Ocean
Recovery Alliance

Towards Circular Plastics

Assessing the Impact of Recycling Technologies in Tackling Plastic Pollution

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Foreword

By Benny Mermans

Chairman of the World Plastics Council (WPC) for the Ocean Recovery Alliance report:

Plastics are essential materials that enable modern life. They play a critical role in sectors ranging from healthcare and food safety to renewable energy and infrastructure. However, plastic pollution remains a global challenge, and we must continue to address it with urgency and responsibility.

As the voice of the global industry, the mission of the World Plastics Council is to help address the challenges facing plastics systems while maintaining the utility that plastics offer society. We are focused on reducing plastic pollution through increased collaboration and dialogue with a wide range of stakeholders, including the plastics value chain, governments, the UN, NGOs, and researchers while promoting policies that drive advances in circularity across the plastics system.

In support of this mission, we commissioned the report "Towards Circular Plastics: Assessing the Role of Recycling Technologies in Tackling Plastic Pollution" by Ocean Recovery Alliance to evaluate the potential scale which recycling technologies can provide in combating plastic waste mismanagement.

Taking a data-driven approach, the report leverages extensive end-of-life plastic datasets to assess the potential of mechanical and chemical recycling technologies for addressing hard-to-recycle plastic waste under four different scenarios. By exploring these varied pathways, the study provides a comprehensive analysis of how strategic policy and infrastructure investments can accelerate global plastic waste reduction.

One of the key findings is that, under an ideal scenario—where effective collection and sorting infrastructure is in place and technological advancements continue—chemical recycling could manage up to 70% of globally mismanaged hard-to-recycle packaging and textile plastic waste by 2040. This equates to 22 million tonnes of waste annually that would no longer be incinerated, landfilled, or leaked into the environment. Rather than replacing mechanical recycling, chemical recycling serves as a vital complement, expanding the range of materials that can be processed and enhancing the overall value of the recycling industry. By providing advanced solutions for complex plastics, it supports jurisdictions in strengthening and diversifying their recycling systems.

The report also highlights significant regional disparities in recycling capacities, emphasising the need for tailored strategies and trusted, verified transboundary trade of plastic to achieve meaningful progress and circularity of materials. Addressing plastic leakage, particularly in regions with inadequate waste management, requires both domestic improvements and an internationally harmonised framework to enable the movement of valuable plastic feedstock for recycling.

Crucially, scaling up recycling technologies presents an opportunity to create jobs and foster sustainable economic development and investments. However, barriers persist, particularly in financing chemical recycling infrastructure and navigating regulatory inconsistencies. A stable and supportive policy framework is essential to drive innovation and secure long-term investment. These frameworks must balance global obligations with national measures, allowing countries to implement the most effective solutions for their circumstances. Mandatory recycled content targets, for example, can increase demand for circular plastic raw materials, enhancing the value of secondary plastic as a feedstock.

The report further stresses the need for trade policies to evolve alongside recycling initiatives. Aligning Global Plastic Treaty negotiations with Basel Convention regulations is critical to ensuring the responsible movement of recycled plastic feedstock and helping to reduce pollution. Restricting trade without viable alternatives could hinder the transition to a circular economy, particularly in regions with limited domestic recycling capacity.

Additionally, access to finance remains a major challenge, especially for emerging economies. Sustainable financial mechanisms—such as subsidies, tax incentives, extended producer responsibility (EPR) programmes, and blended finance models—are essential to bridging the investment gap. This would be enhanced by a robust recycling industry that includes both mechanical and chemical recycling capacities to use secondary materials.

As Chairman of the World Plastics Council, I would like to thank the Ocean Recovery Alliance for its excellent and timely contribution to this critical topic. I believe this report provides a strong foundation for data-driven policy discussions and collaborative action towards a circular plastics system.

I would encourage all stakeholders committed to ending plastic pollution to read and reflect on its findings and recommendations.

Ocean Recovery Alliance

The role of this report is to help inform stakeholders of the potential volume of secondary plastic material which both mechanical and chemical recycling could collaboratively process with the right policies and facilitation, reducing the potential for waste as a result. Estimates in this report show that 30% of today's plastic waste could be reduced in 15 years with the best case scenarios of reductions, reuse, alternative options and potential EPR programs. This means that 70% of plastic which could become waste will still exist, and this is where the importance of both mechanical and chemical recycling are critical in reducing waste inventories. This knowledge on the macro-volumes of plastic which can be absorbed via circular economies can help guide strategic decisions about where investment can be efficiently allocated. This includes consideration, and needs for collaboration on collection and sorting with the informal and private sectors, as many opportunities for jobs and entrepreneurship will be created along the way with increased use of secondary material for each recycling option. The objective is to optimize the reduction of plastic waste mismanagement and leakage into the environment by creating economic value, while enabling circular systems for the increase in recycled content and sustainable plastic use.

In 2022, member states adopted a United Nations (UN) resolution to develop an "international legally binding instrument" on plastic pollution. The goal for this "Global Plastic Treaty" is to reduce and prevent plastic pollution from impacting our communities using a wide range of measures, restrictions, and solutions. The optimization and strategic implementation of dual types of recycling technologies (mechanical and chemical) offers one of the largest, scaled opportunities to capture and circulate plastic which continues to be used in our economies after any reductions in material via reuse, reductions and alternatives, thus facilitating the treaty's overall objectives of reducing plastic waste.

Although the creation of circular economies will be critical to reduce the plastic pollution, with recycling acting as the main engine of circulation itself, strategies to facilitate circular economies have not been a main focus of treaty discussions. To date, focus has been primarily on programs and policies to reduce, reuse and avoid virgin plastic, complemented by extended producer responsibility structures to finance and build plastic collection and recycling capacity. That focus is worthy, but incomplete.

Studies show that even with the most optimistic best-case scenarios of the proposed reduction and reuse programs being fully implemented, by 2040 only 30% of our plastic waste will have been reduced. The purpose of this report is to assess the potential for the circulation via recycling of the other 70% of the plastic feedstock which would still exist, and significantly higher percentages which need to be absorbed into valuable circular systems before those proposals and programs actually reach their full respective scales and efficiencies. The report presents a comprehensive analysis of the current and projected recycling capacities to help stakeholders better understand the potential impact of both mechanical and chemical recycling on the volume of today's plastic lost for circularity due to lack of collection and sorting (mismanaged plastic).

Aside from containment in controlled and approved, sanitary landfills and waste-to-energy (often considered last options in the waste hierarchy), recycling of all types (mechanical, physical, and chemical) play a significant role in the transition to plastics circularity, provided that an enabling framework is established. Such a framework needs to include circularity policies and regulatory regimes, including recycled content requirements, recycling rates, adequate EPR policies, and movement of qualified feedstock via globally approved mechanisms. This will drive then necessary demand signals, help de-risk investments, and create economic growth.

In fact, comparing managed waste to mismanaged waste, our study found that up to 80% of the existing and projected mismanaged plastic waste by 2040 could be recovered and circulated by mechanical, physcial, and chemical recycling technologies. Circularity policies, adequate regulations, value chain buy-in, attractive investment economics and solid business fundamentals would spur the creation of new jobs in the recycling industry. This can empower community betterment, investment and innovation, and the fostering of a broad just-transition into a world of long-term positive impacts for the environment.

In order to achieve Global Plastic Treaty objectives, global circularity needs to be embraced – and financed – because domestic collection and processing for recycling is already significantly under-funded. To truly achieve its goals, the Treaty can and should create strategic alignment with the UN's Basel Convention and its recent plastic amendments on the trade of non-valuable materials. Failing to bridge these instruments by creating a global circular economy for plastic means we will have failed to fully address the world's plastic pollution that might still exist under best case reduction programs by 2040.

Creating a system of verified and standardized rules and regulations on the trade of secondary plastic raw materials (feedstock) from pre-qualified buyers and sellers will open a wide range of opportunities for both collection and circular processing of both mechanical and chemical recycling to take place at scale. This will reduce the financial burden for many of the member-states who do not have sufficient domestic processing infrastructure for materials today. It is also expected that the domestic capacities needed for material collection, sorting and waste processing will be difficult to achieve without the creation of a large global fund for capacity building and infrastructure, and this comes with similar funding challenges that have faced global climate change efforts.

Executive Summary

Plastic pollution continues to pose an environmental challenge. The projected continued increase in plastic production and consumption requires policies that restrain the demand and production of unnecessary products, alongside policies that enhance plastic collection and recycling. While primarily focusing on plastic production and consumption, emerging multilateral environment agreements (MEAs) could also unlock plastics recycling at scale undertaken in environmentally sound manners.

While recognizing that systemic solutions to the plastic pollution problem are the priority, this report assesses the potential role of chemical recycling as another technological solution which works in complementarity with mechanical recycling. The aim of the report is to analyze the potential for recycling technologies to collect and process hard-to-recycle plastic and waste which previously was mismanaged. The focus is on the expanded scale which chemical recycling can potentially provide in order to manage hard-to-mechanically-recycle plastic, working in parallel of mechanical recycling as collection, sorting and semi-processing capacities are expanded via extended producer responsibility (EPR) programs and new public/private financing models.

To analyze the potential capacity of different recycling technologies, the report takes a data-driven approach by leveraging Plasteax data to theoretically show how strategic increase in capacity of mechanical and chemical recycling technologies could address currently mismanaged plastic waste. The study exemplary explores the regional fate of mismanaged plastic packaging and textile waste, coupling it with future recycling capacity enablement, which includes facilitating global circularity for materials for recycling.

To further understand the potential for chemical recycling, the report looks at how hard-to-recycle plastic waste would be dealt with under four scenarios for 2040 (based on the examples of packaging and textile waste):

1) business-as-usual (BAU), i.e., there is a marginal increase in recycling and absence of policies supporting chemical recycling;
2) delayed policy support for chemical recycling until 2030;
3) early policy endorsement of chemical recycling and strategic plant locations with sufficient supporting infrastructure (e.g., Asia and Africa);
4) integrated system of chemical recycling with targeted collection and sorting systems which also facilitate the expansion of mechanical recycling.

The main findings of the report regarding the potential for recycling technologies to treat mismanaged plastic waste are:

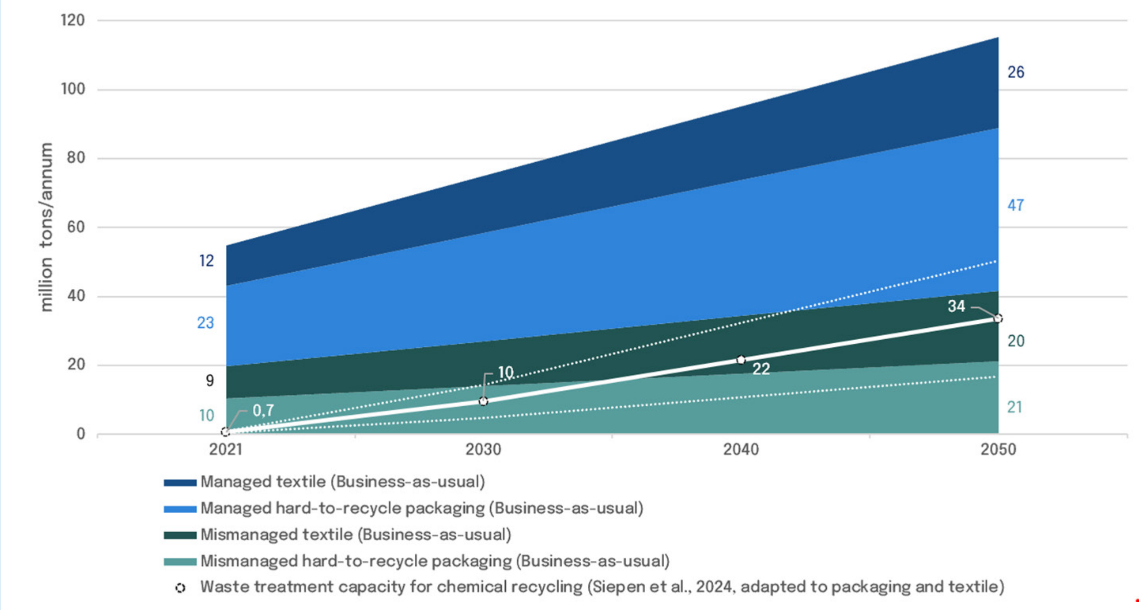
> ***Currently, 40 million tons of plastic packaging and textile waste are mismanaged, leading to environmental pollution. Scaling up mechanical and chemical recycling could help reduce plastic waste mismanagement and mitigate plastic leakage.*** Mechanical recycling is an efficient option for clean, mainly single-polymer, rigid plastic packaging. Chemical recycling offers the ability to recycle more complex or contaminated plastics, including mixed fiber textiles. A combined approach of mechanical and chemical recycling technologies can tackle both easy-to-recycle and hard-to-recycle plastic waste, particularly in regions where plastic waste mismanagement is highest.

Under business as usual, 75 million tons of hard-to-recycle plastic feedstock from packaging and textile waste for recycling would be available by 2040; 31 million tons coming from plastic waste that would otherwise be mismanaged. Chemical recycling technologies could be used to process this hard-to-recycle plastic waste. The data highlights regional disparities, showing the need for region-specific recycling strategies that might require transboundary plastic trade, with local targeted improvements in collection and sorting systems.

Assuming an ideal scenario, by 2040, chemical recycling could handle up to 70% of the hard-to-recycle packaging and textile plastic waste that would otherwise be mismanaged (22 million tons per annum). The ideal scenario considers that appropriate collection and sorting infrastructure is in place, that mechanical recycling processes easy-to-recycle plastic, assumes that the future technology developments can improve chemical recycling dealing with impurities, and does not consider the economic viability of chemical recycling or other limitations. Under these considerations, the report projections show that chemical recycling and mechanical recycling, if scaled properly and supported by policy, could treat a substantial portion of currently mismanaged plastic waste.

Under a systems change scenario, hard-to-recycle plastic feedstock for recycling comes primarily from managed plastic waste. To avoid building lock-in infrastructure with a high risk of becoming stranded assets, chemical recycling projects should plan and size within the range of both BAU and system change scenarios.

The report findings show that the scaling of mechanical and chemical recycling technologies presents an opportunity to remediate existing, and prevent future, plastic leakage. The growth of the recycling industry can bring about societal benefits such as green job creation, cleaner ecosystems and communities, which are hard to value, but these outcomes are what have driven the negotiations to create a UN Plastic Treaty in the first place – to reduce the externalities of plastic pollution. With any industrial development, however, the scaling of the recycling industry may bring externalities, and the impacts of these, as well as the benefits created from such collection and remediation of waste materials, were out of the scope of this report.



Potential plastic feedstock for chemical recycling under BAU compared with global projected capacity found in the literature (Siepen et al., 2024). Shown are global waste treatment capacities balanced by the share of packaging and textile in overall plastic waste (ca. 48%, Plasteax Database, 2024).

Notes

1- Notes on Limitations of the Study and Areas for Further Research

While this study provides valuable insights into the potential of recycling technologies, key limitations highlight the need for further analysis and research:

Systemic Challenges in Scaling Recycling

The study does not fully explore the interconnected barriers to implementing and scaling recycling technologies. Challenges such as inadequate collection and sorting infrastructure, low demand for recyclates, and the absence of effective financing mechanisms hinder progress. Further analysis is needed to develop policy scenarios that integrate measures such as the creation of market demand with mandatory recycled content targets at the product level, taxes on virgin plastic, caps on virgin production, expanded extended producer responsibility (EPR) schemes and eco-modulation of EPR fees, and global support for capacity building in under served regions.

Economic Feasibility of Recycling

The economic viability of recycling, particularly chemical recycling, remains uncertain, but this relies on many factors, including the need for improved collection and sorting infrastructure, strategic permitting and legislation which facilitates recycling investment, and legislation which facilitates the use of recycled content, which includes clear calculation rules including mass balance recognition. Current challenges include high costs versus virgin material reference cases, low profitability due to fluctuating market pricing factors or qualities of feedstock, and inefficiencies in some of the chemical recycling plants which were introduced early into the market, sometimes as demonstration units which were not designed to reach their potential expected scale (which is common in the advent and introduction of new technologies).

Granular Cost and Technology Analysis

While the report provides a high-level assessment of material flows, it lacks a detailed examination of the costs of collection, sorting, and processing specific to different plastic types and recycling technologies. Future research should focus on linking plastic formats to appropriate circulatory technologies and options, offering increased insights for industry and policymakers, as any new options and opportunities versus a BAU scenario usually include lower scale than the optimized fossil value chain. This report offers an opportunity to better understand the value of these interventions and innovations with new resource streams of secondary material (feedstock), as the potential volumes for circulated recycling can be significant.

Assessment of Externalities

The report only considers the potential for plastic waste mitigation. A full picture for the potential of chemical recycling requires a detailed comparison of environmental, health, social, resource efficiency, and economic externalities associated with each recycling technology, and the valuation of the wide range of positive benefits which result in large scale remediation of waste and pollution from the environment, waters and communities via increased collection and recycling.

