TREASoURcE

Identifying Plastic Recycling Practices and Factors Influencing Them

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1. EXECUTIVE SUMMARY

The management of plastic waste is a major challenge for the circular economy and environmental management today, both in Europe and globally. The widespread use of plastics in packaging, agriculture, construction, logistics, and consumer goods stems from their lightness, durability, and cost-effectiveness; however, the slow degradation of plastics and the formation of microplastics pose long-term environmental risks. European Union policies, including waste directives, packaging regulations, and mandatory recycling targets for plastics, have made plastic waste recycling a political, economic, and technological priority.

The aim of this study is to assess the functioning and development potential of the plastic waste recycling system based on the PESTLE framework, focusing on bottlenecks in the value chain, the effectiveness of policy measures, and the applicability of technological and market-based solutions. The study focuses on TREASoURcE project target areas – Estonia, Latvia, Lithuania, Germany and Poland. The study combines expert interviews in Estonia and Latvia with a comparative desktop analysis of examples from Germany, Lithuania, and Poland, enabling the treatment of plastic waste recycling as a holistic value chain.

The analysis shows that the effectiveness of plastic waste recycling depends on several interrelated factors. Politically and legally, the main drivers of the system are extended producer responsibility, packaging regulations, and growing requirements for the use of recycled plastic. At the same time, the actual impact of these measures depends largely on national implementation mechanisms, the readiness of market participants, and the effectiveness of oversight. From an economic perspective, the main bottlenecks are the small market size and the relatively low quality of input material. Establishing new recycling centers may not be economically viable based solely on domestic waste streams, highlighting the need for regional cooperation, such as through the consolidation of raw material flows across the Baltic region. Likewise, contaminated or poorly sorted plastic waste reduces investment attractiveness and increases processing costs. A social analysis revealed that a significant portion of potentially recyclable plastic still ends up in mixed municipal waste, with the main reasons being convenience, the availability of collection points, and low awareness of proper sorting requirements. From a technological perspective, mechanical and chemical recycling are seen as complementary. Mechanical recycling is generally more cost-effective and environmentally sustainable but depends on the purity of the input material. Chemical recycling, including pyrolysis, allows for the processing of more complex plastic streams, but is more energy-intensive and requires a larger input volume. The analysis also highlights the critical importance of automated optical and infrared-based sorting solutions.

In summary, the analysis shows that developing a plastic waste recycling system requires a holistic approach, where policy measures, market mechanisms, technological solutions, and consumer behavior form an interconnected system. The main conclusion is that an effective circular economy requires not only technological innovation but also a systemic transformation of the value chain.

2. INTRODUCTION

The utilisation of plastic as a material is an indispensable aspect of contemporary life, with its pervasive presence in a wide range of items, including packaging, stationery, electronic devices, furniture, medical supplies and clothing, among others. This ubiquity has led to its gradual acceptance as an integral component of our daily lives, to the extent that its presence is now often overlooked. The pervasive utilisation of plastic items invariably culminates in plastic waste at the conclusion of their life cycle, which has become a global problem due to its non-biodegradability (with a degradation rate of 100–1,000 years) and brief life cycle (Panda et al., 2010; Pilapitiya & Ratnayake, 2024; Kazemi et al., 2021). From a global perspective, the primary causes of plastic waste entering the environment are considered to be the ineffective management of plastic waste streams and the inefficient waste treatment. This results in negative physical effects, such as plastics ingestion by animals causing digestive system disorders (Omidi et al., 2012; Hurley et al., 2020), chemical effects, including bisphenol A, phthalates and heavy metals causing various forms of cancer and endocrine system disorders (Wang & Qian, 2021), and biological effects, such as growth and reproductive capacity (Zhang et al., 2023). These effects have a negative impact on biodiversity (Pilapitiya & Ratnayake, 2024; Cholake et al., 2017; Kazemi et al., 2021). In their review, Pilapitiya & Ratnayake (2024) emphasise the detrimental socioeconomic ramifications of plastic waste on sectors such as healthcare, tourism, agriculture, fisheries, and shipping, which incur considerably higher expenses. In light of the dearth of general awareness regarding plastic waste, concerted efforts are being made to raise public awareness through the implementation of regulations (e.g. separate waste collection or bans on single-use plastic containers) and social media campaigns (e.g. promoting the use of metal water bottles) (Pilapitiya & Ratnayake, 2024).

