and waste management, making them more vulnerable to the harmful impacts of plastic pollution (NPAP, 2020b). They are directly exposed to emissions from waste burning and dumping and are more susceptible to chemical accumulation due to higher body fat content (NPAP, 2020b). In the waste management sector, while men dominate formal roles, women are heavily involved in waste picking from dumpsites and sorting within the informal sector, exposing them to health risks, workplace violence and discrimination (NPAP, 2020b). However, their contributions to waste management are increasingly recognized, through participation in community waste banks and mobilization campaigns (NPAP, 2020b). Women are also active in managing waste banks, owning junkshops, engaging in upcycling projects, and sorting waste for large waste aggregators (Becerra, 2021). Yet, their representation in formal waste collection remains limited, and further disparities persist, with men typically earning more in the informal sector (Kristanto et al., 2022). Additionally, marginalized groups, especially those without official land titles, bear a disproportionate burden of plastic pollution impacts, such as flooding from blocked drains (NPAP, 2020b).

While there are many drivers and barriers to plastic waste management, a few stand out. Based on the above analysis, the main barriers to changing behaviour include:

- Weak communication and enforcement of regulations
- Low awareness of plastic’s environmental impact
- Entrenched consumer behaviours and notion of value
- Limited access to waste management services

Figure 8 summarises the main issues captured under the fifth LoI highlighting the key barriers that contribute to illegal disposal behaviours as well as opportunities for promoting changes in consumer behaviour.

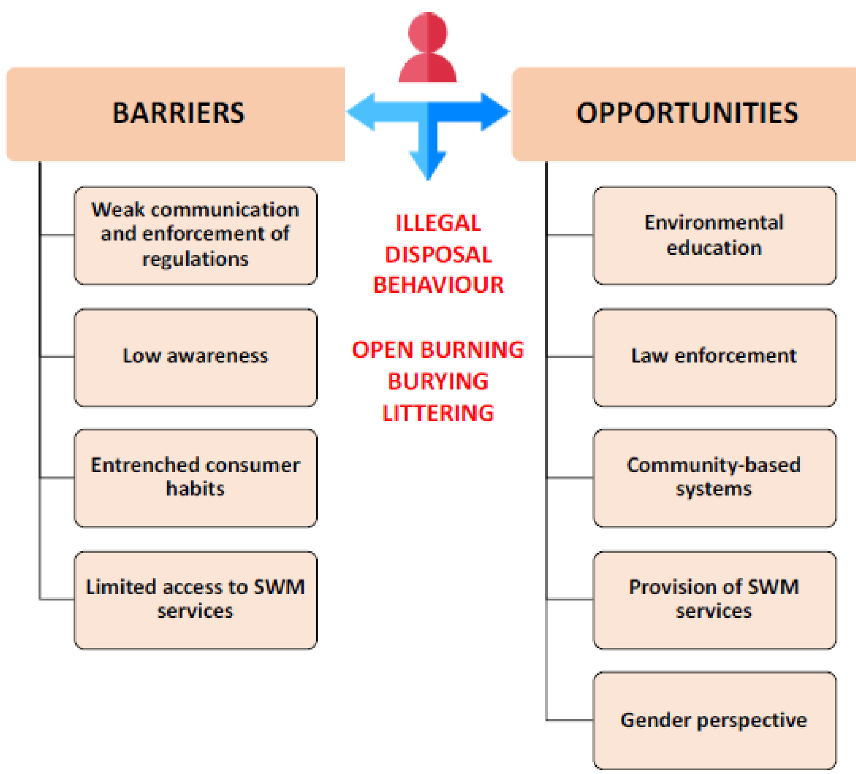


Figure 8. Fifth LoI of the Indonesian plastics value chain as a system

An upcoming PISCES study explores the balance between corporate accountability and individual empowerment, highlighting the need to understand behaviour within a broader context. To support this, the NPAP developed a behaviour change roadmap aimed at reducing plastic waste through collaboration among all stakeholders in the plastic value chain - from individuals and businesses to innovators and the public sector (NPAP, 2021). This roadmap includes strategies to encourage businesses to reduce plastic use and promote sustainable habits through education, collaboration, awareness campaigns, and policy development (NPAP, 2021).