Acknowledging these areas for further study underscores the need for deeper analysis to address systemic, economic, and technical barriers, ensuring a comprehensive approach to tackling plastic pollution which includes the potential for large scale circularity of hard-to-recycle secondary plastic materials which have not had a viable solution in the past.

2- Notes on terminology

The lack of a universally accepted terminology to define principles of waste and its management can lead to different interpretations and confusion in creating rules, legislation and implementation. In reading the report, the use of key terms are defined as follows:

Plastic waste: Plastic materials that are no longer needed or wanted, and that are discarded by the user after their primary or intended use. Plastic which is never recovered for reuse as a material for recycling or value-creation, remains as "waste" unless it has been burned or incinerated and no longer exists. Once secondary plastic (feedstock) has been collected for recycling, the creation of new polymers, or other value-creating purpose (other than waste-to-energy production), it is no longer considered waste, particularly when circular economies are being developed.

Disposal: As defined by the Basel Convention, the term "disposal" for plastic waste refers to the final placement or treatment of plastic waste in a manner that does not lead to the recovery or reuse of the material. Disposal typically involves methods such as landfilling, incineration without energy recovery, or other forms of final treatment that do not result in the material being reused, recycled or value-creating.

Plastic leakage: The Organisation for Economic Co-operation and Development (OECD) defines plastic leakage as the process through which plastic waste enters the environment, particularly marine environments, due to inadequate waste management practices, littering, or other factors. Plastic leakage contributes to environmental pollution, poses risks to ecosystems and wildlife, and can have negative impacts on human health.

Improperly disposed plastic waste: Improperly disposed of plastic waste refers to plastic materials that are discarded or thrown away in a manner that does not follow appropriate waste management practices. This includes any plastic waste that is not disposed of in designated waste collection points, recycling facilities, sanitary landfills, or which is openly burned, leading to environmental pollution, health hazards, and negative impacts on ecosystems.

Mismanaged plastic waste: Mismanaged plastic waste can be understood as plastic waste that is not handled, collected, disposed of, or recycled in an environmentally sound and sustainable manner. Mismanaged plastic waste often ends up in the environment, including the ocean, rivers, and land, leading to pollution, harm to wildlife, and negative impacts on ecosystems and human health.

Managed plastic waste: Within the context of the Basel Convention, "managed plastic waste" refers to plastic waste that is being handled, treated, and disposed of in accordance with the principles of Environmentally Sound Management (ESM). This includes practices that minimize the environmental and health impacts of plastic waste, promote recycling and resource collection, and prevent illegal dumping or improper disposal of plastic waste.

Plastic feedstock for recycling: Secondary plastic raw materials (feedstock) that has the potential to be used as principal input for a recycling process. This material should not obtain "end of waste" status if it is actually recovered and later put into a circular economy system.

Waste Management: Waste management is the collection, transportation, processing, recycling, and disposal of waste materials in a way that minimizes environmental impact, conserves resources, and protects human health. Effective waste management practices aim to reduce waste generation, promote recycling and reuse, and ensure the safe disposal of waste that cannot be recycled or recovered. When plastic waste is collected for recycling and circular economy use, it is no longer considered "waste," but feedstock, or material/commodity for recycling.

Physical recycling: Physically processing plastic feedstock, such as sorting, shredding, washing, and melting, to produce new plastic products without altering the material's chemical/ polymer structure. There are two types of physical recycling:

- **Mechanical recycling:** Mechanical recycling refers to a process in which post-industrial or post-consumer plastic waste is sorted, cleaned, melted, and reprocessed into new plastic products without undergoing a chemical change in the polymer structure. This method involves physical processes such as shredding, washing, melting, and extruding to convert plastic waste into reusable materials.

- **Dissolution (also solvent-based recycling or physical recycling):** Dissolution is a purification process through which the polymer present in a mixed plastics waste is selectively dissolved in a solvent, allowing it to be separated from the waste and recovered in a pure form without changing its chemical nature.

Chemical recycling (also feedstock recycling, or in some geographies, advanced recycling): Chemical recycling converts polymeric waste by changing its chemical structure and turning it back into substances that can be used as raw materials for manufacturing plastics or other products. Different chemical recycling technologies exist, e.g., depolymerization (e.g., solvolysis, enzymolysis), hydrocracking, pyrolysis, and gasification.

3- Notes on Plastic End-of-Life Fates Data

The report uses the **Plasteax** database developed by Earth Action (EA) for end-of-life fates of plastic. Plasteax aggregates thousands of data points from global sources into a centralized and vetted repository. Plastic end-of-life fate data is generated using the Plasteax model, built following the National Guidance for Plastic Pollution Hotspotting and Shaping Action (IUCN, 2019). Country level production and trade data for plastic are used to determine the end-of-life fates for each plastic type. The methodology considers factors such as the country's infrastructure maturity and policy framework to assess end-of-life fates.

Earth Action has a two-stage data validation process for each country, and only after the second stage is a national dataset published for inclusion in the Plasteax database. First, Earth Action sources information from industry databases, and publicly available databases such as the OECD's Global Plastics Outlook and BACI's international trade database. Second, EA turns to regional sources, including government data collectors and research institutions to validate the model. Local scientific literature is used to solve for gaps or uncertainties.

The multi-tiered approach allows for multiple data points for the same variables across countries and regions, facilitating cross-checking. Discrepancies between data sources are evaluated by experts and uncertainty scores are assigned to each data point to identify the most reliable source. The data used for the report is from 2021, the latest year with high confidence that input data will no longer change.

This report uses Plasteax data on consumer packaging and synthetic textiles for two reasons 1) their significant contribution to global plastic waste; 2) the high granularity on their end-of-life fate based on the polymer and product category.

It should be noted that while Earth Action developed the Plasteax database and contributed to modeling the scenarios used in this report, EA does not endorse the results or conclusions drawn in this report. EA's role is limited to providing data tools and modeling frameworks to support analysis, and responsibility for the interpretation and application of results lies with the authors of the report.

List of Abbreviations

ABS	Acrylonitrile Butadiene Styrene
BAU	Business-as-Usual
EPS	Expanded Polystyrene
EA	Earth Action
EPR	Extended Producer Responsibility
EU	European Union
HDPE	High-Density Polyethylene
(L)LDPE	(Linear) Low-Density Polyethylene
MEAs	Multilateral environmental agreements
OECD	Organization for Economic Co-operation and Development
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
UN	United Nations

1. Introduction

1.1. Report Objective

Plastic pollution is one of the most critical and complex environmental challenges of our time. With global plastic production increasing annually, effectively managing plastic waste remains a challenge (UNEP, 2023b). Despite progress in recycling technologies, global recycling rates remain low – between seven and nine percent (Kalali et al., 2023; OECD 2022), mainly due to the lack of sufficient supporting collection and sorting infrastructure to supply material to the plants which have the proper processing equipment. If not recycled, most of the world's plastic waste is sent to landfill, incinerated, or mismanaged, leading to leakage into the environment (Cottom et al., 2024; Lange, 2021). Plastic waste poses environmental and human health risks, and this can be assumed to increase in scope without productive interventions, as plastic production is projected to double by 2050 if no significant action is taken (OECD, 2022).

This report leverages Plasteax data to offer an in-depth analysis of how mechanical and chemical recycling technologies can be scaled up to reduce plastic pollution. By exploring the regional fate of mismanaged plastic waste and coupling it with future recycling capacity enablement, particularly in chemical recycling, the report addresses a crucial knowledge gap: ***how much plastic waste could theoretically be recovered and treated by recycling technologies***, and what impact future recycling developments could have on reducing mismanaged plastic waste globally.

Overall, the report addresses two knowledge gaps:

- **Analysis of plastic waste that could be feedstock for recycling:** In this report, the assessment was made of the plastic packaging and textile waste available for recycling, broken down by region and polymer type, to offer a holistic view of the current and future recycling landscape.
- **Comparison of recycling technologies to provide insight into future chemical recycling capacity:** Leveraging Plasteax data, the report evaluates theoretically the scaling capacity of mechanical and chemical recycling technologies. Focus was put on the potential volumes of hard-to-recycle plastic waste left untreated by mechanical recycling, allowing the model to estimate the potential for chemical recycling to manage hard-to-recycle plastic waste based on future capacity and regulatory scenarios.

The report analyzes the need for both mechanical and chemical recycling technologies in order to reprocess all plastic types, highlighting that both need to be preceded by improved collection and sorting infrastructure and capacities for plastic waste. The report recognizes that the priority is for mechanical recycling to be applied, but that its capacity needs to increase in order to reprocess all easy-to-recycle plastic. The research model studies the plastic leakage reduction potential of chemical recycling for hard-to-recycle plastic only. While the report examines the recycling technologies themselves, it does not address the economics of these solutions, nor the broader societal considerations, pro and con.

Ultimately, the report aims to provide a comparative understanding of the current and future potential of recycling technologies to collect and recycle plastic more effectively, and thus reduce plastic pollution. The report offers insights into how recycling can contribute to the reduced reliance on virgin plastic materials, helping to mitigate the broader environmental challenges associated with plastic production and disposal.

1.2. Overview of the Global Plastics Recycling Context

Addressing the global plastics crisis requires a comprehensive range of solutions, including facilitating legislation, design-for-recycling measures, coupled with the increased recycling of plastic waste can tackle growing plastic leakage (The PEW Charitable Trust and Systemiq, 2020). Despite low global recycling rates, recycling remains a proven circular economy practice that places a value on plastic waste, converting collected material into reusable feedstock.

The lack of infrastructure and capacity of plastic waste management remains a major barrier to increasing global recycling rates. More effective collection and sorting systems could enable the recycling of some plastics currently labelled as hard-to-recycle (Ragaert et al., 2017). However, challenges such as material contamination, mixed waste streams, and inadequate infrastructure, particularly in low and middle-income countries, hinder scalable recycling solutions, leading to open burning or dumping of plastic waste (Garcia-Gutierrez et al., 2023; Browning et al. 2021; Cook, 2022).

In addition, the market price of virgin plastics, often much lower than the price of recycled plastics, with variability depending on the underlying price of oil and user-demand, creates economic challenges that impede the expansion of recycling and undermine efforts to increase plastic circularity via recycling (Bedard et al., 2021; Williams et al., 2020). To spur innovation and direct investments into recycling, some countries are setting ambitious recycling and recycled content targets. For example, starting in 2030, the EU Packaging & Packaging Waste Regulation requires 10-35% recycled content in plastic packaging by 2030, increasing to 50-65% by 2040, depending on packaging type (European Commission, 2022, article 7).

Further, the European Commission has proposed setting mandatory recycled plastic content targets for various other physical goods like textiles and cars (25% for plastic parts in all new cars by ~ 2032). However, despite the positive momentum, many EU member states are still not on track to meet recycling goals (EEA, 2023), often due to collection methods and costs of processsing within the EU. In contrast, estimates show an excess demand for recycled content globally, mainly from the large global brands which have made commitments to use percentages of 20-30% of recycled content for some of their products or packaging, some even by 2025. For example, the demand for recycled PET already exceeds supply by threefold in the United States of America (McKinsey & Company, 2023).

Multilateral environmental agreements (MEAs), such as the Basel, Rotterdam, and Stockholm (BRS) Conventions, are vital for controlling and avoiding illegal practices and the dumping of non-valuable and hazardous plastic waste. However, MEAs should not hinder recycling by limiting the movement of valuable plastic feedstock for recycling (ICCA, 2024). The ongoing negotiations for a UN Global Plastics Treaty present a pivotal moment in the global effort to combat plastic pollution, providing a platform for standardization of plastic terminology, ensuring consistency in definitions and creating opportunities to prevent plastic pollution and broader climate impacts at all stages of the plastics lifecycle. This also means that alignment with the BRS Conventions for the allowance of standardized, efficient trade of verified plastic feedstock between countries is necessary in order to create a circular economy which works to facilitate the reduction of plastic pollution which may be locked within countries which do not have sufficient processing capacities and/ or which cannot access global markets for the sale of their qualified material. This will help to ensure that hard-to-recycle plastics can be processed in regional hubs with the necessary infrastructure, creating a broader global circular economy in the process. Such an approach also promotes investment in recycling technologies and aligns trade policies with environmental goals, enabling countries, particularly smaller economies, to efficiently handle, recover and have access to international market to sell qualified feedstock, particularly if they are unable to process all of the material domestically (ICCA, 2024).

While the Plastic Treaty is expected to advance measures to reduce plastic production and consumption by balancing upstream reductions, which include reuse and refill models, with downstream solutions, such as extended producer responsibility (EPR) programs that encourage the use of recycled materials, waste management and recycling are essential to address plastic pollution and environmental impacts all stages of the plastics lifecycle. Recycling technologies – whether mechanical, physical or chemical – play a critical role in reducing plastic waste and acting as the engine which drives circular economies and reuse of materials. The future challenge will be the scaling up these technologies and the supporting collection and sorting infrastructure required to help meet recycling targets (Landrigan et al., 2023).

2. Plastic Feedstock for Recycling: How Much is Available?

This section analyzes the following knowledge gaps:

Analysis of plastic waste that could be feedstock for recycling: *a comprehensive assessment of the types and volume of plastic waste available for recycling, broken down by region and polymer type to offer a holistic view of the current and future recycling landscape.*

Understanding the types, volumes, and regional distribution of available plastic waste is crucial for developing recycling infrastructure where it is most needed. This section provides an overview of the global plastic waste landscape, defines and assesses the capability and treatment limitations of key plastic recycling technologies, and introduces current trends in chemical recycling.

The report focuses on consumer packaging and synthetic textiles[1] due to their significant contribution to global plastic waste, accounting for 48% of global plastic waste – consumer plastic packaging accounts for about 30% and textiles for 18% (Plasteax database, 2024). Across regions, the data shows significant variations in the generation and handling of these waste streams. Although Asia leads in waste generation across both streams, waste collection and recycling challenges are evident globally, with mismanagement particularly affecting low-income regions.

Plastic packaging and synthetic textiles have a short (less than half a year) and medium (on average five years) lifespan respectively, making them critical targets for reducing plastic pollution (Geyer et al., 2017). Further, some types of plastic packaging, and almost all synthetic textile waste, have few to no recycling options in current waste management systems. Identifying mismanaged plastic packaging and textile waste hotspots are strategic location opportunities for scaling up recycling efforts and addressing high impact sources of waste.

2.1. Waste Treatment Technologies and Available Waste Volumes

Plastic waste management includes all of the processes of handling plastic when it finishes its intended primary use, i.e., from collection, to transport, sorting, and recycling or disposal (sanitary landfill or incineration) (Directive 2008/98/EC, article 3). Plastic waste management ensures that plastic waste that is suitable as feedstock for recycling is collected for further processing, thereby preventing pollution from plastic waste that would have otherwise been mismanaged.

Waste management programs which do not end up with materials for recycling use disposal methods such as incineration, the burning of plastic waste at high temperatures, and sanitary landfilling, the burial of plastic waste in a controlled environment. While incineration significantly reduces waste volume and can include energy recovery, incineration also releases greenhouse

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[1] Due to data availability the study only considers textiles of 100% synthetic fibers.

gases and pollutants, contributing to air pollution and climate change (Kortsen and O'Hare, 2023). Scientists are also suggesting that incineration might be more harmful than landfilling, as it produces a greater amount of greenhouse gases and toxic pollutants, depending on the type of scrubbing and filter systems installed, causing risks to both human health and the environment if not using modern technologies (BBC News, 2024). Even though "sanitary" landfills contain plastic waste, they contribute to land-use change and may leach harmful chemicals into surrounding soils and water bodies over time (Kortsen and O'Hare, 2023). Landfills also create methane from organic material and food waste, which often contaminates plastic, making the collection, cleaning and sorting of plastic more expensive for recycling. In regions with insufficient waste management infrastructures, collected waste may end up mismanaged in uncovered unsanitary landfills or open dumps, where it maybe be burned. Uncollected waste is also often burned or illegally dumped.

Recycling technologies enable the reprocessing of plastic, avoiding the creation of new material, but also preventing it from becoming waste. Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations (Directive 2008/98/EC, article 3). Mismanaged plastic waste and often managed plastic waste can represent potential feedstock for recycling if adequate infrastructure for efficient plastic collection, sorting, cleaning exists.

Textile Waste Generation and Management

Synthetic fibers account for 69% of global textile production (Chen et al., 2021). Today, over half of all textiles produced contain polyester, making textiles one of the key contributors to plastic waste generation (Changing Markets, 2023). In 2021, global synthetic textile waste amounted to approximately 63 million tons. Asia generated 62%, the Americas contributed 18.7%, and Europe generated 15.4%, while Africa and Oceania accounted for only 3% and 0.8%, respectively, reflecting lower textile consumption and waste generation (see Figure 1).