3. METHODOLOGY

A total of 10 experts from various fields participated in the two interviews conducted in Estonia. The delegation comprised one representative from the Ministry of Regional Affairs and Agriculture and two representatives from the Ministry of Climate, whose remit includes the management of plastic waste streams, including agricultural plastics. The project was overseen by a specialist in organic farming technology from Tallinn University of Technology, and a representative from a professional association was also involved. During the research, a total of seven businesses were interviewed. Among these, one large company specialises in the manufacture of plastic materials, two companies' market various types of agricultural plastics, and one company is specialised in the cleaning and recycling of large plastic packaging (transport packaging). Furthermore, one waste management operator participated in the interviews. To provide an overview of the current situation in Latvia, an interview was conducted with a local academic. Furthermore, an additional interview was conducted with a Finnish company whose business profile involves collecting agricultural plastics for the purpose of recycling. The latter was employed to articulate potential recycling practices. Prior to the commencement of the interviews, the consent was obtained from all participants to record and transcribe the interviews, with the explicit caveat that their anonymity and the integrity of their views would be preserved. The PESTLE methodology was employed to formulate questions concerning the political, economic, social, technological, legal, and environmental factors, with the objective of eliciting responses to the project's primary research questions. The interview questions were presented in a semi-structured format. A desktop research exercise was conducted for Lithuania, Poland and Germany, utilising the PESTLE (political, economic, social, technological, legal, environmental) framework. A comprehensive overview was obtained through the utilisation of national documents, statistical data, and scientific articles. After the collection of data, the results were described, and conclusions and recommendations were drawn based on them.

4. BACKGROUND AND CONTEXT

2.1 Types of Plastics

As suggested by Pilapitiya & Ratnayake (2024), plastics can be classified based on several characteristics. Table 1 provides an overview of this classification.

Table 1. Categorisation of plastic types based on characteristics by Pilapitiya & Ratnayake 2024.

CHARACTERISTIC	DESCRIPTION
THE ORIGIN OF THE MATERIALS	the origin of the materials can be categorised as either natural, for example lignin and starch, semi-synthetic, such as cellulose-based materials, or synthetic, including silicone and nylon (Khan et al., 2019; Napper & Thompson, 2020);
STRUCTURES	the structures can be linear, branched, or cross-linked;
MOLECULARITY	can be thermoplastic or thermoreactive plastics, elastomers, and fibers;
PHYSICOCHEMICAL PROPERTIES	*a. thermoreactive* materials are non-deformable and do not degrade when heated (Chen et al., 2019; Okan et al., 2019), for example vulcanised rubber and components of composite materials with a long service life (Kazemi et al., 2021), *b. thermoplastics*: As Al-Salem et al. (2009) point out, 80% of the volume of plastic that is consumed (including textile fibers and packaging suitable for the food industry, as Kazemi et al. (2021) also note) melt when repeatedly heated. These plastics then take on "any shape" as they solidify and can deform, making them non-biodegradable (Sharuddin et al., 2016; Zheng et al., 2015; Kazemi et al., 2021). The lifespan of thermoplastics has been shown to range from single-use to an average lifespan (Kazemi et al., 2021);

APPLICATIONS	general (wide range of uses), engineering plastics (replacing metal in construction materials) and functional (radiation resistance, electrical conductivity) (Pan et al., 2020);
DEGRADABILITY	biodegradable (degrade in nature) and non-biodegradable (Chandran et al., 2020);
LIFE CYCLE	single-use and reusable (McGain et al., 2010);
RECYCLABILITY	The following SPI codes are associated with the incorporation of waste into new products: a. SPI 1 – PETE (polyethylene terephthalate) – product: water bottles – incorporation of waste into new products, including as a filler or alternative construction material (Albatayneh & Akhtar, 2024), b. SPI 2 – HDPE (high-density polyethylene) – product: consumer-grade canisters – recycled HDPE is suitable, for example, for creating composites with glass-fibre-reinforced polymers to produce decking boards, fence posts, etc. As posited by Spychała et al. (2024), c. SPI 3 (PVC, or polyvinyl chloride) is a product in the category of rigid construction materials. The potential exists for this to be used instead of landfill or incineration, through the process of 'melting together' post-recycling with renewable starch-based thermoplastics, which are plasticised with biodiesel glycerol waste (Correa et al., 2019). As stated by Zou et al. (2024), d. SPI 4 (LDPE, or low-density polyethylene) is a product in the category of packaging and flexible foam plastics. The recycled LDPE has the potential to be reused as foam after reprocessing, e. SPI 5 - PP (polypropylene) - product: medical devices - The addition of a ceramic aggregate (quarry) to recycled PP has been shown to be a viable method of producing low-cost composite products for construction purposes (Ngugi et al., 2024), f. SPI 6 - PS (polystyrene) - product: foam plastic, food containers - The incorporation of recycled expanded polystyrene in adobe has been demonstrated to result in alterations to its compressive strength and reduced water absorption, thereby rendering it a promising material for

	utilisation in building construction and restoration work (Puy-Alquiza et al., 2025), g. SPI 7 - Other types of plastics;
MATERIAL BASIS	bio-based and fossil-based;
DEGRADATION OF BIOPLASTICS	biodegradable bio-based, biodegradable petrochemical, and non-degradable bio-based.