4. DISCUSSION

Identifying and addressing systemic challenges, and their many 'hidden' drivers and impacts, through a holistic analysis is crucial in promoting circularity and preventing poor decision-making rooted in a limited understanding of the system and reliance on single-dimensional assessments (Iacovidou et al., 2020). CVORR's 5LoI method provides a structured framework that delves deep into the governance structures and processes, to reveal hidden aspects and identify critical intervention points across the value chain, moving beyond mere 'end-of-pipe' solutions. Even though plastic pollution mitigation has been widely studied, research often focuses on specific LoI or regional-scale analyses with a limited body of research addressing plastic pollution holistically, especially in Indonesia. For instance, existing work has explored waste composition and management challenges at the regional level (Zahrah et al., 2024), while several studies have examined the impacts of plastic pollution on marine resources and ecosystem services through case studies (Alam et al., 2019, Cordova & Nurhati, 2019, Cordova & Wahyudi, 2016, Manalu et al., 2017, Patton & Li, 2021, Purba et al., 2019, Syakti et al., 2017).

At the Indonesian national level, research has primarily focused on assessing waste management infrastructure capacities (USAID, 2022) identifying inefficiencies in existing management practices (Arisman & Fatimah, 2023), and evaluating financial challenges (GIG, 2020). Additionally, discussions have examined the role of the political context in shaping plastic waste management strategies (Ratnasari et al., 2023), and several frameworks have been published. These include the NPAP's financing roadmap (NPAP, 2020a), policy roadmap (NPAP, 2022) and behaviour change roadmap (NPAP, 2021), all aimed at strengthening waste management financing and policy development. Moreover, research has also explored the role of businesses in addressing plastic pollution (IPEN, 2022a, Patton & Li, 2021) and public behavioural patterns related to plastic use (Meidiana et al., 2021). Despite these substantial contributions, a critical gap remains. There is a notable lack of a comprehensive, system-wide assessment that examines the multi-dimensional aspects of the plastic value chain, integrating economic, technical, social, and environmental factors. Addressing this gap is crucial to developing holistic and effective strategies to combat plastic pollution across Indonesia.

Unlike static "snapshots" of systems, the 5LoI method offers insights across the entire value chain— upstream, midstream, and downstream—justifying intervention strategies and deepening stakeholders' understanding of the plastics sector. Critical broader factors for change, such as ecosystem impacts, relationships with provisioning systems, social equity and justice, human health and behaviour, and government and market dynamics, are integral to the CVORR approach. While these interconnected factors are rarely addressed collectively in the global literature, they are critical for shaping effective interventions toward circularity, especially in Indonesia, where urgent action is needed.

1st LoI: Natural environment and provisioning services

Interestingly, provisioning services in waste management in Indonesia vary significantly based on location. Touristic and economically active areas, particularly those contributing to GDP, tend to benefit from these services, while much of the country lacks a clear action plan (A. N. K. B. P. Iskandar et al., 2024). Still, addressing Indonesia's plastic waste management challenges requires tailored strategies that prioritise provisioning services across the food-energy-water nexus, adapted to local contexts. Currently, efforts are largely focused on mitigating the impacts of mismanaged plastic in rivers, which support water- and food-related needs, and on improving infrastructure— efforts that often result in quick fixes merely perpetuating the problem rather than addressing its root causes. This short-term approach risks undermining ecosystem functions and services over the long term, threatening livelihoods and well- being, and adding additional pressure on water and food security.

Inadequate waste collection services in many communities lead to widespread dumping and open burning, threatening water and food security through air, soil, and water contamination. This not only undermines community resilience and public health but also has immediate and long-term impacts, especially on vulnerable populations such as children, the elderly, and those with pre-existing health conditions, deepening health inequalities. These issues highlight the need for integrated, long-term waste management strategies to reduce pollution, support ecosystem services, and improve infrastructure resilience and health outcomes. Sustainable solutions require prioritising investments in safe waste disposal alternatives and fostering community engagement to shift away from harmful disposal practices, safeguarding both environmental and human health.