The plastic textile waste management modelled by Plasteax for 13 countries suggests varying end-of-life fates. In Asian countries, 34% of textile waste remains uncollected. In comparison, European and American countries show more organized waste management practices, with a combination of reuse, recycling, and incineration, yet substantial portions still end up in sanitary landfills. Furthermore, high-income European countries export on average a quarter of their plastic textile waste (see Figure 2).

Most synthetic textiles are made of multiple materials, where the main plastic component is combined with other fibers (such as cotton or viscose), or with functional elements (such as zippers and buttons). The multi-material composition of synthetic textile complicates the processes of separation and circulation for recycling. Figures 1 and 2 show the need for improved plastic textile waste collection, sorting, and recycling infrastructure to reduce plastic textile waste mismanagement.

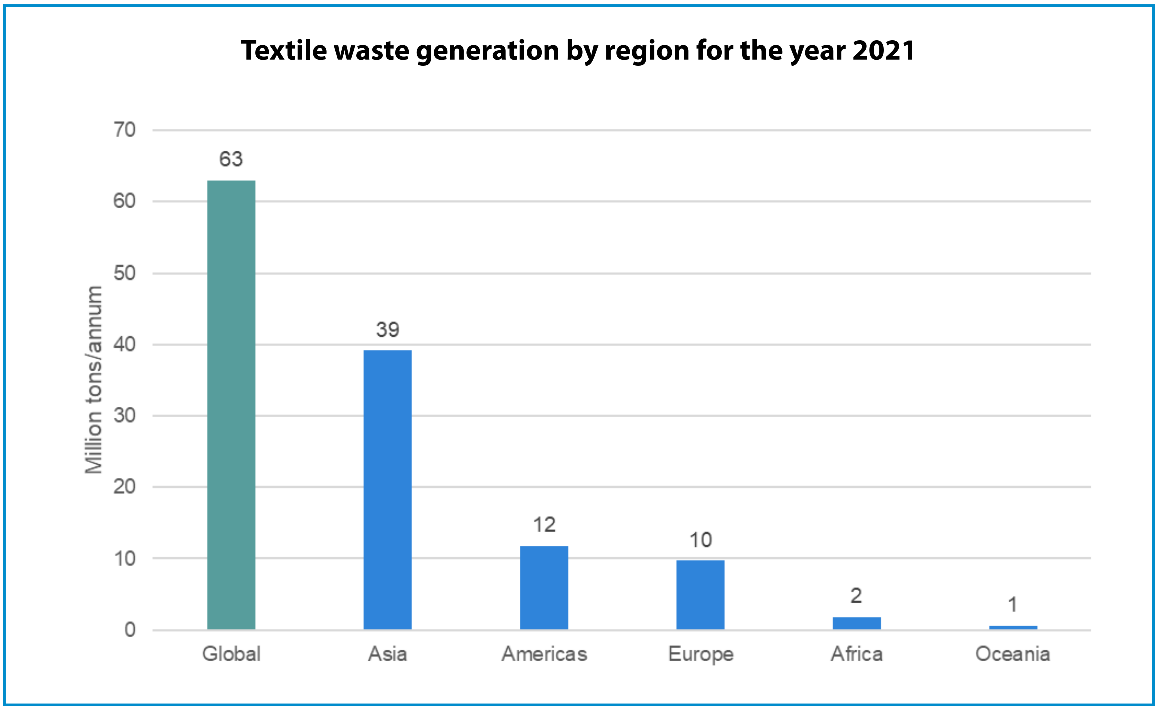

Figure 1 : 2021 Global and regional textile waste generation (Plasteax, 2024; Kounina et al., 2024).

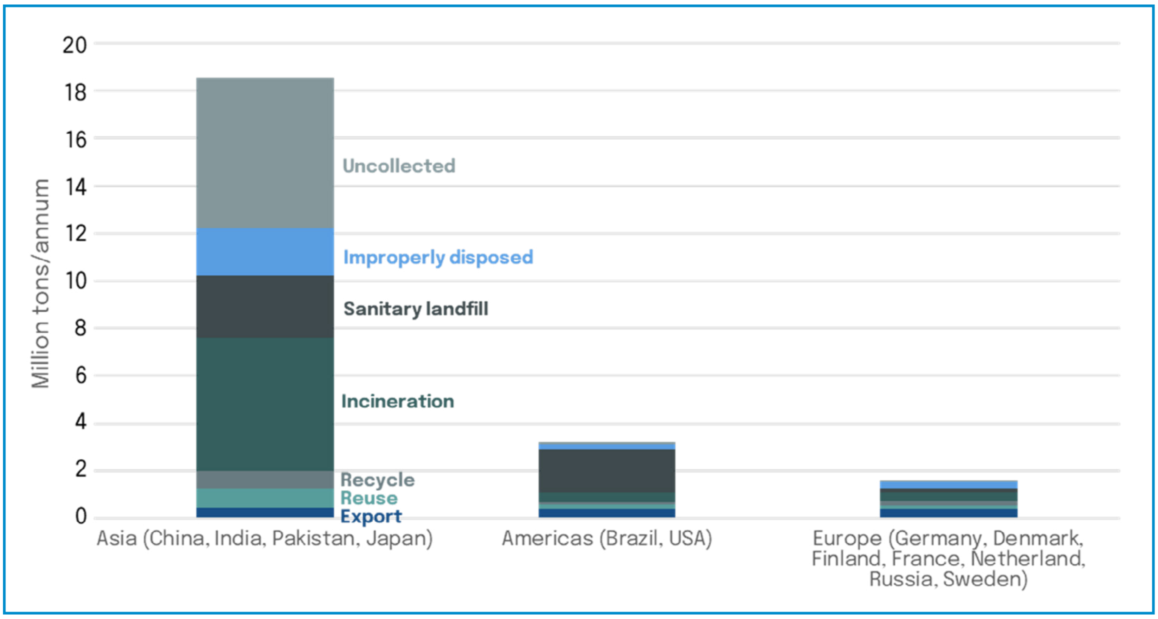

Figure 2: Regional textile waste management for the year 2021 (Plasteax, 2024; Kounina et al., 2024). NB: granular Plasteax data on end-of-life fates of textiles is only available for a subset of countries per region as listed in graph. Share of end-of-life fates are indicated in the table for each region.

Packaging Waste Generation and Management

In 2021, global consumer plastic packaging accounted for approximately 106 million tons of waste. Asia generated 47%, followed by the Americas with 30%, and Europe with 18% (Plasteax database, 2024). Figure 3 illustrates the regional breakdown of packaging waste generation by plastic packaging type, while Figure 4 provides insight into the specific polymer types in the regional plastic packaging waste.

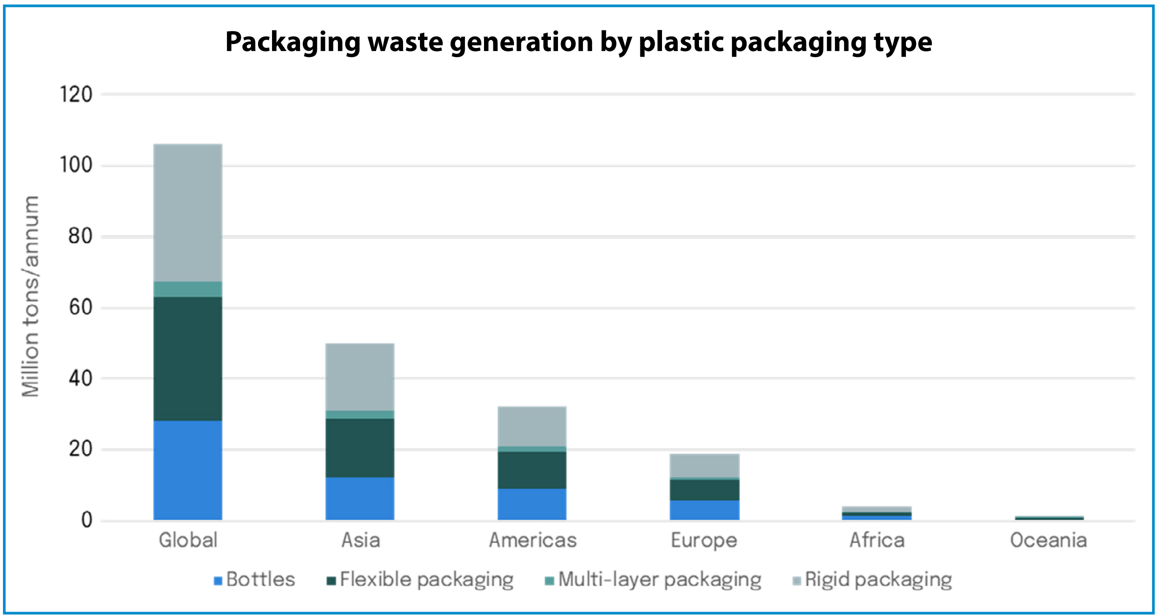

Figure 3: 2021 Global and regional waste generation by region and material type (Plasteax, 2024).

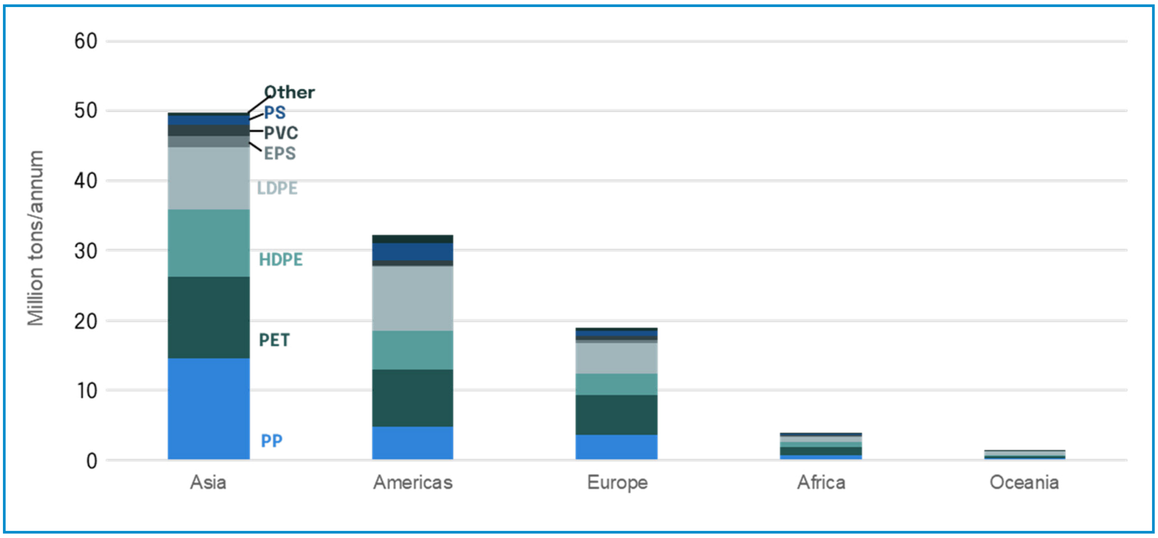

Figure 4: Regional plastic packaging waste generation by polymer type for the year 2021 (Plasteax, 2024). The Plasteax Europe graph shows that 37% of 18MT are recycled, and that 11.34MT is not recycled..

End-of-life fates of plastic packaging are tied to the polymer and packaging type, as well as the uniformity and consistency of material types. Thermoplastics are easier to recycle because they can be repeatedly softened and reshaped to some extent, while thermosetting plastics, rubbers and elastomers are not. Rigid packaging, like bottles, are often made of a single polymer type and generally easier to collect, sort and mechanically recycle. Flexible packaging is light weight, prone to leakage, and complicates collection, sorting and mechanical recycling. Often multi-layered, flexible packaging requires material type separation for recycling and de-inking processes (Pan et al., 2020). Currently, rigid packaging waste is of higher quality, resulting in a higher market value than flexible packaging waste.

Nevertheless, mechanical recycling technologies are continually improving to treat flexible packaging (Van Rossem, 2023). Polymer-specific data as in Figure 4 is essential for understanding what packaging formats are best fit for specific recycling technologies. Table 1 further summarizes the current ease of recyclability of polymer types used for packaging.

Polymer	Usage	Recyclability	Considerations for the cases of mechanical recycling
Polyethylene terephthalate (PET)	Beverage, bottles, and rigid and flexible food packaging	High (mechanical and chemical)	Requires proper sorting
High-density polyethylene (HDPE)	Bottles, rigid packaging containers	High (mechanical, chemical)	Sorting issues, difficulty to achieve food-contact sensitivity standards due to contamination
Polyvinyl chloride (PVC)	Rigid and flexible packaging for non-food items	Low (mechanical)	Contamination by toxic additives and chlorine, difficult to recycle safely safely
(Linear) Low-density polyethylene (LDPE; LLDPE)	Flexible films, plastic bags, food wraps	Moderate (mechanical), high (chemical)	Sorting, contamination, mixed material composition (some multi-layers) and difficult to achieve food-contact standards
Polypropylene (PP)	Bottle caps, various flexible and rigid packaging items	High, yet challenging to maintain a closed loop (mechanical, chemical)	Contamination, mixed waste streams
Polystyrene (PS, EPS)	Disposable food containers, protective packaging	Low to high (mechanical, chemical)	Low density, contamination
Other Plastics (ABS, PU, etc.)	Mixed packaging components	Low (mechanical) to high (chemical)	Mixed material composition, unknown additives

Table 1: Packaging polymers and recyclability considerations (Sources: Löw et al., 2021; Pan et al., 2020; Source Green, 2024; Uekert et al., 2023; Zaman et al., 2021).

Considering that 88% of plastic packaging is dominated by four polymer types – PET, PP, (L)LDPE, and HDPE (see Figure 5), the end-of-life fate analysis focuses on these four polymer types. Currently, 48% of PET, PP, (L)LDPE, and HDPE plastic packaging is managed via incineration and sanitary landfill, yet 30% remains mismanaged, polluting the environment, and only 20% is recycled (see Figure 6). Recycling consumer plastic packaging waste remains as low as 9%, 7%, 7% in Africa, Oceania and the Americas, respectively; 30% in Asia; and 14% in Europe (see Figure 7). In all regions, rigid packaging and bottles represent more than 80% of the total recycled plastic packaging. (Plasteax database, 2024). For more information on the database, see section 6.1.2.

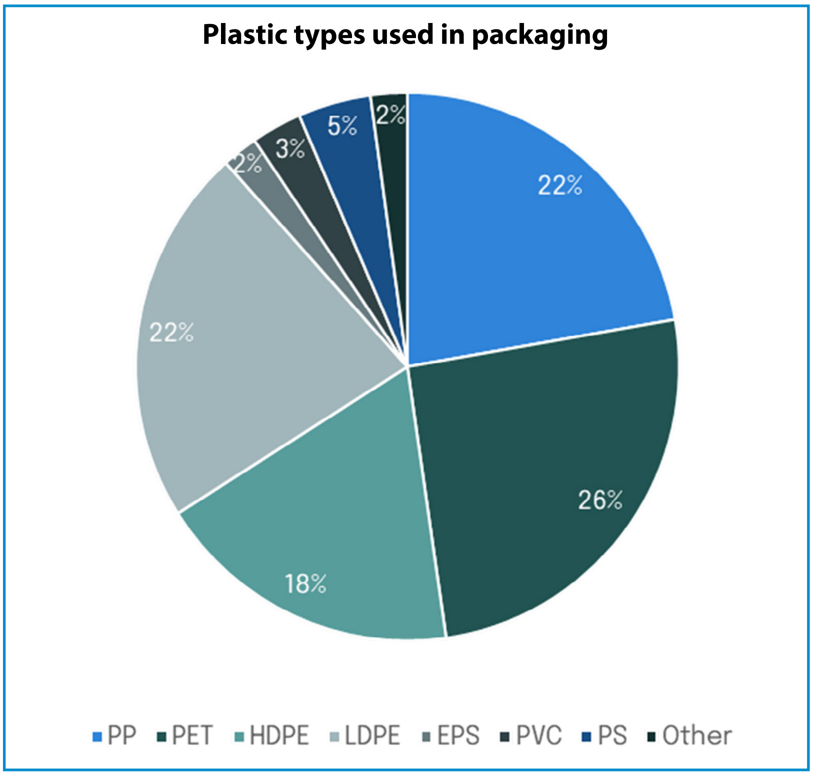

Figure 5: Distribution of plastic types used for packaging application (Plasteax, 2024).