2.2 Plastic Recycling Technologies

The recycling of plastic is predicated on the reduction of demand for virgin raw materials (da Cruz et al., 2014; Kazemi et al., 2021) and the waste hierarchy, wherein the primary objective is the prevention of waste generation, with subsequent strategies directed towards the reuse and/or recycling of the resulting waste through R-strategies (reuse, repair, remanufacture, refurbish). A third option involves the utilisation of plastic waste through mechanical and chemical recycling or composting. As a fourth option, the use of materials in energy production is no longer considered reuse (Keskkonnaministeerium, 2019), and landfilling is the least preferred option (Umezor et al, 2021, Lamtai et al, 2023).

The range of available recycling options is broad, yet the adoption of technological solutions that are in accordance with regional capacity is generally prevalent. On the one hand, the selection of technology is contingent on investment readiness, as a prosperous recycling industry effectively addresses the problem of substantial quantities of plastic waste and the considerable costs associated with industrial operations (in addition to technology and processes, infrastructure upgrades, labour, etc.). On the other hand, the efficacy of processing technology is contingent upon the sorting outcomes; that is to say, the extent to which diverse waste materials have been accurately categorised and the purity levels thereof. Furthermore, technologies differ in terms of energy intensity. (TalTech, 2021) Table 2 summarizes the different options of plastic recycling mechanisms.

The chemical structure of plastic waste utilised in **mechanical recycling** processes undergoes only negligible changes. The process typically involves the sorting of plastic waste, followed by the cutting or crushing of the material into smaller particles, the removal of contaminants, and, if necessary, the use of separation (e.g. density- or buoyancy-based) to separate different polymer fractions. Subsequent to this, the material is subjected to either pelletisation or the direct production of new products. As posited by TalTech (2021), the merits of mechanical recycling are manifold. Chief amongst these is the minimal generation of waste, a consequence of the simplicity of the process (Pilapitiya & Ratnayake, 2024). A further advantage is the low cost of the process. However, the process is not without its challenges, the most significant of which pertain to issues of waste contamination, the variety of plastic types, and raw materials of a lower quality than the original (TalTech, 2021).

In the process of **extrusion**, the volatile components that are generated during the melting of polymers are removed, thereby enabling the production of upcycled material (Chung et al., 2024). The molten material is then shaped (Jicsinszky et al., 2023). A salient advantage of this extensively utilised technology (Wilczyński et al., 2019) is its capacity to process brittle materials (Jicsinszky et al., 2023), and it is employed to produce profiles, films, sheets, and tubes (Gaspar-Cuncha et al., 2022; Wilczyński et al., 2019).

Dissolution is a key process in the recycling of various polymers (Lulu et al., 2025). For instance, when a solvent is employed, LDPE is dissolved, resulting in a homogeneous solution. Dissolution processes are characterised by their low-temperature operation, a feature that confers two key benefits: cost efficiency and reduced environmental impact. As asserted by Naviroj et al. (2019), effective material reuse is contingent upon the selection of an appropriate solvent (Walker et al., 2020).

Enzymolysis is predicated on biochemical processes and results in the depolymerization of polymers. Despite the fact that the technology is not yet widely utilised and experiments are still being conducted at the laboratory level, the implementation of the process has the potential to contribute to the achievement of circular economy goals in the context of plastic recycling (Tournier et al., 2020). (Keskkonnaagentuur, 2025)

In the case of **solvolysis**, depolymerisation is carried out using solvents, thereby effecting the breakdown of polymers into monomers. Solvolysis is regarded as a highly effective method for the recovery of plastic waste, particularly in the context of fibre-reinforced composites (El Gersifi et al., 2003). (Environmental Agency 2025)

The **depolymerisation** process entails the fragmentation of plastic into its fundamental monomer components. Consequently, a new plastic product is synthesised, exhibiting equivalent quality to its original raw material. Therefore, from a quality perspective, it is mechanically preferable. Conversely, the implementation of this technology is constrained by substantial investment costs, as it necessitates larger facilities and greater quantities of input raw materials, whilst the process itself is costly. It has been estimated that, given the volume of plastic waste in Estonia, this is not a reasonable technological solution (TalTech, 2021).

Pyrolysis, otherwise referred to as thermochemical recycling, facilitates the transformation of plastic waste into liquid products, including liquid fuels, waxes, and oils, amongst others. As posited by Zhou et al. (2016), the process of "the breakdown of high-molecular-weight polymer chains into smaller chains of lighter hydrocarbons" (Bernardo et al., 2018) is of significance. Pyrolysis can be executed as a standalone process; alternatively, it can be incorporated into the additional processes of other methods (e.g., gasification). In addition to the primary products (oils, etc.), pyrolysis also yields charcoal and various gases. (Kantarelis et al., 2013). (Environmental Agency 2025)

Table 2. Recycling processes and related technologies.