2nd LoI: Technologies, infrastructure and innovation level

Currently, the production of plastics is dominated by the petrochemical industry, which has a relatively short supply chain and significant control over the plastics value chain outputs (IPEN, 2022a). Incorporating recycled content into new plastic materials, components, and products has not disrupted the traditional operations of upstream industries (petrochemicals and plastic production), which continue their business largely unaffected by recycling efforts. Given that the petrochemical industry is composed of only a few key players, this concentration of power presents a potential opportunity to influence upstream practices. In contrast, the recycling infrastructure at the end of the value chain is under considerable strain. Although efforts have been made to expand recycling capacity, they are not matched by waste collection efforts, resulting in a capacity gap that has driven demand for plastic waste imports (IPEN, 2022a, Petrlik et al., 2019). Imported plastic waste is often reported to be of inferior quality, contributing to higher mismanagement rates and pollution risks (NPAP, 2020b). It must be emphasised that this inflow of plastic waste should not be viewed as the primary cause of plastic pollution, as over 90% of the issue originates from domestic waste generation and handling practices.

Identifying funding options to improve recycling technology and enhance collection rates is crucial for optimising the recycling sector's output and resource recovery (Kurniawan et al., 2024). Funding sources, such as local government budgets, national government subsidies (e.g., Ministry of Public Works and Housing), external donor support, corporate investment, and Public-Private Partnerships (PPPs) (IGES & CCAC-MSWI, 2019), should be directed toward the development of a national waste collection and management system to mitigate pollution across essential systems that support community livelihoods and promote circularity. However, engaging private stakeholders in waste management infrastructure investment presents numerous challenges to policymakers that require careful consideration, strategic planning and intervention. Most of the financing opportunities in the waste management field are blocked (NPAP, 2020a) due to the absence of key enabling conditions including robust regulatory frameworks, enforcement, technology and blended finance approaches (i.e., PPPs); all of which are needed to attract private capital in SWM, resulting in immature investment readiness (NPAP, 2020a). Uncertainty surrounding, for example, the existence of viable investment models offering sufficiently attractive risk-return profiles dissuades investors from committing funds, as the private sector generally requires predictable returns on investments to justify its participation. The absence of established frameworks exacerbates this issue, creating hesitancy among investors.

Economic viability is key. Ensuring that waste management projects are financially sustainable through reliable public revenue streams and enforcement by the public sector is essential for attracting private investment. Private sector investors need assurance that their investments will yield profitable returns. This includes factors such as a reliable supply of recycled materials, the costs of collection and (pre-)processing, and the potential revenue streams from selling recycled products. However, concessional financing, such as corporate social responsibility (CSR) funds, adds another layer of complexity, as such funds often come with stringent conditions and limited scalability, complicating refinancing agreements (NPAP, 2020a). The poor infrastructure and logistical challenges pose a major obstacle to the establishment of a reliable supply chain for recycled materials. For instance, material contamination and inadequate pre-processing result in low-quality plastic waste that reduces the value of recycled materials and increases the cost of recycling, thereby reducing the return on the investment (NPAP, 2020b, Patton & Li, 2021). Inconsistent and complex regulations create additional barriers, discouraging investment and highlighting the need for regulatory reforms to create a more conducive environment for private sector participation (NPAP, 2020b). Developing clear regulatory frameworks and investment models (IGES & CCAC-MSWI, 2019, Patton & Li, 2021), and enhancing market access are all crucial steps toward the creation of a more attractive investment environment for the private sector. Additionally, strengthening the roles of community-based waste banks and private waste management companies can enhance the collection and recycling of plastic waste, as demonstrated in cities like Bandung and Yogyakarta (Zahrah et al., 2024).