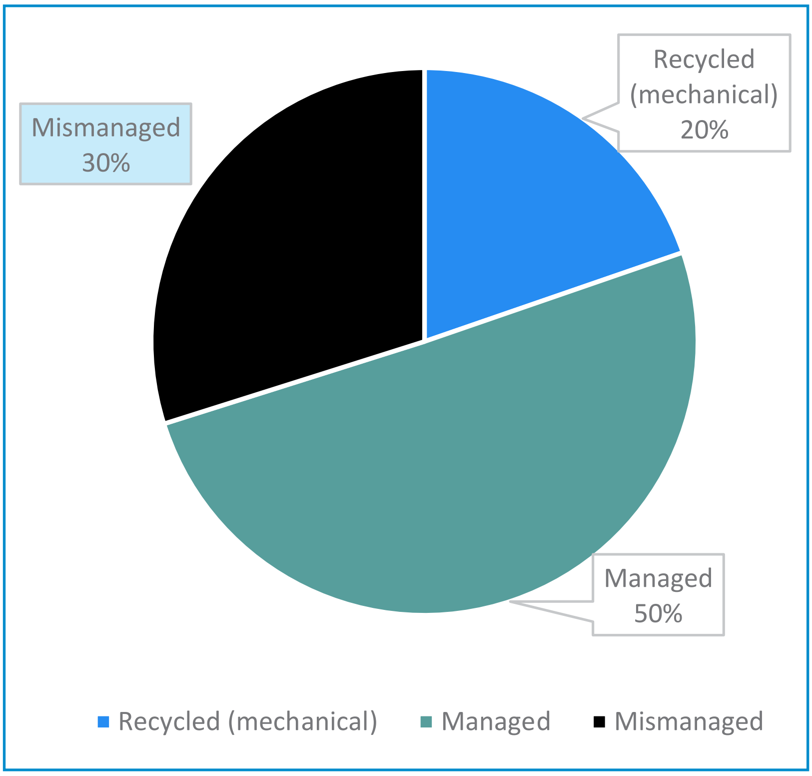

Figure 6: Global end-of-life fate of PET, PP, HDPE, and LDPE plastic packaging (Plasteax, 2024). More information on the data behind the graph is available in section 6.1.2.

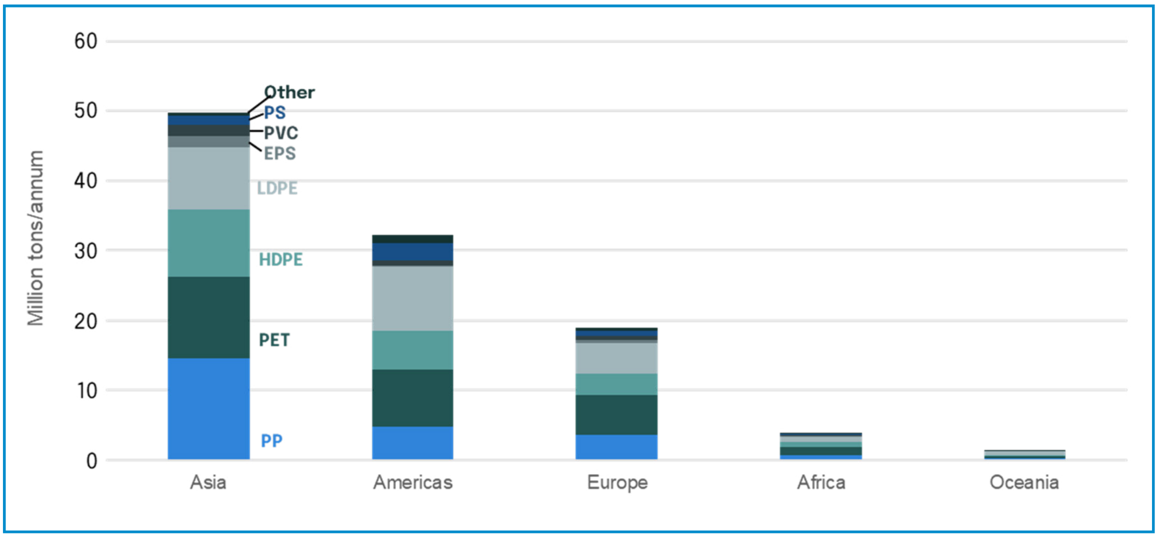

Figure 7: Regional waste management by packaging polymer type for the year 2021 (Plasteax, 2024). More information on the data behind the graph is available in section 6.1.2.

Potential Mismanaged Plastic Textile and Packaging Waste for Recycling Feedstock

Condensing the end-of-life fates into one global overview, plastic waste can either be well managed, i.e., recycled, incinerated, or landfilled, or mismanaged. As shown in Figures 1 to 7, globally almost 40 million tons of plastic textile and packaging waste is mismanaged and polluting the environment, and thus has potential for collection and sorting for either mechanical or chemical recycling if capacities and infrastructure can be improved. Also noteworthy, is the discrepancy between collection and well-managed, suggesting that collection alone does not guarantee well-managed waste (see Figure 8). For instance, in regions with more than 90% of collection rates (i.e., Americas and Europe), more than 10% of collected waste becomes mismanaged (the E.U. numbers include Russia, which has less infrastructure for proper managed waste). In Asia and Africa, this number amounts to 23% and 58%, respectively. Furthermore, the gap between collection and effective waste management underlines the need for policies that support recycling. Investments in collection, sorting, and recycling technologies could help reduce plastic leakage and its impact on communities worldwide.

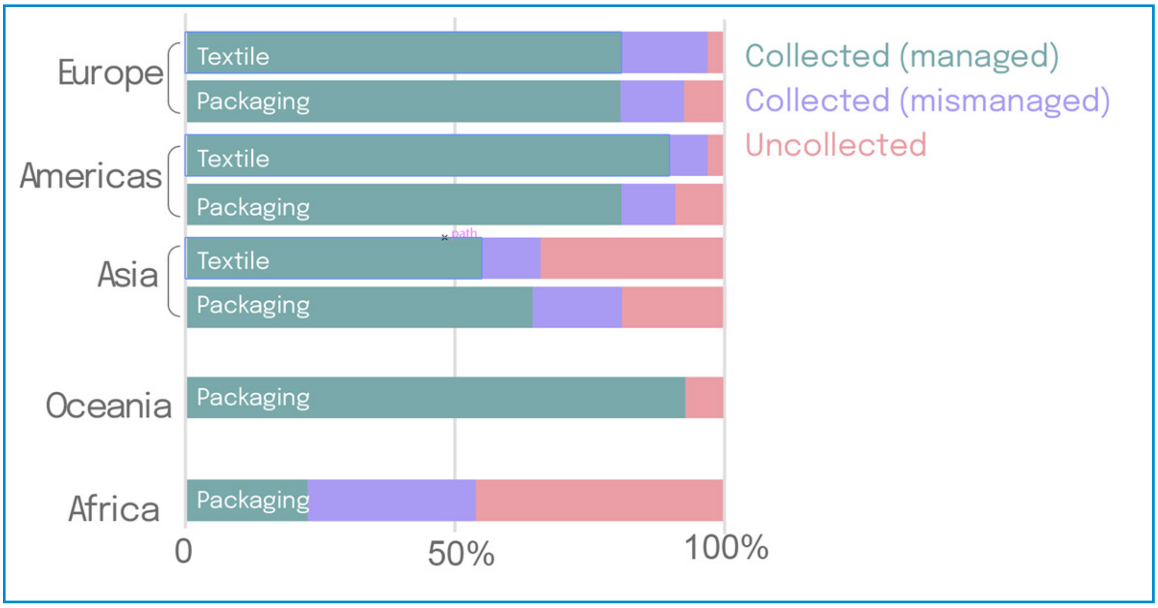

Figure 8: Share collected (well managed), collected (mismanaged), and uncollected plastic textile and packaging waste by region for the year 2021. Note that for Oceania collected (mismanaged) waste is less than 0.001% (Plasteax, 2024).

2.2. Recycling Technologies

Recycling technologies are diverse, encompassing various processes, each tailored to specific feedstocks producing specific recycled materials. To date, the competitive market price and quality of virgin plastic have held back the scaled growth of recycling. Improved sorting and collection programs are needed to generate reliable, quality feedstock streams for both mechanical recycling and chemical recycling, which can each operate in a complementary fashion.

From a systemic perspective, "plastic recycling" encompasses the entire chain of actions that start with the end-of-life stage of a plastic product, including collection, sorting, and reprocessing (see Figure 9) (Ragaert et al., 2023). The European Waste Framework Directive defines "recycling" more narrowly, referring only to the reprocessing stage, while the broader process, including collection and sorting, is considered "waste management" (Directive 2008/98/EC, article 3). All processes related to plastics recycling are, however, interdependent. Collecting and sorting plastic waste is the foundation for reprocessing recycling technologies, as effective separation by polymer type and contamination level (e.g., food residue, dirt, labels, adhesives, or non-compatible plastics) ensures higher-quality recyclates. Table 2 provides an overview of all recycling technologies and their respective advantages and limitations.

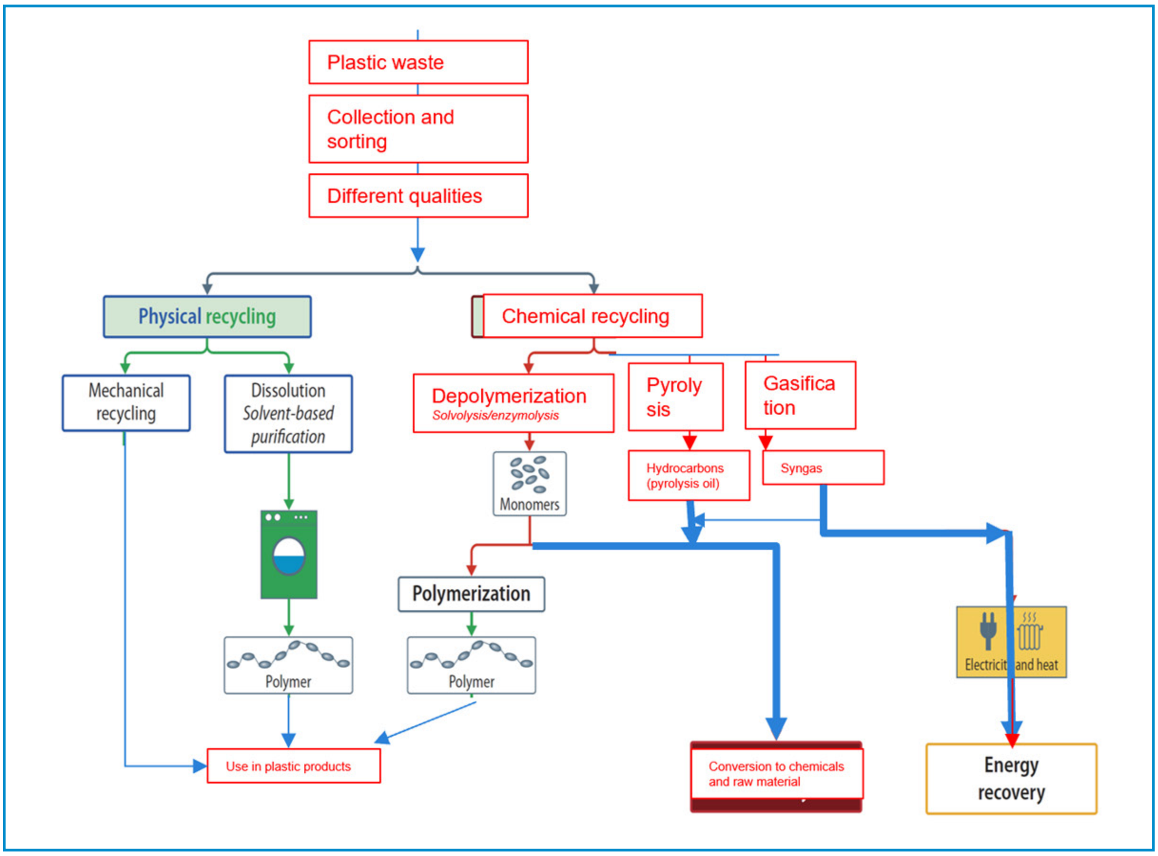

Figure 9: Landscape of technologies being used in the recycling of plastics (adapted from Schlummer, M. et al. 2020 and Nova-institute, 2024).

Table 2: Exemplary overview of recycling technologies (Ragaert et al., 2017; Ragaert et al., 2023; Garcia-Gutierrez et al., 2023; Collias et al., 2021; Das et al. 2022).

Technology	Process	Compatible plastic types	Key features / function	Advantages	Limitations	Suitability for contaminated / multi-layer plastics
Physical recycling - Mechanical recycling	Grinding, washing, melting, and re-granulating	• Rigid thermoplastics (PET, HDPE, PP) • Some flexible packaging (LDPE, PP)	Physical process relying on high purity of input material	• Low energy requirement • Cost-effective for single-polymer plastics	• Struggles with some flexible / multi-layer plastics, and complex contamination • Recyclate quality limitations • Recyclate quality decreases with each recycling cycle, unless carefully controlled	Moderate
Physical recycling - Dissolution (also solvent-based recycling)	Dissolution without altering polymer chemistry	• Rigid thermoplastics (PET, HDPE, PP) • Some flexible/ multilayer packaging (LDPE, PP, PE-PA) • Decontamination of PS • Mixed polyester-based textiles (PET, PET-cotton, elastnae, PA)	Physical process using dissolution and precipitation to isolate the target polymer and remove contaminants, without altering the polymer's structure	Improves purity for high-quality output without altering polymer chemistry	• Can be expensive and complex • Mainly suitable for high-value plastics • Requires re-addition of additives to provide function	Moderate to high for many polymers and contaminants
Chemical recycling - Depolymer-ization	Selective breakdown of polymers with reactants, heat, or catalysts into original monomers	Condensation polymers (PET, polyamide, polycarbonate, polyurethane)	• Solvolysis uses specific solvents to tackle multi-layer plastics. • Enzymolysis revolves around biochemical reactions.	• Produces virgin-equivalent plastics suitable for high-quality applications (e.g., food-grade) • Ideal for specific polymers	• Limited to certain polymers • Expensive and complex • Purification steps required to isolate monomers • Reactants need careful handling for environmental safety	• Moderate to high for certain contaminated plastics like PET or polyamide 6
Chemical recycling - Pyrolysis	Heating of plastic waste (thermolysis) in the absence of oxygen	Mixed plastics, particularly polyolefin-based plastics (PE, PP)	• High-temperature process converts plastic waste into pyrolysis oil, wax and gas. • Yield depends on the polymer structures and thermal stabilities. • Can be affected by contamination	• Handles a range of mixed polyolefin and contaminated plastics • Recyclate quality is maintained with each cycle • Pyrolysis oil is a chemical feedstock for petrochemicals, including new plastic and chemical applications. • Can make (partial) use of already existing assets, e.g., in chemical production, hence reducing the overall investment needs for circularity	• Higher energy requirement • Higher cost • Post-treatment purification needed •	• Moderate to high – can handle mixed plastics • Contaminants can neutralize the pyrolysis catalysts, reducing treatment capacity.
Chemical recycling- Gasification	High-temperature conversion to syngas (hydrogen and carbon monoxide) with oxygen-rich gas	Complex mixtures and multi-layer plastics (PE, PP, PS, PET, polyamide)	Converts plastics into syngas, a versatile product used in fuel or chemical manufacturing	• Efficient for complex carbon carbon-containing waste streams (e.g., plastics, organic waste, municipal waste)	• Requires very high temperature • Resulting ash requires disposal. • Syngas requires further purification for most down-stream applications.	High – ideal for complex, contaminated, and mechanically non-recyclable plastics

Mechanical recycling is suitable for processing large volumes of single-polymer, clean, and easily collected plastics such as rigid PET, PP, and HDPE plastic packaging. However, contaminated, flexible and multi-layered plastic packaging pose a challenge for mechanical recycling, reducing the quality of recycled materials over time (Ragaert et al., 2023; Garcia-Gutierrez et al., 2023; Kibria et al., 2023;

The PEW Charitable Trust and Systemiq, 2020). Consequently, hard-to-mechanically recycle plastics with low market value are left untreated and have proportionally a higher risk of leakage. For instance, more than 30% of PP and PE are mismanaged compared to 26% for PET (see Figure 7).

Almost all recycling technologies and processes could benefit from improved waste collection and sorting and would have increased efficiencies from design-for-recycling measures to minimize loses and residues. To overcome the limitations of mechanical recycling and avoid continued leakage of hard-to-recycle plastics, chemical recycling could provide a complementary solution to mechanical recycling. Although chemical recycling technologies may currently still struggle with challenges related to the contamination of feedstock (see Table 2), they have the potential to produce high-quality recyclates, including food- and medical-grade plastics. Chemical recycling processes can break down complex plastic polymers into monomers, which are the building blocks used to manufacture new plastics. Thee monnomers can be purified and used to create virgin-quality plastics without degradation in quality. As a result, via chemical recycling, the monomers can create a plastic-to-plastic recycling loop, potentially extending the lifecycle of non-mechanically recycled plastics, thus reducing reliance on on virgin resources while playing a key role in addressing more challenging waste streams (Garcia-Gutierrez et al., 2023; The PEW Charitable Trust and Systemiq, 2020).