TECHNOLOGY	PROCESS	KEY ADVANTAGES	KEY LIMITATIONS	BEST USE CASE
MECHANICAL RECYCLING	Physical processing (sorting, shredding, melting)	Low cost, simple, low waste generation	Sensitive to contamination, quality loss (downcycling)	Clean, sorted plastic streams
EXTRUSION	Melting and reshaping polymers	Widely used, processes brittle materials	Requires pre-sorted material	Films, sheets, tubes
DISSOLUTION	Polymer dissolved in solvent	Low temperature, cost-efficient	Depends on solvent selection	Specific polymers (e.g. LDPE)
ENZYMOLYSIS	Biochemical depolymerisation	High circularity potential	Early-stage, not scalable yet	Future applications
SOLVOLYSIS	Chemical depolymerisation using solvents	Effective for complex materials	Cost, complexity	Fibre-reinforced plastics
DEPOLYMERISATION	Breakdown into monomers	Produces virgin-quality material	High cost, large scale needed	High-value recycling
PYROLYSIS	Thermal breakdown into oils/gases	Handles mixed waste	Energy-intensive, byproducts	Low-quality plastics
GASIFICATION	Conversion to syngas	Energy recovery + material use	Sensitive to contamination	Mixed waste streams
INCINERATION	Energy recovery from waste	Reduces waste volume	Not circular, emissions	Non-recyclable waste
BIODEGRADATION/COMPOSTING	Biological breakdown	Environmentally friendly	Slow, limited applicability	Bioplastics

Gasification constitutes a method of thermochemical recycling, wherein solid fuels are converted into synthetic gas for the purpose of producing electrical energy and heat, in addition to further processing. This concept has been further elaborated upon by Mastellone and Zaccariello (2014) and Ayuso-Díaz et al. (2025). The feedstock for gasification consists of plastics derived from consumer waste (Falascino et al., 2024). The presence of contaminants is widely regarded as the primary impediment to gasification (Ayuso-Díaz et al., 2025).

As posited by the Environmental Agency (2025), the process of **incineration** results in the capture and utilisation of carbon dioxide as a source to produce fuels, chemicals, and other products.

Several solutions exist for the biodegradation of plastic waste, with the production of new products and materials being a key outcome of this process. Industrial **composting** is the most recommended approach, as home composting does not guarantee sufficient results at lower temperatures, and the compost is not enriched with carbon. Furthermore, home composting of plastics does not ensure the release of the chemical compounds necessary for plastic production. (Pilapitiya & Ratnayake 2024)

Effective **sorting** is paramount for the recycling of non-biodegradable plastics. The utilisation of sorting technologies is highly recommended to ensure the efficacy of the process. However, a substantial number of scientific articles have documented the pivotal function of human labour in plastic sorting, which primarily entails the separation of plastics based on their visual characteristics. In the context of automated dry sorting, a range of sorting methods can be employed, including infrared, X-ray, air, electrostatic, mechanical, and melting sorting techniques. (Lange, 2021; Kibria et al., 2023). As Masoumi et al. (2012) and Ruj et al. (2015) demonstrate, automated wet sorting methods such as hydrocyclones, selective dissolution, and hydrolytic digestion are also described. (Pilapitiya & Ratnayake 2024)

A comparison of the various types of recycling reveals that biodegradation is the most environmentally friendly of these. The advantage of mechanical recycling is the generation of minimal residues through a simple process, while chemical recycling enables the production of new materials and products. However, both mechanical and chemical recycling are energy-intensive processes. In mechanical recycling, material quality declines with each recycling cycle, while chemical recycling produces toxic byproducts and carries a higher risk of generating landfilled waste. Nevertheless, the substantial time requirement represents a disadvantage associated with the process of biodegradation. (Pilapitiya & Ratnayake, 2024)

2.3 Policy and Legislative Context

European Framework Directive 2008/98/EC (European Commission, 2008) examines waste from a life-cycle thinking perspective (Lazarevic et al., 2010) and stipulates that by 2015, there was an obligation to sort at least paper, metal, plastic, and glass waste from households and, where possible, from other sources. The target for preparing the same waste for reuse and the recycling rate was set at 50% by 2020 (European Commission, 2008). New recycling targets were set for plastics at 50% and 55% for 2025 and 2030, respectively, and for packaging at 65% and 70%, respectively. It was specified that plastic packaging which degrades due to the action of UV rays is not considered biodegradable. (Keskkonnaministeerium, 2019)

In accordance with the provisions of the **Packaging and Packaging Waste Regulation** (EU) 2025/40 (European Parliament and Council, 2024), which aims to promote the principles of the circular economy (requirements for packaging recyclability and minimum content of secondary materials), plans are in place to address the reduction of packaging waste (avoiding overpackaging and the use of complex materials) and to enhance the environmental sustainability of packaging. The regulation in question permits the provision of more favourable tax conditions for those who have used secondary raw materials in packaging. As stated in the report by the Estonian Chemical Industry Association (2026) and the European Parliament and Council (2024).