Furthermore, the concentration of recycling facilities in a single location (IPEN, 2022a) in a geographically large and diverse country like Indonesia hinders efforts to improve recycling rates. While investing in recycling infrastructure across multiple locations is financially risky due to weak collection systems, this points to a vicious cycle that prevents progress in reducing plastic pollution and achieving circularity. Even with robust collection systems, there will be a lag before investments in recycling infrastructure become viable. This underscores the need for an integrated solid waste management approach that includes different treatment processes and models to ensure financially feasible and sustainable outcomes (Chaerul et al., 2014). In this context, investment in waste-to-energy (WtE) infrastructure as an alternative to uncontrolled landfills and dumpsites appears sensible. Additionally, the monopoly of Perusahaan Listrik Negara (PLN), Indonesia's state-owned electric utility company, over the transmission and distribution of electricity in Indonesia (GIG, 2020) gives the company significant bargaining power, which has been stalling plans for energy generation from waste.

3rd LoI: Regulatory framework and political landscape

The regulatory landscape in Indonesia is gradually evolving to address plastic pollution and promote circularity. The main challenge is the implementation of policies and targets at the local government level attributed to political constraints, inadequate budget to operate an oversight system, and lack of understanding of the law. The distribution of power to local government creates challenges due to limitations in the administrative capacity (IGES & CCAC-MSWI, 2019), budget constraints, and organisational issues that result in many local governments struggling to achieve meaningful progress. Additional challenges stem from the diverse priorities of local governments, which may focus on tourism, economic activities, or religious values, influencing how funds are allocated—and at times misappropriated—due to corruption and weak oversight. A weak regulatory system, characterised by weak enforcement, can lead to systemic failures and short-term decision-making, highlighting the need for stronger regulatory frameworks and innovative financing models, such as public-private partnerships (PPPs) (NPAP, 2020a). However, there is little (almost no) scientific information about factors that could drive policymakers to implement stronger law enforcement for waste management.

Indonesia could adopt a range of regulatory frameworks aimed at promoting sustainable practices, increasing investment in waste management infrastructure, and formalizing support for the informal recycling sector. One effective strategy could be the introduction of a plastic tax or excise (Purwoko & Wibowo, 2018, Saputra et al., 2023), which has the potential to reduce plastic consumption, especially for single-use items significantly. This approach not only curtails plastic usage but also generates state revenue that can be reinvested into sustainable waste management initiatives. Moreover, providing subsidies for biodegradable plastics could encourage their adoption by alleviating the cost disparity compared to non-degradable alternatives, thereby driving market demand for environmentally friendly options (Purwoko & Wibowo, 2018). Implementing an integrated waste management system, similar to those in China and the EU, can help prevent regulatory overlaps and ensure cohesive policy enforcement (Subekti, 2023). Such a system should actively involve all stakeholders, including government entities, the private sector, and civil society, to foster a synergistic approach to waste management (Nurhasanah et al., 2021, Sulistyowati et al., 2022). All these aspects have been discussed in the recently issued Roadmap & National Action Plan for the Circular Economy in Indonesia 2025-2045 (Bappenas, 2024).

The political system also heavily influences local governance, with political leaders often prioritising different sectors to increase their votes. A notable example is the government's decision to move the capital from Jakarta to Nusantara, located in East Kalimantan, positioning Nusantara by 2045 (Perwira et al., 2024) as a symbol of green development and prosperity. This is seen as a political move to completely reinvent the Indonesian national ethos (Perwira et al., 2024). However, this shift underscores institutional weaknesses and problem shifting attitude, as Jakarta continues to face severe pollution, coastal erosion, and other climate-related challenges that may remain unaddressed. In addition, foreign plastic waste imports are an easy target for national politicians. Rather than sorting out the domestic waste issue, which takes time and money, they seem to be blaming plastic waste imports, but this only accounts for a small fraction of the waste.