2.3. Current Commercial Trends in Chemical Recycling

Any industrial transition begins with high costs and low technical efficiency, improving over time through continued investment and development (Siltaloppi & Jähi, 2021). The chemical recycling market is still in its early stages, but growing. The ongoing research and development and iterative improvements in chemical recycling contribute to the industrial transition of the plastic industry. Currently the scale of chemical recycling is limited compared to mechanical recycling, yet momentum for expansion is building, with updates on announced investments posted regularly on **Global Partners for Plastics Circularity's** site. Significant global investments are advancing chemical recycling technologies. Between 2018 and 2023, 413 chemical recycling deals were made in 41 countries, totaling USD 4,1 billion (The Circulate Initiative, 2024) and USD 18 billion announced globally as of end-2024. In Europe, plastic manufacturers are steadily increasing planned investments in chemical recycling, rising from 2.6 billion Euros by 2025 to an anticipated 7.2 billion Euros by 2030 (Plastics Europe, 2024). One notable example is the Eastman Chemical Company's announcement of a USD 1 billion investment to build a plastic-to-plastic recycling facility in France. Timely legal clarity on the introduction of new chemical recycling facilities for jurisdictions which have infrastructure to support them, along with standardized mass balance policies, are critical for these types of large investments to be made.

Chemical recycling technologies vary in stage of maturity. Ranging from early-stage pilot projects to semi-commercial scale with first-of-its-kind units (demonstration plants). Conventional pyrolysis is already implemented on a commercial level in various regions, however other pyrolysis techniques such as plasma pyrolysis and microwave-assisted pyrolysis are still in laboratory and pilot testing (Solis and Silveira, 2020). Some technologies, like solvolysis or pyrolysis, can also be applied in decentralized, smaller facilities (Quicker et al., 2022). Currently, twenty plants are already operational worldwide, mostly using pyrolysis technology, with annual waste treatment capacities ranging from 300 tons to 100 kilotons. Over thirty additional projects are either planned or under construction, mainly in Europe, North America, but also Australia and Asia. In 2023, Asia held the largest share of the chemical recycling market with 36%, followed by Europe (26%), North America (21%), Latin America (12%), and Africa and Middle East (7%) (Grand View Research, 2024). This surge reflects growing interest in chemical recycling as a complementary solution to mechanical recycling.

While chemical recycling holds promise for sustainability, realizing its potential requires careful oversight. Transparent and standardized mass balance methodologies should be follwed (e.g., ISCC PLUS, Redcert2), which also express the value generated to support the economic model of the industry. To build trust and ensure accountability, establishing and enforcing standardized, transparent regulations is important to enabling the industry to validate its sustainability claims with measurable progress.

Looking forward, the maturation of chemical recycling technologies will depend on continued innovation, investment, and policy support. As chemical recycling technologies evolve, they may play an increasingly important role in the global plastic waste management system, particularly for plastics that are not suitable for mechanical recycling (Holland Circular Hotspot, 2023; CEPS, 2023). To maximize the effectiveness of chemical recycling vis-à-vis plastic pollution reduction, it should be part of broader plastic pollution mitigation strategies, notably designing-for-recycling, extended producer responsibility, improved collection and sorting, and be complementary to mechanical recycling (The PEW charitable trust and Systemiq, 2020).

Key insights

- Inefficient global waste management systems result in almost 40 million metric tons of mismanaged plastic waste from packaging and synthetic textile, contributing to environmental pollution, especially in Asia and Africa. Asia generates the highest portion of plastic textile and packaging waste, with significant portions remaining uncollected, especially for textiles.

- Increasing recycling rates is essential for meeting goals in reducing plastic pollution, with various national and product-related recyclability or recycled content objectives, while contributing to the reduction of reliance on virgin plastics. Globally, recycling rates remain low for plastic textiles and packaging, with a majority of both still being incinerated, landfilled or mismanaged.

- Mechanical and chemical recycling complement each other, addressing different types of plastic waste. Mechanical recycling is best for clean, generally single-polymer thermoplastics, while chemical recycling targets contaminated thermoplastics, thermosets resp. types of materials which cannot be easily processed by mechanical recycling like synthetic textile waste. However, both methods face challenges with mixed materials in various compositions, and their suitability depends on the uniformity and consistency of a specific waste stream.

- Building efficient plastic collection and sorting for both mechanical and chemical recycling requires significant investment and societal change in the way that municipal solid waste is managed, with each country and jurisdiction facing different needs. Despite varying levels of maturity, the chemical recycling market is already experiencing important investments, driving development of new facilities, especially in Europe, North America, and Asia. New investment announcements for other regions are updated regularly on the Plastics Circularity site.

- Trusted and standardized rules for transparent mass balance methods are important for chemical recycling technologies to deliver their promised sustainability benefits, and for the industry to have clarity in operations and future planning.

3. Chemical Recycling: What is its Potential for Mitigating the Risk of Plastic Waste Being Mismanaged?

This section addresses the following knowledge gap:

Balanced comparison of recycling technologies to provide strategic insight into future chemical recycling capacity: Leveraging Plasteax data, the report evaluates the scaling capacity of mechanical and chemical recycling technologies, and focuses on how much plastic waste could become feedstock for chemical recycling technologies based on future capacity and policy scenarios.

To help inform strategic decisions about where investment can have the greatest impact, the study assesses, alongside mechanical recycling, the potential for chemical recycling to reduce the risk of plastic waste being mismanaged. The modelling focuses on recycling technologies that have the potential to promote plastic-to-plastic recycling, particularly depolymerization and pyrolysis . The model excludes waste-to-energy conversion technologies. This section first evaluates the current mismatch between current mechanical and chemical recycling capacity and the total plastic waste available as feedstock for recycling. Second, this section models future scenarios to explore the potential feedstock which might be available for plastic-to-plastic chemical recycling technologies.

3.1. Current Mismatch of Feedstock Availability and Recycling Capacity

Potential plastic feedstock for recycling includes mismanaged plastic waste and plastic waste being managed through incineration and landfilling. Matching current mechanical and chemical recycling capacities with Plasteax data provides insights on the recycling capacity and feedstock match.

Despite global mechanical recycling capacity estimated at 48 million tons per year (ICIS, 2021) for PET, PE and PP, only 17% of the estimated 106 million tons of consumer packaging waste is effectively recycled (Plasteax, 2024). Global chemical recycling capacity is estimated at 1.4 million tons in 2023 (Sustainable Plastics, 2023; Grandview Research, 2023), representing less than 3% of the current global recycling infrastructure potential. As seen in Figure 10, recycling technologies currently cannot process the potential plastic feedstock which could be available for recycling, yet alone the mismanaged plastic textile and packaging waste in regions like Asia.

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[2] Note that currently, a significant share of the output from pyrolysis is converted into fuels and chemicals, sometimes due to the size of the facilities and capabilities (precursors for plastics but also in general other chemical products - Zero Waste Europe, 2023). Future plants with scaled operations and clear legislation on recycled content use will increase the focus on producing plastic-to-plastic via the conversion of pyrolysis oil.

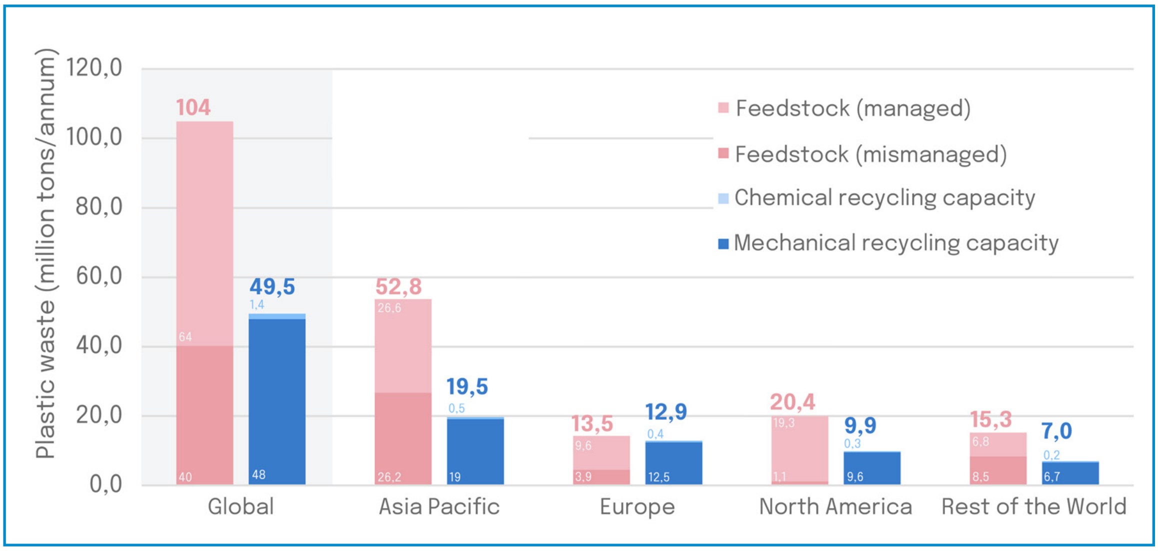

Figure 10: Plastic packaging and textile waste feedstock compared with mechanical and chemical recycling capacities from 2021. Feedstock is separated into plastic waste managed (incineration and sanitary landfilled) and mismanaged (uncollected, mismanaged, littered). Sources: Plasteax database for feedstock (covers 73 countries for packaging and 13 countries for textile). ICIS (2021), Plastics Recyclers Europe (2022), Sustainable Plastics (2023) and Grandview Research (2023) for capacity values.

Figure 11 provides further insights into the potential plastic feedstock for recycling, separating feedstocks into hard-to-recycle, under improvement, and easy-to-recycle feedstocks. Regarding potential plastic feedstock for recycling that was mismanaged in 2021, of the 40 million tons of mismanaged plastic textile and packaging waste, 15 million tons were hard-to-recycle. As for potential plastic feedstock for recycling that was managed in 2021, of the 64 million tons of managed plastic textile and packaging waste, 22 million tons was hard-to-recycle material. A further 4 million tons of mismanaged plastic packaging waste and 7 million tons of managed plastic packaging waste of polymers currently under improvement for mechanical recycling, could also represent potential feedstock for chemical recycling. **To effectively tackle plastic pollution, chemical recycling should focus on processing hard-to-recycle plastic waste streams that mechanical recycling cannot handle.**

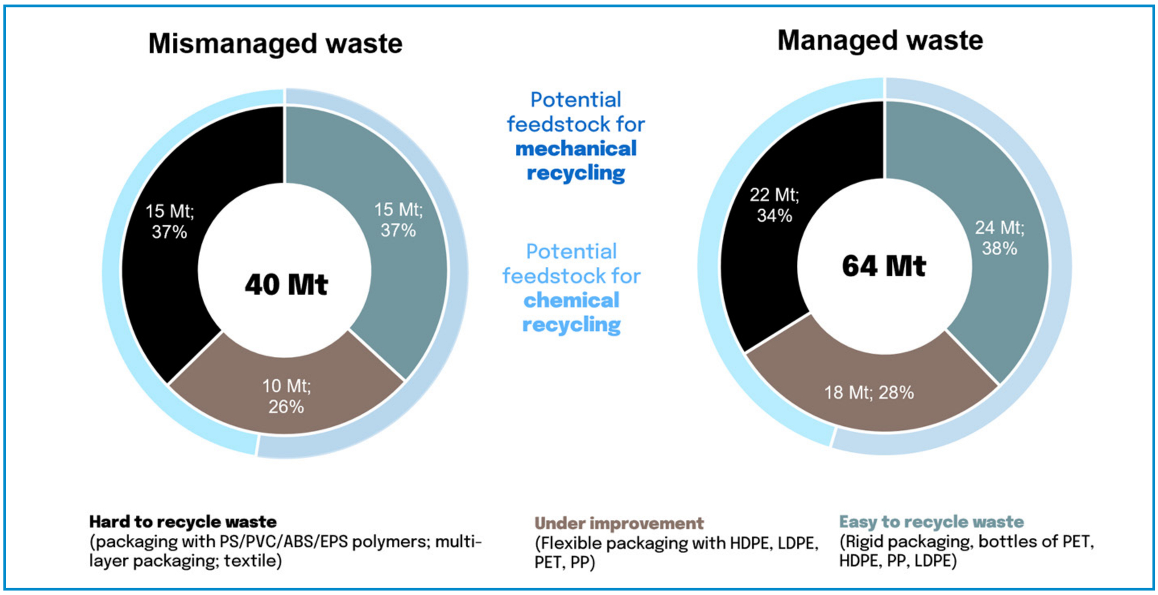

Figure 11: Amount of mismanaged and managed plastic and textile waste in 2021. The stock was grouped into three categories, based on which recycling technology can address them (Plasteax, 2024). 40% of polymer in the under-improvement group are hypothetically hard-to-recycle due to contamination (ink, additives, food). More information on the assumptions is available in section 6.1.1.

3.2. Modelling the Future of Chemical Recycling Feedstock

To understand the potential of recycling technologies to reduce plastic pollution from mismanaged plastic waste that inevitably leaks into the environment, the report modelled how much mismanaged plastic waste could hypothetically become chemical recycling feedstock, following a set of assumptions. Through four scenarios, the model showcases the potential for reducing mismanaged hard-to-recycle plastic waste, as well as part of the under improvement flexible plastic waste streams, through chemical recycling (see Figure 11).

Assuming that chemical recycling complements rather than competes with mechanical recycling, the model allocates feedstock for chemical recycling as 100% of the hard-to-recycle plastic packaging and textile and 40% of the mono-material flexible plastic packaging under improvement; assumed to be too contaminated to be processed by mechanical recycling. See section 5.1.1, methodological notes related to recyclability, for more details on recyclability categorization.

Grouping plastic types into recyclability categories requires a certain level of data granularity. The Plasteax database offered resolution on the end-of-life fates by polymer type, and by application, for 73 countries for plastic packaging and 13 countries for synthetic textiles. See section 5.1.2. methodological notes related for the Plasteax model for more information on end-of-life fate data used.

Advancements in mechanical recycling technologies expected by 2040 could enable some currently hard-to-recycle plastics to be processed through mechanical recycling or dissolution. Since the model assumes no competition between chemical and physical recycling for plastic feedstock, the scenarios account for the anticipated improvement of mechanical recycling technologies by adjusting the hard-to-recycle feedstock accordingly. For more details on these adjustments and future advancements in mechanical recycling technologies, see Section 5.1.3 of the methodological notes.

The four chemical recycling scenarios focus on four key factors for reducing mismanaged waste: policy endorsement, regional plant distribution, implementation capacity, and collection and sorting resources. Policy support is essential for scaling up chemical recycling, while strategically placed plants in regional hubs with the necessary infrastructure can improve global pollution reduction, with complementary trade regulations which promote global circularity. Regional capacity influences the speed of infrastructure development, with implementation delays varying by region. Effective collection and sorting provide necessary feedstock for recycling. By adjusting these factors, the model predicts changes in mismanaged plastic textile and packaging waste, highlighting the importance of a coordinated, regionally tailored approach to waste management. See methodological notes section 5.1.3 for more details on the key scenario factors. The model scenarios are:

- **Business-as-usual (BAU):** current trends continue without any major policy changes or technological breakthroughs. Waste generation steadily increases based on growing plastic consumption worldwide, with marginal growth for chemical recycling. BAU serves as a comparison baseline, illustrating what might happen if no significant efforts are made to address plastic leakage.

- **Scenario 1 – Delayed policies:** limited policy support for chemical recycling technologies up to 2030. In 2030, chemical recycling, alongside mechanical recycling, is recognized as a solution to address hard-to-recycle plastics. Projected implementation of chemical recycling plants kicks in after 2030, with a transitional phase that can be more or less extended depending on the region archetype.

- **Scenario 2 – Policy endorsement:** following the potential ratification of the UN Global Plastic Treaty in the coming years, in this scnario, governments recognize the use of chemical recycling as a mitigation strategy to address hard-to-recycle plastics and impose mandatory recycled content levels as of 2028 to stimulate market for recyclate. Policy instruments allow to deploy investments and stabilize market value of recycled plastics versus virgin plastics. Based on delays in policies, the results of this scenario can be shifted to later dates in annual increments to get a rough estimate of outputs, but "x" years later based on the period of delay.

- **Scenario 3 – Strategic locations:** under business as usual, most plants are built in Europe, North America and Asia as per current project inventories (see section 2.3). Few projects are developed in other locations where mismanaged waste index is projected to be higher on average. This scenario proposes relocating new chemical recycling plants strategically to regional hubs which have sufficient infrastructure and which can receive collected material for feedstock from locations with higher mismanaged waste, but with improved collection and sorting capacities. This assumes that trade regulations support global circularity and the movement of feedstock for recycling via pre-approved buyers and sellers, and agreements between the countries who are participating in such trade agreements.
- **Scenario 4 – Targeted collection and sorting:** following scenario 3, plants are in strategic regions identified as pollution hotspots. Collection and sorting systems are drastically scaled up as part of the chemical recycling plant infrastructure in the region or the hub. In this scenario, mechanical and chemical recycling evolve together as complementary processes. This integrated approach maximizes the potential for reducing plastic leakage by leveraging the strengths of both recycling technologies.