The extended producer responsibility (EPR) system has been mandatory for all member states of the European Union since the end of 2024. This obligation is outlined in Directive 2008/98/EC, which requires every producer to fulfil their EPR obligations. The definition of these obligations is that of financial or financial and organisational responsibility for the management of products once they have reached the end-of-life phase of their life cycle (Rogers, 2021). (Ministry of Climate, 2025).

National laws and regulations, which include country-specific adaptations, such as waste management laws, waste management and waste prevention plans, laws governing packaging and packaging waste, requirements for the management of municipal waste, laws on environmental pollution taxes, etc.

2.4 Country Profiles

In Estonia, the consumption of plastic is closely associated with the overall economic activity and consumption levels of the nation. This is due to the fact that plastic materials are extensively utilised in a variety of sectors, including packaging, construction, electronics, and other industries. For instance, an average of approximately 160–170 kg (139.3 kg according to Eurostat data) of packaging waste is generated per person per year in Estonia, a significant portion of which consists of plastic packaging (ERR, 2023); in 2023, for instance, this accounted for 25%. Concurrently, the quantity of plastics allocated for recycling amounted to 95.5 kilograms. The recycling rate for plastic packaging waste was 42.4% in 2023, which is equivalent to the EU average of 42.1%. (Eurostat, 2023). Plastic consumption and the resulting waste generation have been shown to increase in line with economic growth and rising GDP. This is due to higher consumption and production, leading to greater use of packaging and plastic products. Concurrently, policy measures and the utilisation of alternative materials have engendered stabilisation, or even a marginal decrease, in select sectors (e.g., plastic packaging) in recent years. (Keskkonnaportaal, 2023) Consequently, the reduction of plastic usage and the augmentation of recycling are being regarded as integral components of a comprehensive circular economy policy that is aimed at achieving the decoupling of economic growth from the escalating growth in material consumption.

The Estonian plastics industry is a constituent of the overarching rubber and plastics manufacturing sector, which encompasses approximately 200 enterprises whose primary or secondary operations pertain to the processing and distribution of plastics or rubber products. Many companies are small or medium-sized and operate in various industries, supplying plastic products to both domestic and export markets. The sector is predominantly privately owned and encompasses companies with both domestic and foreign capital participation. The economic role of the plastics industry in Estonia's manufacturing sector is significant. The sector provides employment for approximately 3,200 people, accounting for approximately 3.4% of manufacturing employment. The total output of plastic and rubber products exceeded 600 million euros in 2023, and the sector's share of the manufacturing industry is approximately 4%. Most of the production is directed towards foreign markets, with over 70% of production being exported, primarily to Latvia, Sweden, Finland, Lithuania, and Germany. (EPL, 2026)

Regarding the range of products and applications, the plastics industry in Estonia is characterised by a high degree of diversification. Plastic products have a wide range of applications across numerous sectors, including the packaging industry, the construction sector, the automotive and electronics industries, and environmental technology. The primary exports of the country under scrutiny are furniture and vehicle fittings, plastic packaging (consisting of containers, boxes, and bottles), plastic films and sheets, and pipes and hoses. (EPL, 2026) The Estonian plastics industry identifies the mechanical recycling of plastic waste, whereby the material is sorted, cleaned, crushed, and granulated into new raw material. Estonia has significant potential for the establishment of chemical recycling, a field in which a local company has already made notable advances. However, the future operations of this initiative are contingent upon additional financial support from the government. (Keskkonnaagentuur, 2025).

In Latvia, as in other European Union countries, plastic consumption is closely linked to economic activity and consumption levels. This is due to the fact that plastic materials are widely used in packaging, construction, agriculture, and industry. According to Eurostat data, Latvia generates an average of approximately 144.8 kg of packaging waste per person per year, of which a significant portion—17.8%—is accounted for by plastic packaging in 2023. Furthermore, the volume of packaging sent for recycling per capita per year was 91.4 kg. The recycling rate for plastic packaging waste reached nearly 59% in 2023, which is significantly higher than the EU average of 42.1%. (Eurostat, 2023). The correlation between plastic consumption and the subsequent generation of waste is well-documented; increases in GDP and consumption invariably lead to greater utilisation of packaging and plastic products. As in other EU countries, Latvia has implemented several policy measures in recent years, including restrictions on single-use plastic products and an extended producer responsibility system, which have contributed to an increase in plastic waste collection and recycling. At the national level, the reduction of plastic usage and the promotion of recycling are regarded as integral components of a comprehensive circular economy strategy. This strategy is designed to disassociate the escalation in material consumption from economic growth, with the overarching objective being the enhancement of resource efficiency (Interview, 26.02.2026). The plastics industry in Latvia is a constituent of the broader category of rubber and plastic products manufacturing, encompassing small and medium-sized enterprises. The sector is predominantly privately owned, encompassing both domestic and foreign-owned enterprises.