4th LoI: Businesses and the market

Socioeconomic factors have driven the growth of the informal recycling sector (IRS), which remains unregistered, unorganised, and unregulated (Medina, 2000). Many waste pickers migrate to urban areas due to the lack of opportunities in their hometowns, often bringing their families, who may also work in waste collection or other low-wage jobs (Kristanto et al., 2022). The IRS predominantly consists of marginalized and impoverished urban populations, providing them with crucial income but also perpetuating inequality and corruption, issues that largely go unaddressed (Ackerman & Mirza, 2001). Concerns about child labour exploitation and human trafficking in the sector are also under-researched, highlighting a critical gap (USAID, 2022). The 1997 global economic crisis worsened the situation, leading many to enter the IRS, where they remain today (Sembiring & Nitivattananon, 2009). While the IRS plays a vital role in supporting the recycling industry and helping the government meet some regulatory targets, it also faces significant issues, including social injustices (NPAP, 2020b).

Despite these challenges, efforts to formalise the IRS system and address inefficiencies and corruption should not be discouraged. Strategies aimed at integrating and empowering this sector could lead to more effective waste management and greater environmental sustainability (Gall et al., 2020, Velis et al., 2022). In conjunction with these incentives, supporting Micro, Small, and Medium Enterprises that utilize plastic waste to create innovative products through capacity building and community engagement can serve as an effective complementary strategy (Hidayati et al., 2023, Suryani et al., 2023). Offering legal recognition and support for the IRS can facilitate its integration into formal waste management systems, leveraging its adaptability and resilience to develop innovative, context-specific solutions that are both effective and sustainable. As Indonesia's waste management landscape evolves, it is essential to upskill waste pickers with the capabilities needed to operate advanced waste collection and sorting facilities. This approach will help ensure continued employment opportunities for those currently managing end-of-life resources. A hybrid model could offer substantial benefits, as the IRS is deeply integrated into Indonesia's recycling sector, with many small recycling companies heavily dependent on informally sourced waste (Silva de Souza Lima Cano et al., 2022). This close connection between the IRS and the recycling industry partly explains the reluctance of finance institutions to invest in the sector due to its lack of long-term stability (SYSTEMIQ, personal communication, 2022c). Strong enforcement could help regulate practices and ensure fair pricing, although this remains a significant challenge under the current regulatory framework and political climate (IGES & CCAC-MSWI, 2019). Improving transparency across the supply chain and ensuring adherence to social and environmental standards are crucial steps to attract investment (NPAP, 2020a).

The widespread use of sachets, deeply embedded in the market, is often defended by the industry as meeting the needs of low-income communities who depend on small, affordable portions and convenience (Singh et al., 2009). Despite initiatives promoting reusable and refillable solutions, the market continues to favour sachets, by way of serving important societal needs for affordable and accessible goods. Strategic marketing tailored to these consumer needs facilitates market penetration and encourages product trials with minimal financial risk (Tang, 2011), creating a strong demand for sachet-based products and further solidifying communities' reliance on sachets across various consumer goods sectors (Yan et al., 2022). As a result, phasing them out is challenging, and the industry continues to capitalise on them to justify their production (Pardesi et al., 2015, Sy - Changco et al., 2011). However, sachets generate a vast stream of low-value waste that remains largely uncollected. The IRS lacks the incentive to collect low-value waste and focuses on materials and areas where the collection is profitable, while formal systems are ill-equipped to process it, hindering circularity. As a result, large portions of the waste stream that hold little value are neglected. Similarly, formal waste management systems are not structured to process or absorb these materials effectively (SYSTEMIQ, 2021b). This creates a substantial barrier to achieving circularity within the plastics value chain, highlighting the need for comprehensive, multi-dimensional interventions and a subsidised system that leverages the efforts of the IRS. For instance, Indonesia must initially separate economic advancement from the increase in SUP consumption by implementing waste reduction or material replacement strategies involving new delivery approaches like returnable container systems, innovative materials, and durable goods for long- term use (Patton & Li, 2021).