To assess the impact of each scenario, the model begins with a 2024 baseline and projects to 2040, using data on plastic waste generation and rates of mismanaged waste. The modeling process for each scenario involved projecting waste generation, integrating technical improvements of mechanical recycling, estimating chemical recycling capacity growth, identifying synergy of recycling technologies, allocating mismanaged plastic waste as feedstock, and adapting through system change. To review the key steps and assumptions of the modelling process, refer to methodological notes section 5.1.4.

Projecting Potential Plastic Feedstock for Recycling to 2050

Before modeling the waste treatment capacity, the amount of projected yearly mismanaged, incinerated and landfilled plastic in packaging and textile was compared with projected global waste treatment capacity values from literature (Siepen et al., 2024, adapted to the scope of this study by accounting for packaging and textile share of plastic waste).

The comparison of the business-as-usual growth of hard-to-recycling plastics to the chemical recycling capacity projected by the chemical recycling sector in the next decade shows that current investments are not at scale to tackle mismanaged plastic textile and packaging waste (see Figure 12). **At 10 million tons of annual chemical recycling capacity projected for 2030, 68% of mismanaged hard-to-recycle plastic packaging could be treated.** At 22 million tons in 2040, all the mismanaged hard-to-recycle packaging feedstock could be recycled. **By 2050, 60% of the mismanaged textile waste could be addressed in addition to all the hard-to-recycle plastic packaging waste being mismanaged.** Incinerated and sanitary landfilled plastic textile and packaging waste would remain untouched.

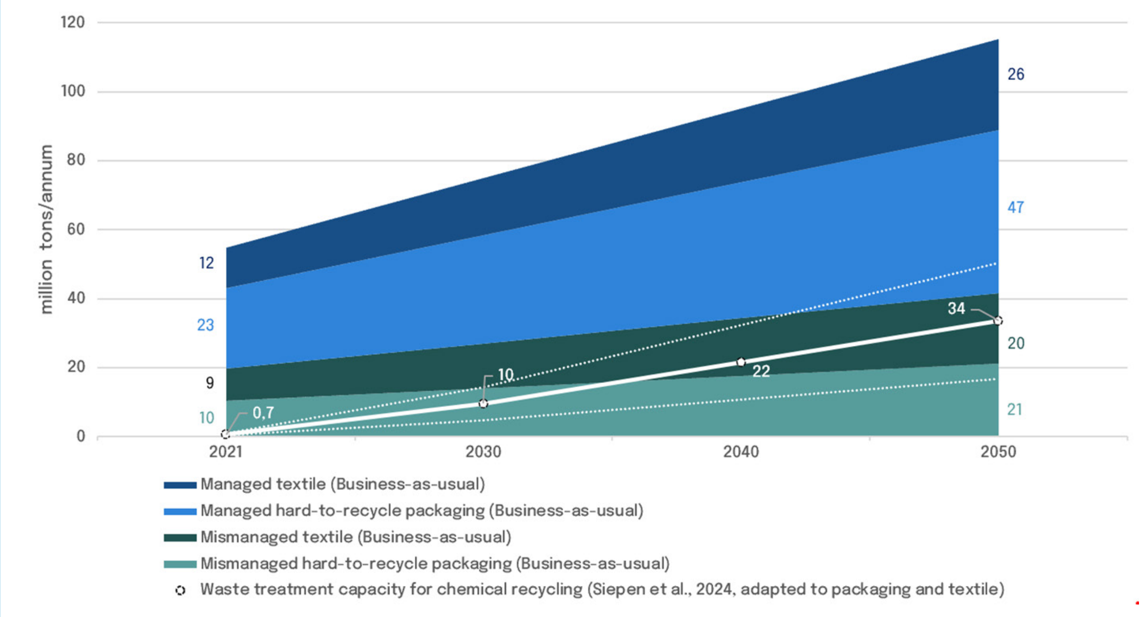

Figure 12: Potential plastic feedstock for chemical recycling under BAU compared with global projected capacity found in the literature (Siepen et al., 2024). Shown are global waste treatment capacities balanced by the share of packaging and textile in overall plastic waste (ca. 48%, Plasteax Database, 2024).

Modelling Chemical Recycling Plastic Waste Treatment Capacity

By 2040 in a business-as-usual scenario, 33 million tons of hard-to-recycle plastic could end up as managed waste. While chemical recycling infrastructure can also treat managed waste, focusing on mismanaged waste remains a higher priority for an effective impact on plastic pollution. Figure 13 below illustrates how chemical recycling could tackle the mismanaged hard-to-recycle packaging and textile waste by 2040, highlighting the interaction over time between regional feasibility, the impact of international policies, and local collection and sorting capacities.

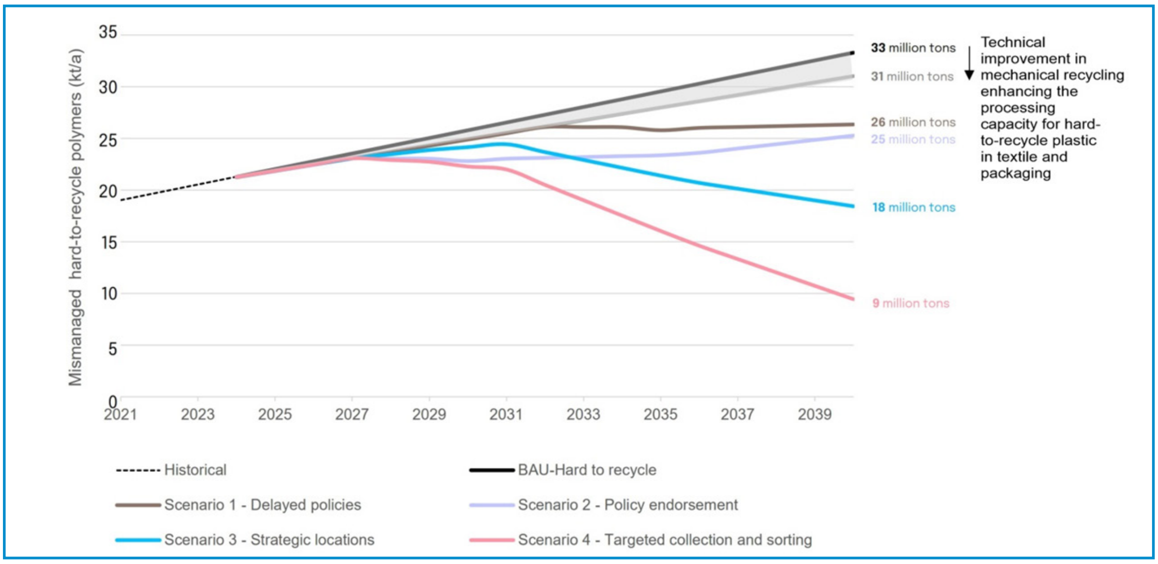

Figure 13: Four scenarios illustrating the mitigation of mismanaged hard-to-recycle plastic packaging and textile waste through chemical recycling from 2024 to 2040 under business-as-usual conditions. The scenarios are modeled with a more conservative hard-to-recycle plastic feedstock (grey line) compared to the business-as-usual (BAU) case, considering the potential improvement of mechanical recycling. Plasteax data were used to project future regional mismanagement levels. Methodology and assumptions are available in section 6.

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[3] Note that the textile waste management data covers 13 countries. The values presented in this study are likely underestimating the global values. However, lack of data in the waste management of textile prevents from assessing by how much the data are representative of the real world.

To understand the contribution of these three key aspects, four scenarios were established:

Policy endorsement (Scenarios 1 and 2): Global policy guidelines which drive national regulations have the potential to increase recycling rates by 43% in 2040 (Systemiq, 2023). A delay in the recognition of chemical recycling and mass balance for recycled content calculation rules in national and international policies (Scenario 1) will put a burden on infrastructure and investments to achieve the same mitigation results in 2040 compared to policies that integrate chemical recycling as part of recycling strategies early on (Scenario 2).

Strategic location (Scenario 2 and Scenario 3): When policy support is optimal, and assuming the necessary infrastructure exists, strategically placing recycling plants in regional hubs, and complemented with enhanced local collection and sorting capacities, near areas where plastic waste is most likely to become mismanaged, is an effective way to remove waste that could potentially leak into the environment. In Scenario 2, most chemical recycling plants are in regions with good waste management systems (e.g., Europe and North America), as is currently the case. Such plants would quickly address local mismanaged feedstock while also managed feedstock. While it contributes to circularity efforts, it does not directly tackle the global plastic pollution crisis, and the reduction of mismanaged waste becomes inefficient overtime, making the potential 43% reduction by 2040 unachievable. This could be improved upon if the facilities are also able to access collected and approved feedstock from other countries, with trade regulations which support global circularity for verified material for recycling, as stated previously. Despite a slower implementation time, locating future plants in regions or regional hubs near higher amounts of mismanaged feedstock could reduce global mismanaged waste by an additional 27%, thereby reducing associated leakage. This scenario also highlights the importance of allowing the trade of legitimate feedstock within regions or between participating member states. It is important to note that despite an early policy endorsement, project location may become an important driver of success over time.

Effective collection and sorting (Scenario 4): With facilitating and clear policies implemented early in the time horizon, and chemical recycling projects strategically located to minimize leakage, with enhanced collection and sorting processes for both mechanical and chemical recycling infrastructure, these initiatives could achieve a 70% reduction in mismanaged waste by 2040, or 22 million tons/annum. This number aligns with Siepens et al. (2024)'s projection for chemical recycling input capacity in 2040 (see Figure 10). This scenario also assumes that financing for this infrastructure (not part of this study), is already accounted for, most likely through a mix of EPR programs and public/ private partnerships.

Plant size can range from 3 tons up to 200 thousand tons of waste treatment capacity (Siepens et al., 2024; British Plastics Federation, 2024). Considering an average capacity of 100 thousand tons/year for the current generation of chemical recycling with scale, this all-in-one best-case scenario suggests that by 2040, approximately 180 plants which could receive collected material for recycling, and closest, or within, regions with a mismanaged waste index above 30% would treat almost 60% of the global estimated mismanaged hard-to-recycle packaging and textile waste. This assumes that they become fully operational by 2032 and collection and sorting is optimized (see also Figure 16b).

Based on the type of feedstock, half of this infrastructure investment could be dedicated to depolymerization (synthetic textiles; hard-to-recycle PET) and a third to pyrolysis (PE, PP, PS, ABS). An additional 10% of mismanaged waste located in all other regions could be treated with a little less than 40 plants.

Enhanced collection, sorting and chemical recycling projects could support the overall municipal collection system, benefiting the existing mechanical recycling infrastructure. Directing private investment funds to areas with inadequate public waste management systems could improve efficiency and service quality. The private sector may offer more consumer-focused services than the public sector, potentially delivering them at the same or lower cost. However, success depends on careful planning, contracting, and oversight by local governments (Cointreau-Levine, 1994; Albostan and Sharifli, 2023).

Considerations of Trade for Chemical Recycling Feedstock

The scenarios were simulated on domestic waste and did not include import/ export flows. Europe is the most important waste trade region, where exports (57% of all exports) exceed imports (43%) (Figure 14). Africa and Asia, on the other hand, have import fluxes that largely exceed their exports. Africa and Asia regions have an average mismanaged waste index of 77% and 35% respectively, indicating that their waste management capacity is limited. Although import/ export flows account for less than 6% of global packaging and textile waste, the facilitation of global circular economies with verified and qualified feedstock for recycling means that the international trade of material to pre-approved buyers from pre-approved sellers offers an opportunity to expand the reuse of materials through either mechanical or chemical recycling. Site location will need to be considered accordingly based on the ability to move feedstock efficiently from source locations to processing locations, with chemical recycling likely to happen in countries which have existing and sufficient infrastructure to handle such facilities and inputs and outputs.

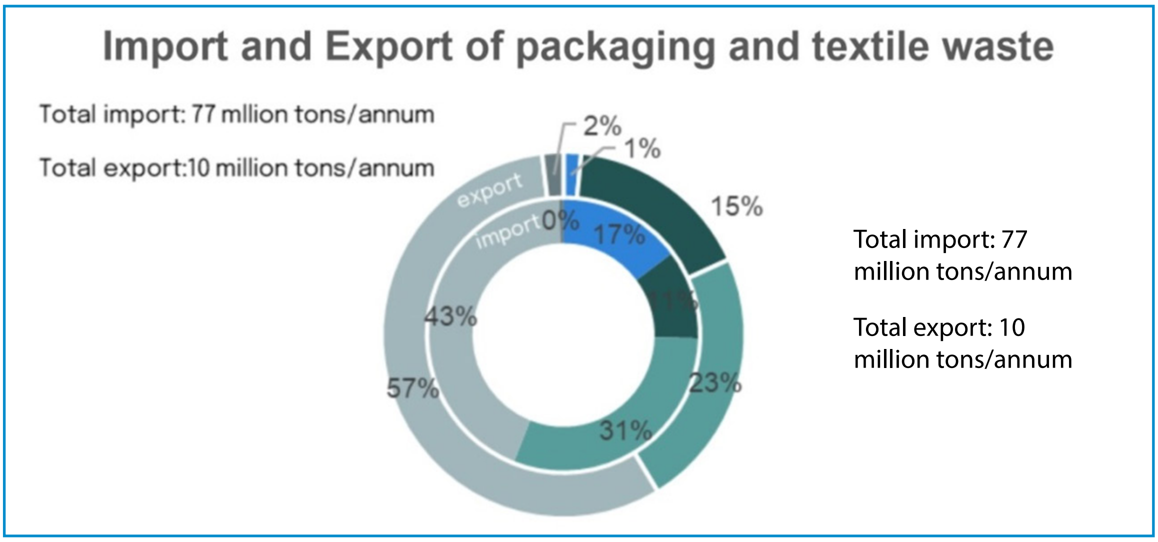


Figure 14: Import and export trends of plastic textile and packaging waste by region (Plasteax, 2024).

Modelling Chemical Recycling Plastic Waste Treatment Capacity Under a Systems Change Scenario

Several studies have modeled the impact of system change scenarios on the fate of plastic waste, with the assumption that all types of reduce, reuse and EPR programs being proposed, are actually implemented (The PEW Charitable Trust and Systemiq, 2020; Systemiq, 2023). Though this scenario is unlikely to happen across all member countries and regions, if all interventions considered along the plastic value chain are successful by 2040(Figure 15), mismanaged waste could potentially be reduced by over 90%, and managed plastic waste by 30%.

Although the remaining mismanaged hard-to-recycle waste would shrink to a small amount (4 million tons by 2040), chemical recycling could still play a role in addressing the managed hard-to-recycle waste feedstock (31 million tons). Chemical recycling, rather than using landfills or incineration for disposal, would help to mitigate the environmental impacts linked to these types of disposal, such as water contamination, land-use change, and greenhouse gas emissions (Jiao et al., 2024).