In Latvia, there are associations for both waste management and waste management companies operating in the plastics sector, where the plastics sector is well-developed. The Latvian Waste

Management Association is the representative body for the sector, overseeing all waste streams in addition to plastic waste. The Association's key areas of activity include sector development, participation in policy-making, and the raising of awareness among the public. (LASA, 2026) The Latvian Association of Waste Management Companies (LAWMC) is another significant organisation in the region. The primary objective of LAWMC is to represent the economic and operational interests of its member companies. The primary focus of these organisations is on the implementation of pragmatic waste management strategies, encompassing collection, sorting, and processing. This emphasis directly influences the efficacy of plastic recycling. In doing so, they develop relevant services, collaborate with local governments, and improve the efficiency of systems. (Vides pratiba, 2026) There are two plastic waste recycling industries in the Baltic region that are operating successfully, with production capacities that exceed domestic needs.

Lithuania's plastic consumption and plastic waste generation are in line with general European Union consumption trends, where plastic packaging constitutes one of the most significant waste streams. According to Eurostat data, in 2023, the proportion of packaging comprised of plastic materials accounted for 25.8% of all packaging (140 kg per capita), with 85 kg of packaging being recycled. The recycling rate for plastic packaging waste has increased in recent years, reaching approximately 43% in 2023, which is slightly higher than the EU average of 42.1%. (Eurostat, 2023). The plastic waste collection and management system is supported by extended producer responsibility (EPR) schemes and a deposit-return system covering plastic bottles, which has helped achieve a high collection rate for beverage packaging. Lithuania's plastics policy is centred on the reduction of plastic packaging, the promotion of reusable solutions, and the enhancement of recycling quality. This is achieved through improved sorting and traceability of waste streams. Furthermore, efforts are being made to cultivate the market for secondary plastic materials and to incorporate circular economy principles into industry, with the objective of reducing reliance on virgin raw materials and minimising the environmental impact of plastic waste. (EEA, 2025) Among Lithuania’s waste prevention objectives, a key priority is “... to promote the ecological design of products and implement models ensuring waste prevention” (European Environment Agency, 2025).

The development of Lithuania's plastics industry and circular economy has been significantly influenced by the Lithuanian Plastics Cluster, an association comprising companies in the plastics sector, research and development institutions, and other stakeholders in the value chain. The cluster's primary objective is the promotion of innovation through the development of novel plastic materials and products, as well as the adoption of environmentally sustainable and circular economy-based solutions. The organisation's activities include the initiation of collaborative projects, the empowerment of research and development, and the enhancement of the competitiveness of companies at both the local and international levels. It is imperative to acknowledge the significance of enhancing plastics recycling, optimising resource efficiency, and fostering the development of novel technologies (including bio-based and recyclable materials). Moreover, the cluster functions as a conduit for knowledge transfer and collaboration among various stakeholders, thereby contributing to the sustainable development of Lithuania's plastics sector and its integration with the objectives of the European circular economy. (The Lithuanian Plastics Cluster, 2026)

In Poland, there has been a substantial increase in the use of plastics in recent decades, primarily attributable to the growth of the packaging industry and rising levels of consumption. It is estimated that approximately 1 million tons of plastic materials are used in the country each year, with a significant proportion of these materials ultimately becoming waste (Foltynowicz, 2005). Despite the fact that the amount of municipal solid waste generated per capita in Poland is below the European average, there is an increasing volume of plastic waste, which is concomitant with rising consumption (Ciuła et al., 2023). For instance, in 2023, the total packaging waste generated (172.7 kg per capita per year), 19.9% was attributed to plastic waste, and 116.4 kg of packaging was recycled (Eurostat, 2023). Key trends identified include the development of recycling infrastructure, the planned implementation of a deposit-return system, and pressure stemming from European Union targets to increase the recycling rate of plastic packaging and reduce waste sent to landfills.

The Polish plastics industry comprises companies engaged in the processing of plastic materials and the manufacture of plastic products and packaging for various economic sectors. The sector is responsible for the production of a variety of goods, including but not limited to plastic packaging, film products, plastic components, and various industrial and consumer goods that are made from plastic materials. A variety of technologies are employed in the plastics processing industry, including injection molding, extrusion, and plastic film production. Many companies operate within both domestic and international markets. The sector also encompasses companies that produce additives for plastic materials, polymers, and components necessary for plastics processing, as well as companies that develop solutions for the recycling and reuse of plastic materials.