5th LoI: Human behaviour, needs and practices

Social norms have fostered the conditions for sachets to dominate the market, as they meet a societal demand for conveniently portioned, hygienic, and safe products, making them appealing to consumers with limited purchasing power in developing regions, where access to bulk or larger-sized products may be restricted (Bradley & Corsini, 2023, Coelho et al., 2020). Additionally, the cultural inclination towards smaller, single-use portions significantly influences consumer behaviour and the prevalence of sachet packaging (Steenis et al., 2017). These conditions create a dilemma in efforts to phase them out— one that the industry continues to exploit. However, the issue extends beyond a lack of awareness of the environmental pollution caused by sachets. It is deeply rooted in long-established behaviours shaped by preferences, values, and convenience. Shifting these ingrained norms and behaviours presents one of the most significant challenges in tackling plastic waste and promoting circularity in the plastics value chain, with progress remaining in its early stages.

Women play a crucial role as agents of change. As primary caretakers and managers of household needs (NPAP, 2020b), they often make waste management decisions, but harmful practices such as open burning, burying, or discarding waste in rivers are still prevalent. These behaviours are rooted in historical practices when waste was largely organic. Today, these actions persist due to longstanding norms around cleanliness and hygiene. Religious beliefs are also seen to influence these practices, but their role in recent years suggests they may not be central to the issue. Compounding the problem is a reluctance to use formal waste collection services and the perception within communities regarding the ownership and responsibility of waste. This challenge is not unique to Indonesia but reflects broader global issues around littering and waste mismanagement. Raising awareness through campaigns that emphasise the importance of material recovery is essential, not just for Indonesia but in a global context (UN-ESCAP, 2021, UNCRD, 2016).

5. CONCLUSIONS

This study provides a novel and rigorous systemic analysis of Indonesia's plastics value chain, offering crucial insights into the intertwined nature of its natural, social, economic and political subsystems using CVORR - a pioneering systems-based approach. While CVORR analysis can be time-consuming and may initially seem complex, this paper demonstrates its value in uncovering systemic interdependencies and identifying how lock-ins and blind spots hinder progress toward a circular economy. The methodological approach developed enables the structured analysis of five interrelated sub-systems, each corresponding to a distinct level of information, using specific descriptive elements that define the underlying dynamics. This systematic and replicable approach ensures a rigorous examination of complex value chains within carefully defined systems. By providing a comprehensive analysis of the root causes of resource and waste management challenges, illustrated here through the case of plastic waste mismanagement and associated pollution, the approach proves effective in addressing complex, interconnected and multifaceted sustainability challenges.

Key findings emerging from the 5LoI analysis reveal that the journey toward circularity involves reconfiguring the very institutions and societal norms and reshaping the social, economic, and political systems that govern resource management, alongside implementing targeted technical, infrastructural, policy, economic and communication-based interventions. These foundations are vital to unlocking the potential for plastic value retention and breaking through entrenched barriers, such as underinvestment in infrastructure, weak regulatory system and political landscape, fragmented IRS systems, and lack of coordinated technical and communication-based interventions, geared towards plastics value recovery. However, without commitment to developing these processes, desired outcomes will remain out of reach. This is a critical challenge that must be addressed to establish a circular plastics value chain in Indonesia.

By empowering the human agency to redefine these constructs, this paper not only sheds light on current challenges but also sets a course for meaningful, sustainable change, offering a transformative perspective on the plastics value chain in Indonesia. It underscores that the shift from end-of-pipe solutions to lifecycle-based interventions requires novel and out-of-the-box approaches where multi- level strategies focus on retaining plastic value, preventing waste and ultimately fostering a circular economy that transcends simple problem-shifting.

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DECLARATIONS

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SUPPLEMENTARY MATERIALS

For supplementary materials click here or copy the following into your url bar: https://circulareconomyjournal.org/wp-content/uploads/2025/05/Appendix_Iacovidou_et_al_System-Wide-Analysis-of-the-Plastics-Value-Chain-in-Indonesia-The-Five-Levels-of-Information.pdf

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