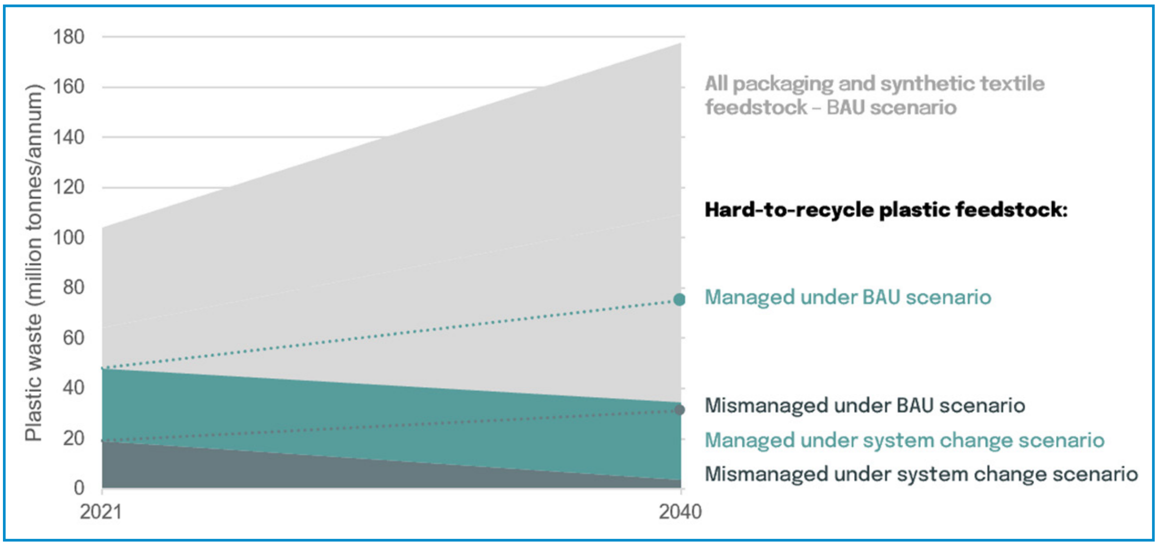
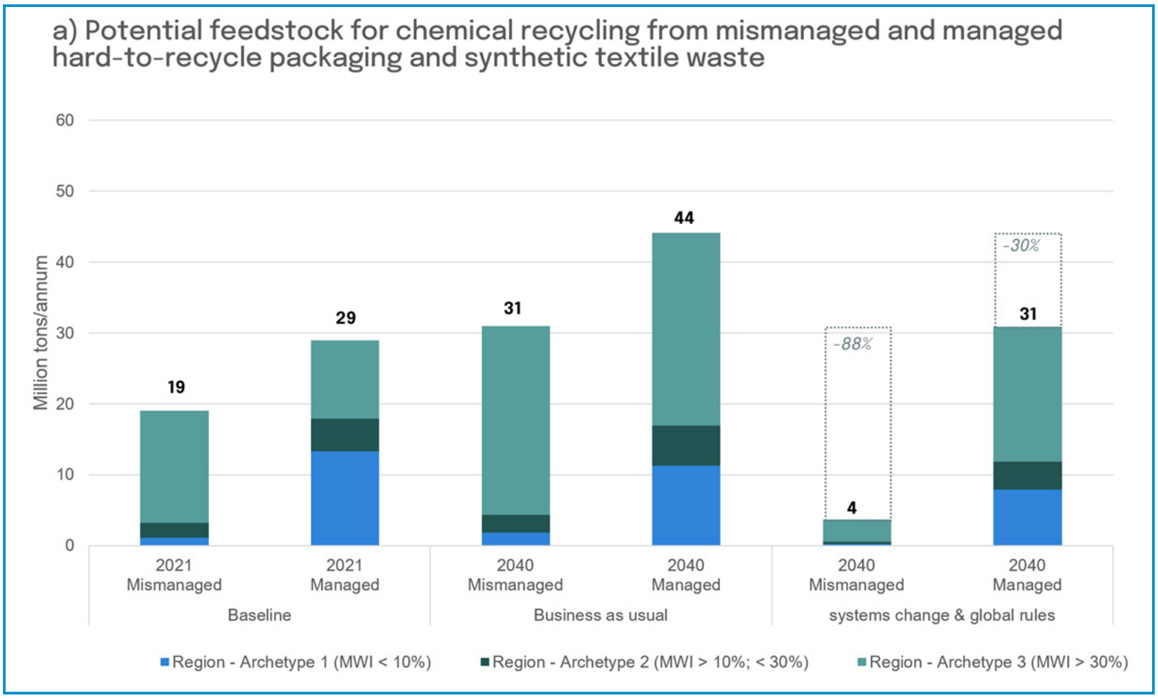


Figure 15: Mismanaged and managed hard-to-recycle plastic feedstocks under a system change scenario (The PEW Charitable Trust and Systemiq. 2020) compared with business-as-usual scenario (this study).

To reduce the managed feedstock (assuming landfill and incineration), under a system change scenario by 80% in 2040, approximately 300 chemical recycling plants of 100 thousand tons waste treatment capacity each would be required (Figure 16c). To capture this potential feedstock, and assuming the material was not fit for a large-scale contribution by mechanical recycling, infrastructure planning should prioritize Asia, North America, and Europe. Since the feedstock is already collected, efforts should focus on enhancing sorting processes and improving transport logistics to recycling plants. Building these facilities near incinerators or engineered landfills could be a strategic move to reduce logistical challenges, though overall infrastructure for chemical recycling is needed, meaning that these facilities will not likely be established in many underdeveloped locations for years to come, thus highlighting the need for efficient and trusted trade regimes. In order to avoid building lock-in infrastructure with a high risk of becoming stranded assets, it is crucial to plan and size chemical recycling projects within the range of both BAU and system change scenarios (Figure 16 b and c). Co-locating chemical recycling plants with mechanical recycling facilities could enhance synergies in plastic recycling.



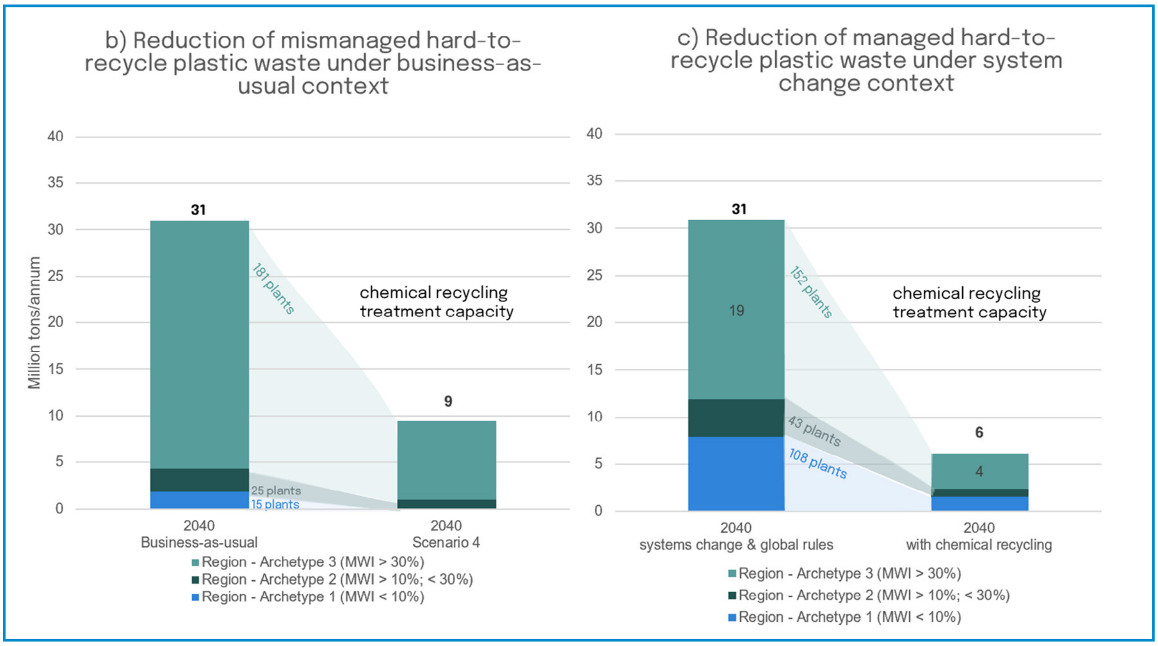


Figure 16: a) Potential feedstock for chemical recycling from mismanaged and managed hard-to-recycle waste in 2021 (Plasteax) and under business as usual (this study) and systems change scenario (The PEW Charitable Trust and Systemiq, 2020; Systemiq, 2023) in 2040. Panels b) and c) display the reduction in mismanaged and managed feedstock, respectively, when chemical recycling is scaled up in 2040.

Model Boundaries and Considerations

The model offers an illustrative assessment of the potential for chemical recycling based on a set of best-case assumptions. Interpreting the results must consider several key factors about the model:

- **Collection and sorting capacity is assumed to increase**, yet it does not fully reflect regional and societal variations in waste management systems. In many low-income regions, waste management is often informal and may not be suited for chemical recycling systems, but the countries would benefit from improved collection and sorting capacities, so that they could enter the global supply chain with their feedstock. It is not likely that integrating large-scale chemical recycling plants into these countries is likely in the medium term, which is why the trade of legitimate feedstock offers opportunities for both countries with material (export), and for those with processing capacities in regional hubs. The findings should be viewed as representative of an idealized scenario.

- **Potential impact of market dynamics is not accounted for**, particularly the competition between virgin plastics and recyclates. Recycled content targets will be important to create a market pull and demand for circular materials, which should be technology neutral. Final application and performance needs will drive demand for mechanical and chemical recycled output, as the quality of each will differ.

- **Input capacities are primarily projected** and do not address recycling yields or the fate of the output products, critical to understanding how chemical recycling can contribute to global sustainability and circularity goals.

- **Feasibility of chemical recycling plant location in a region is not assessed**, only identifying potential locations for plants (domestic or regional), near feedstock availability. A more comprehensive evaluation of local collection and sorting infrastructures is necessary to determine whether the feedstock can be effectively captured and what type of technology should be installed. With a lack of full processing, collection and sorting improvements can still benefit all countries and allow them to be involved in the global supply chain of recyclate if trade within regions under the guidelines of the Basel Convention for global circularity is facilitated.

In summary, while this model highlights the potential of chemical recycling, the findings should be considered within the context of the model's assumptions. The results emphasize the need to address gaps in collection systems, market dynamics, legislation, trade regulations and regional feasibility to fully unlock the potential of chemical recycling within a circular economy.

Key insights

- **Chemical recycling has the potential to complement mechanical recycling to reduce plastic leakage, particularly from hard-to-recycle plastics** such as synthetic textiles and some plastic packaging. Strategic and coordinated investment in all recycling technologies is needed.

- **Between 31 and 75 million tons of mismanaged and managed hard-to recycle plastic waste will be potentially available as feedstock for recycling in 2040**, depending on future global actions. Chemical recycling could be part of the treatment solutions in all scenarios.

- **Sizing, location, and type of chemical recycling plants** should consider the range of both BAU and system change scenarios to avoid building lock-in infrastructure and stranded assets. Chemical recycling plants should be co-located with mechanical recycling facilities, or near the collection and sorting infrastructure to support it when possible.

4. Conclusion

Each year, 63 million tons of synthetic textile waste and 106 million tons of plastic packaging waste are generated globally. Current recycling capacities are below what is needed to manage global waste generation effectively, underscoring the need to increase investment in recycling infrastructure. The modeling results highlight the substantial role that chemical recycling can play in reducing plastic pollution by addressing mismanaged hard-to-recycle plastic waste and thus complement mechanical recycling.

The key findings are:

- **Recycling capacity needs:** addressing mismanaged plastic waste requires both mechanical and chemical recycling. While mechanical recycling is more effective for clean, generally single-polymer plastics, chemical recycling can handle more complex or contaminated plastics.

Table 6: Pros and cons of mechanical and chemical recycling

Technology	Pros	Cons
Mechanical recycling	**Significant global capacity:** 48 million tons annually as of 2021, making it essential for plastics like PET and HDPE	**Limited applicability:** Struggles to process 19 million tons of mismanaged hard-to-recycle materials such as unsuitable flexible packaging and multi-layered plastics
	Lower energy input: Requires less energy compared to chemical recycling, making it more sustainable for large-scale recycling of clean, rather single-polymer plastics	**Material degradation:** Quality diminishes after multiple recycling cycles without high quality sorting and reprocessing, potentially limiting its use in certain applications, such as food-contact products
	Cost-effective: More economical for clean, uncontaminated, and rigid plastics, preferred in regions with advanced waste management systems	**Dependence on relatively standardized inputs:** Requires well-sorted, clean materials, making it less effective in regions with poor waste collection and sorting infrastructure, but these regions, with the engagement of the informal collection sector, can supply feedstock to a global circular economy if verified and trusted trade is facilitated.
Chemical recycling	**Capable of handling contaminated thermoplastics and thermosets:** Can process contaminated plastics to a certain level, making it critical for the 19 million tons of mismanaged hard-to-recycle plastics	**Limited capacity today:** As of 2023, global capacity is between 1.2 and 1.4 million tons, or less than 3% of the overall recycling infrastructure capacity. The capacity may vary widely depending on the chemical technology, though large systems are coming onstream. Contamination can still be a problem for pyrolysis catalysts
	Produces high-quality outputs: Can generate near-virgin quality material suitable for high-value applications, such as food-grade packaging	**Higher energy consumption:** Requires more energy than mechanical recycling per ton processed, potentially reducing energy efficiency depending on the scale of the plant and the volume of output.
	Potential to scale: Can potentially address 19 million tons of mismanaged hard-to-recycle plastics	**Unclear environmental impacts** require further research

- **A coordinated approach between recycling technologies:** Hard-to-recycle plastics make up 48% of mismanaged plastic waste, posing challenges for mechanical recycling. Current infrastructure lacks the capacity to address this growing waste, especially in regions with large amounts of mismanaged waste. Chemical recycling could support mechanical efforts for hard-to-recycle plastics if paired with effective collecting, sorting and pre-treatment. If business proceeds as usual, expanding chemical recycling can help tackle waste challenges in areas like Asia and Africa, particularly with improved collection and sorting, and trade regulations which facilitate the movement of approved feedstock to regional hubs where appropriate infrastructure exists for chemical recycling. Under a systems change global rules scenario where mismanaged waste drastically reduces, chemical recycling could address managed feedstock alongside mechanical recycling.

5. Methodologies

5.1. Methodological Notes Related to the Recycling Potential Model

5.1.1. Recyclability

In this study, recyclability refers to a material's or product's ability to be collected, processed, and transformed into new products after its initial use, following mechanical recycling methods. As a non-competitive, complementary approach between chemical and mechanical recycling is recommended (Klotz et al., 2024; Garcia-Gutierrez et al., 2023), it is essential to assign the appropriate waste feedstock to the corresponding recycling technology. Accordingly, we grouped the Plasteax data based on the recyclability of plastic packaging and synthetic textiles (see Table 8).

Table 8: Classification of Plasteax data based on polymer and packaging recyclability.

Type of packaging in Plasteax	Polymer in Plasteax	Recyclability category assigned in this study	Rationale	Source
Bottles, rigid packaging	PET, HDPE, PP, (L)LDPE	Easy-to-recycle plastics	Cleaner recycling streams, single material, easier to handle	Source Green, 2024 Uekert et al, 2023 Löw et al, 2021
Flexible packaging	PET, HDPE, PP, (L)LDPE	Under improvement	While some flexible packaging can be recycled, others may be more challenging because of food contamination and inks. They are also harder to handle due to their lightweight	
Multi-layer packaging	PET, HDPE, PP, (L)LDPE	Partially hard-to-recycle	Complex structure and composition make the sorting and recycling harder	
All packaging	PVC, ABS, EPS, PS, Others[4]	Hard-to-recycle	• Contamination and additives issues • Limited market demand for these polymers and low recyclate quality affect incentive for recycling	
Synthetic textile	Polyester, synthetic rubber, polyamide, acrylics	Hard-to-recycle	• Presence of synthetic dyes, finishes and other additives • Blend of synthetic fabrics • Specialized infrastructure to treat fibers are currently not at scale.	Harmsen et al., 2021

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[4] "others" encompasses all other plastic polymers that may exist in packaging, e.g.m epoxy resins, polycarbonates, polychloroprene, polymethyl methacrylate, silicone, etc.

The model considers that feedstock for chemical recycling represents hard-to recycle plastics and a share of mono-material flexible packaging under improvement. Mono-material flexible packaging are currently not very well recycled because of:

1) contamination (ink, other substances) is major obstacles in the recycling process;
2) limited collection, cleaning and deodorizing;
3) tendency to become tangled in recycling/ sorting machinery and requirement of specific infrastructure.

Point 2 and 3 are independent of the chemical composition of the packaging and can be addressed downstream by improving the mechanical recycling infrastructures in the future. Point 1, however, is inherent to the packaging and can only be addressed upstream (change in design). This falls then into plastics that are inherently hard to recycle for mechanical recycling technologies, unless composition changes. Based on these conclusions, we assume that 40% of mono-material flexible packaging cannot be properly handled by physical recycling.

5.1.2. Plasteax

The output of the Plasteax model provides the distribution of consumer plastic packaging waste into its possible **end-of-life fates** in 73 countries. Note, it does not account for industrial packaging. The information is broken down into two levels of granularity: **polymer type** and **packaging category**. For instance, if we consider the polymer LDPE and the category flexible packaging, the model will specify how much of this particular product category (flexible packaging made of LDPE) is recycled, exported, incinerated, landfilled, or mismanaged. Figure 17 shows the system map behind the Plasteax model for packaging. More information on the model is available on https://docs.plasteax.earth/explainers/model.