The Polish Union of Plastics Converters (PZPTS) is an organisation that unites companies in the Polish plastics industry. The PZPTS represents the interests of companies operating in the plastics processing sector and supports the development and cooperation of this sector at both national and international levels. PZPTS is a member of the European Plastics Converters (EuPC). A key initiative is the establishment of a working group on the Deposit Return System (DRS), which is aimed at supporting the development of a packaging return system in Poland and increasing the collection rate of single-use packaging, including plastic bottles. The working group facilitates discourse among plastics industry companies on the system's structure, technical solutions, and sectoral cooperation. Moreover, the organisation disseminates knowledge and promotes sectoral cooperation by organising conferences, seminars, and meetings addressing topics such as plastics recycling, the circular economy, and the sustainable use of plastic materials. The objective of these initiatives is to enhance corporate cognisance of pertinent regulations, technological solutions, and optimal practices that facilitate the enhancement of plastic waste collection and recycling. Moreover, Polish companies engage in the activities of the European Plastics Converters (EuPC), which facilitates their involvement in European-level discussions concerning plastic packaging recycling, regulations, and the development of the circular economy. This collaborative endeavour fosters the exchange of experiences and facilitates the development of solutions that contribute to enhancing the level of plastic packaging collection and recycling. (PZPTS, 2026)

Germany is one of the European countries with the highest plastic consumption, with a figure of approximately 143 kilograms per person in 2017 (Schmidt et al., 2026). Plastic packaging constitutes a substantial proportion (17.4%) of packaging waste, and the recycling rate for plastic packaging waste reached just over 52% in 2023, which is higher than the EU average of 42.1% (Eurostat, 2023). In order to manage this waste, the country has developed an extensive separate collection and recycling system, which is in turn supported by extended producer responsibility schemes and a deposit-refund system for plastic bottles (Hebisch & Linsel, 2012; Picuno et al., 2021; Kwond et al., 2023). According to Eurostat (2023), the average amount of packaging sent for recycling per person in 2023 was 149.3 kg. Key trends in plastics policy include the reduction of plastic packaging, the promotion of reusable solutions, the development of recycling technologies, and the strengthening of circular economy principles throughout the value chain (Federal Ministry…, 2023; European Environment Agency, 2024). Concurrently, heightened focus is being directed towards the high-quality sorting of plastic waste, the evolution of the market for secondary raw materials, and the mitigation of the environmental impacts of plastic materials (Lorang et al., 2022; Schmidt et al., 2026).

The German plastics processing industry is represented by the umbrella organisation GKV (Gesamtverband Kunststoffverarbeitende Industrie), which serves to represent the interests of companies in the sector and acts as a conduit between them and policymakers and the public. The plastics industry is a pivotal sector within the German economy, comprising approximately 3,000 companies, over 300,000 employees, and an annual turnover of around 69 billion euros. The industry produces a wide range of plastic products, including packaging, construction materials, and technical components, and actively participates in circular economy initiatives aimed at increasing plastic recycling and the use of secondary raw materials. GKV also promotes the practice of 'design for recycling' of plastic products and packaging, with a view to improving the sortability of materials and the quality of recycling. The organisation engages in policy discourse and serves as a representative voice for the industry in the formulation of regulations that impact the circular economy for plastics in Germany and the European Union. Furthermore, GKV promotes collaboration across the value chain among plastic manufacturers, processors, waste management companies, and research institutions to develop innovative solutions for the more sustainable use of plastics. The objective of these initiatives is twofold: firstly, to enhance the market for recycled plastics, and secondly, to mitigate the environmental impact of plastic materials. (GKV, 2026)

2.5 A Global Exchange for Recyclable Plastics

At the global level, ENF Ltd. is a recycling materials exchange platform that was established in the Birmingham area in 2005. The company's primary function is to facilitate connections between buyers and sellers of waste, with a view to promoting recycling. The web platform provides access to comprehensive databases on recyclers of plastic, metal, paper, glass, and organic waste, as well as producers of new raw materials from secondary raw materials on a global scale. The database contains information on approximately 50,400 companies, of which 11,400 are involved in plastic waste. Furthermore, they provide an overview of the plastic recycling technologies available by country (approximately 2,000 different types of equipment). The primary objective of the platform is to sell data at a range of prices from €860 to €3,400. The number of plastic waste recyclers registered in the database is as follows: four in Estonia, seven in Latvia, 17 in Lithuania, 197 in Poland, 205 in Germany, and six in Finland. Among plastic waste handlers, 11 companies have been recorded in Estonia, 15 in Latvia, 19 in Lithuania, 257 in Poland, 337 in Germany, and 21 in Finland. (ENF Recycling (2026)

Globally, both primary materials (e.g. granulates) and non-primary materials (e.g. finished products such as panels and pipes) are exported and imported. It is evident that the volume of exports from Europe exceeds the volume of imports. The most significant export markets are the United States, Turkey, and China. The primary importers are the United States, South Korea, and, to a lesser extent, China and Iran. (EEA, 2021)