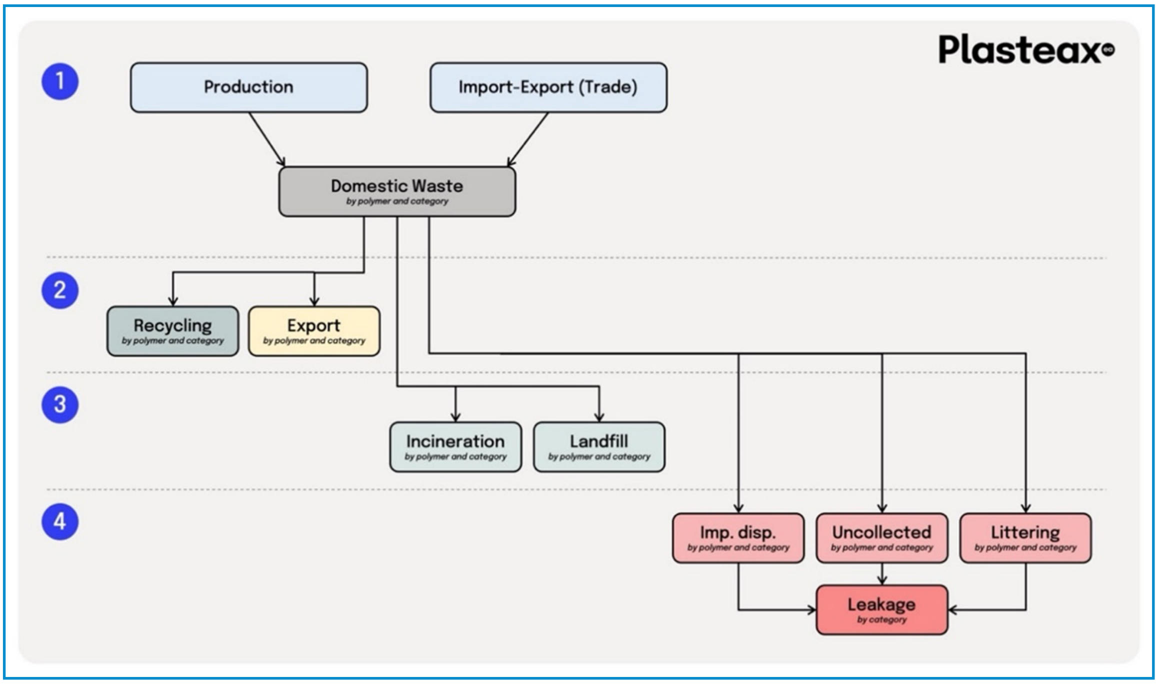

Figure 17: System map of the Plasteax model covering 1) Domestic waste generated, 2) Recycling and Export, 3) Incineration and Landfill, 4) Mismanaged Waste and Leakage

The same system map was applied for **synthetic textiles**, for 13 countries , including an additional fate "reuse". The model considered four clothing fabric polymers: polyester, elastane, polyamides, acrylics. While the waste management fate for textiles is only available for the 13 countries, textile waste generation data is available for all 73 Plasteax countries.

5.1.3. Key Factors for Scenario Modelling

The scenarios offer a comprehensive perspective on how different pathways, shaped by policy endorsement, regional distribution and implementation capacity, as well as collection and sorting resources, could influence the future of hard-to-recycle plastic waste management. The scenarios are articulated around four factors that are decisive for diverting mismanaged plastic waste away from the environment:

- **Policy endorsement:** Policy recognition, both nationally and internationally, is essential to position chemical recycling as a complement to mechanical recycling, and partof the solution to reduce plastic pollution. By endorsing the need for chemical recycling, governments can drive progress and attract the investments necessary to scale up chemical recycling technologies. Investment, in turn, accelerates the transition towards a sustainable system where plastic waste is effectively and sustainably managed and recycled. It is assumed that any delay in policy endorsement would postpone the scale up of chemical recycling.

- **Regional plant distribution:** Pollution hotspots arise in countries where plastic consumption exceeds plastic waste management capacity. The placement of semi-processing plants for feedstock aggregation and preparation will play an important role in complementing domestic or regional recycling facilities (mechanical or chemical), and this will play a crucial role in determining the overall effectiveness of global plastic pollution reduction efforts. All countries grouped in three regional archetypes, defined by high, medium and low mismanaged waste index and waste management resources.

- **Regional implementation capacity:** The model accounts for regional differences in implementation capacity, as some countries may already have well-established waste management systems and can build the necessary infrastructure around them more rapidly. The model accounts for a delay in implementation of two, four, and six years post-policy, depending on the region archetype.

- **Collection and sorting resources:** Waste treatment capacity relies on the efficiency of collection and sorting processes to provide suitable plastic waste feedstock for recycling facilities. Regional improvement in collection and sorting is considered in Scenario 4, which assumes improved collection and sorting systems adapted to the different region archetypes.

5.1.4. Parameter Used in Modelling Scenarios

Two scenarios are built following these key steps:

- **Waste generation projections:** The model projects future mismanaged plastics for each scenario, considering factors such as population growth, consumption trends, and economic development (OECD, 2024).

- **Recycling capacity growth:** The model estimates how chemical recycling could evolve in each scenario and reduce consequently the annual mismanaged hard-to-recycle packaging and synthetic textile. In the BAU scenario, global recycling capacity grows only slightly, with limited improvements in infrastructure. The model also accounts for potential improvements in mechanical recycling technologies, allowing treatment of a portion of the hard-to-recycle feedstock by 2040. The chemical recycling scenarios (1-4) are based on the remaining hard-to-recycle feedstock, after accounting for the contribution of these mechanical recycling advancements. The maximized scale-up scenario (scenario 4) assumes strong investment in chemical recycling as well as in collection and sorting, resulting in a sharp rise in capacity to process hard-to-recycle plastics in strategic location.

- **Synergy of technologies:** Mechanical recycling is expected to remain focused on easier-to-recycle plastics, which are cleaner, purer, more uniform in composition, easier to sort and handle, and have established recycling systems at scale. In regions where mechanical recycling struggles, chemical recycling offers a solution to reduce plastic leakage. The scenarios illustrate how and where chemical recycling can make a difference without competing with mechanical recycling.

- **Mismanaged waste as feedstock:** Mismanaged plastic waste, which often ends up polluting the environment, is modeled as potential feedstock for chemical recycling. By diverting mismanaged hard-to-recycle plastic waste into chemical recycling systems - especially in regions with underdeveloped waste management infrastructure - the model estimates how much mismanaged hard-to-recycle plastic waste could be diverted back to well-managed system. Mismanaged encompasses uncollected waste including littering as well as collected waste disposed in unsanitary landfills.

- **Adapting through System Change:** Numerous mitigation actions are projected to happen in the future. Consequently, mismanaged plastic may become too small as a potential feedstock for chemical recycling. The model offers a window on how chemical recycling could reduce incinerated and landfilled plastics, which are also a cause of concern for the environment.

Furthermore, each scenario has their specific assumptions.

Business-as-usual scenario

- By 2040, packaging and textile waste is expected to increase by 68% and 82%, respectively. These values are taken from OECD's report (2024).

- A constant increase of synthetic textile and packaging mismanaged waste is assumed between 2021 and 2040.

Scenario 1 and 2 – policy actions and endorsement

These two scenarios illustrate the impact of policy action as well as the timing of regional implementation. Policy endorsement can significantly influence sustainability by guiding industries towards best practices and providing regulatory support for innovative solutions. Without policy recognition, technologies may face challenges in scaling and gaining public trust, limiting their potential environmental impact.

Following assumptions were made:

- **The impact of global guidelines which drive national legislation related to recycling** was modelled by Systemiq (2023), resulting in 43% of reduction in mismanaged waste compared to the business-as-usual scenario in 2040 (Systemiq, 2023). This value, which can be interpreted as an increase of waste treatment capacity by 43%, was applied in our model as the maximum reduction potential that could be achieved from policy actions by 2040.

- Year of policy endorsement: This parameter illustrates the global readiness of policies. The year of policy endorsement takes place in 2030 for scenario 1 – less ambitious – and 2025 for scenario 2. To account for the delay in the delay in the INC process for the Plastic Treaty discussions, the time scale for this can and should be shifted annually (depending on the term of the delay in a more ambitious scenario.

- **Year of implementation:** The reduction of waste by chemical recycling starts on the year of implementation which depends on the region archetype (see Table 9). The year of implementation is defined as the year of policy endorsement + the delay of implementation (in years).

- **Assigning regional waste treatment capacity:** Based on current project and investment inventories (Global Partners for Plastics Circularity, n.d.; The Circulate Initiative, 2024), recycling infrastructures are located mostly in regions from archetype 1, and very rarely in regions in archetype 3. We assume that regions with more more capacities to collect, sort and at be part of the global supply chain of recyclate, with local capacities, or the ability to move feedstock regionally, will process more rapidly the local mismanaged waste. To reflect this spatial distribution, the maximum increase in waste treatment capacity, as defined by the global rules (see point 1), is allocated across the different regions. The regional distribution of this increased capacity is 60% for Archetype 1, 30% for Archetype 2, and 10% for Archetype 3.

To isolate the impact of a shift in policy engagement, the only difference between scenario 1 and 2 was set as the year when governments would include chemical recycling in their recycling strategies.

Scenario 3 - strategic location

This scenario illustrates the impact of improving collection and sorting, and allowing access to regional hubs where chemical recycling plants exist. It builds on scenario 2, which displays an ambitious policy timeframe.

The following assumption was made:

- **Re-assigning regional waste treatment capacity:** Compared to scenario 2, most of the waste treatment capacity is moved to Archetype 3 regions. We changed the regional share of waste treatment capacity to be 15% in Archetype 1, 15% in Archetype 2 and 70% in Archetype 3.

Scenario 4 – collection and sorting

Building from scenario 3, this scenario illustrates the potential contribution of chemical recycling in addressing packaging and textile mismanaged waste.

The following assumption was made:

- Parallel development of collection and sorting: Depending on the region archetype, we assume that between 70% and 90% of the remaining uncollected and improperly disposed waste is collected and sorted by 2040 through ambitious initiatives from the private sector in collaboration with local municipalities. Archetype 3 regions, where socio-economic context is more challenging to scale up collection and sorting, has a lower collection and sorting rate. We assume that litter is less frequently collected due to actions that are not feasible for the private sector to implement (Keep Britain Tidy, 2011). Only 30% to 50% of the remaining littered waste is collected and sorted by 2040, depending on the region.

Scenario System change – addressing disposed and landfill feedstock

All previous scenarios are built on a business-as-usual evolution of waste generated over time. However, various actions and interventions across the plastic value chain are expected over the next 15 years, which will lead to a reduction in plastic pollution and overall waste generation. As a result, the feedstocks available for chemical recycling will be smaller than in the business-as-usual scenario outlined above. To estimate the reduction in mismanaged, landfilled, and incinerated waste under a system change scenario, we apply reductions of 88% for mismanaged waste and 30% for landfilled and incinerated waste. These Figures are based on the average results from Pew (2021) and Systemiq (2023).

Region archetypes

The 73 countries in Plasteax were grouped in 3 archetypes based on their mismanagement waste index (MWI). The archetype classification allows to comprehensively illustrate the impact of strategic location as well as the delay of implementation.

Table 9: characteristics and parameters used for the three regional archetypes.

	Archetype 1	Archetype 2	Archetype 3
Threshold MWI	Smaller or equal to 10%	Between 10% and 30%, or equal to 30%	Larger than 30%
Delay of full chemical recycling implementation	2 years after policy endorsement	4 years after policy endorsement	6 years after policy endorsement
Scenario 1 and 2 – default location	60%	30%	10%
Scenario 3 – strategic location	15%	15%	70%
Scenario 4 – collection and sorting of uncollected and improperly disposed	90%	80%	70%
Scenario 4 – collection and sorting of littering	50%	40%	30%
Countries (Plasteax)	Denmark, Sweden, Hungary, Korea, Singapore, Czech Republic, Poland, Finland, Netherlands, Austria, United Kingdom, France, Germany, Switzerland, United Arab Emirates, Belgium, New Zealand, Japan, Canada, Croatia, United States, Lithuania, Portugal, Australia, Slovenia	Cyprus, Spain, Slovak Republic, Estonia, China, Italy, Colombia, Latvia, Chile	Turkey, Malaysia, Mexico, Costa Rica, Tunisia, Argentina, Brazil, Morocco, Peru, Thailand, Romania, Ecuador, South Africa, Bulgaria, Greece, Saudi Arabia, Indonesia, Vietnam, Russian Federation, Philippines, India, Panama, Pakistan, Jamaica, Uruguay, Kenya, Cambodia, Egypt, Qatar, Nigeria, Tanzania, Dominican Republic, Uganda, Bangladesh, Bahrain, Kuwait, Zambia, Mozambique, Rwanda

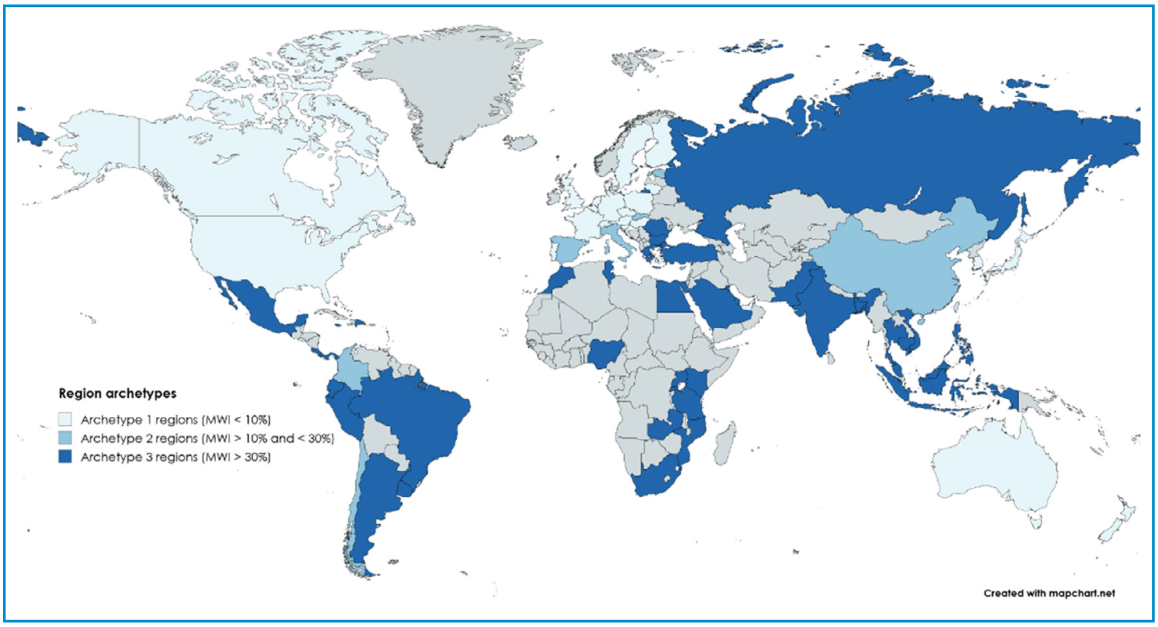

Figure 17: geographical distribution of the three region archetypes. Grey indicated the countries that are not part of the Plasteax database

Note that some European countries have mismanaged waste index that exceeds 50%

Future improvement in physical recycling

Potential technical improvements of mechanical recycling technologies may happen by 2040 for consumer packaging. For example, ongoing research and development are focusing on enhancing sorting accuracy with AI and digital tech (i.e., HolyGrail 2.0 project); refining deodorizing technologies; using optical sensor technology to separate unwanted objects and colors from plastic flakes; improving design for mechanical recyclability; use of compatibilizers to facilitate the mechanical recycling of mixed plastics (Klotz et al., 2022; Klotz et al., 2023; Scientific American, 2022). As a result, mechanical recycling and dissolution will be able to address some of the hard-to-recycle packaging feedstock. This reduction in potential plastic feedstock for chemical recycling has been considered in the model based on the following assumptions:

Table 10: Assumptions on the share of hard-to-recycle plastic feedstock that can be treated by 2040 through physical recycling technologies. Assumptions are provided by region archetypes and type of plastics.

Physical recycling technology	Type of plastics	Addressable share of hard-to-recycle plastic in 2040	Rationale	Source
Dissolution	Consumer packaging (ABS, (L)LDPE, PP, PS, PVC, PET)	10% (Archetype 1) 5% (Archetype 2) 0% (Archetype 3)		For dissolution: https://www.cleantech.com/solvent-dissolution-next-gen-advanced-plastic-recycling/ PET dissolution: https://wkaiglobal.com/blogs/can-dissolution-technology-effectively-address-pet-plastic-waste
	Synthetic textile	10% (Archetype 1) 5% (Archetype 2) 0% (Archetype 3)	Dissolution can be used to separate fibers in blends and isolate synthetic fibers. Dissolution techniques are under development but they seem promising for polycotton,polyamide and acrylic.	Assumptions based on expert judgement and from information in Re-fashion, 2024
Mechanical recycling	Consumer packaging (HDPE, (L)LDPE, PP, PS, PET)	32% (Archetype 1) 25% (Archetype 2) 15% (Archetype 3)		Archetype 1 value based on Kotz et al., 2023. Archetype 2 and 3 assumptions based on expert judgement
	Synthetic textile fibers	10% (Archetype 1) 5% (Archetype 2) 0% (Archetype 3)	A key limitation is the friction between fibers, which progressively shortens them and lowers quality, impacting yarn and fabric production.	Assumptions based on expert judgement and from information in Baloyi et al., 2024

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