5. RESULTS: PESTLE ANALYSIS

4.1 Political Factors

At the European Union level, the issue of plastic waste recycling has been a matter of particular concern in recent years. In the context of European Commission working groups, which include a representative from the **Estonian** Ministry, the primary subject of discussion pertains to the harmonisation of end-of-waste criteria across the European Union. The presentation of a draft proposal on this matter was scheduled to occur in 2025. A comprehensive analysis of plastic waste recycling capacity was conducted by the Environmental Agency and subsequently published in Estonia during the summer of 2025. This analysis provided a detailed overview of the current situation and future possibilities in this area. The analysis indicated that the recycling of all types of plastic in Estonia may not be economically or technically viable. However, there is potential for development in relation to specific plastic streams. In addition to mechanical recycling, the development of chemical recycling, including pyrolysis, is regarded as a future direction. It is imperative to emphasise that the primary objective of pyrolysis is the production of raw materials suitable for utilisation within the chemical industry, as opposed to the generation of fuel.

In addition to the aforementioned factors, the European Union's policy on the recycling of plastic is also influenced by the so-called 'plastic tax', which was introduced in 2021 as part of the EU's own resources system. The introduction of a plastic tax has been proposed, with member states being required to contribute €0.80 to the European Union budget for every kilogram of non-recycled plastic packaging waste. This initiative is intended to serve as a direct economic incentive for countries to enhance their recycling rates of plastic packaging. The plastic tax has been a significant financial contribution to the Estonian economy, with the country paying approximately 19 million euros in 2021 and 16 million euros in 2022. Consequently, the development of plastic waste recycling has become a key priority of national waste policy. As stated in the report by the Environmental Agency (2025), Estonia has considerable capacity for mechanical recycling, estimated at 22,000 tonnes per year. However, in 2023, only approximately 16,500 tonnes of this capacity were utilised (Estonian Statistics, 2024). Consequently, the existing capacity remains underutilised. Concurrently, the international trade in plastic waste is ongoing, thereby underscoring the intricate nature of the system. A study on mixed municipal waste indicates that plastic waste constitutes over 20% of the total, of which a proportion could potentially be recycled. This underscores the necessity for the advancement of discrete collection systems, thereby ensuring the incorporation of valuable materials into the recycling process. In this context, both waste reform and the extended producer responsibility (EPR) system are of particular significance. The objective of waste reform is to facilitate and enhance the collection of separate waste for residents. The EPR system, meanwhile, is designed to ensure the collection and diversion of plastic waste into the recycling stream. It was further noted that silage bags, fishing equipment, and, in the long term, wind turbine blades and solar panels were also identified as problematic waste streams for the future. The development of effective solutions for these issues, whether domestic or cross-border in nature, is imperative.

At the national level, the development of recycling is supported through a variety of measures. The recycling measure of the Environmental Investment Centre facilitates support for the development of existing facilities and the construction of new ones, including potential chemical recycling plants. Additionally, an infrastructure measure has been implemented with the objective of encouraging separate collection within municipalities. Concurrently, state support for the construction of a pyrolysis plant, for instance, is constrained, thereby imposing limitations on the rate and magnitude of investments. The national waste policy of Estonia is informed, in part, by the Estonian Waste Plan 2022–2028, which includes a target to enhance the recycling of packaging waste. A study of plastic waste recycling capacity, conducted in 2025, primarily sought to identify solutions for the management of problematic plastic streams and to determine which relevant technologies require investment (Keskkonnaagentuur, 2025).

A significant problem is the discrepancy between regulatory targets and the actual market situation. For instance, a target has been established that, commencing in 2028, contact-sensitive packaging, such as that employed in food and medical products, is to contain up to 30% post-consumer recycled plastic.

Concurrently, data indicates that in Europe today, only approximately 0.2% of plastic waste is subjected to chemical recycling, a process which renders the material suitable for reuse in food packaging or other high-tech applications. This prompts the question of the feasibility of meeting such a significantly higher requirement within such a limited timeframe.

Moreover, a discrepancy has been identified concerning the recycling of plastic waste. Although it is estimated that 20% of plastic waste is recycled, there is often a lack of transparency regarding the final destination of this material and whether it is used in the same way as before. According to the European Union's taxonomy, the definition of recycling is restricted to equivalent use; for example, packaging must become packaging again. This approach is predicated on the establishment of elevated standards, necessitating the utilisation of monostructural materials and design solutions that are not detrimental to the properties of the regranulate (e.g., colours, adhesives, additives). In practice, this may result in the adoption of standardized and visually simplified packaging, characterised by transparency, to ensure optimal recyclability. Concurrently, regulatory inconsistencies have been identified. The utilisation of secondary plastics is imperative, yet its employment is concurrently constrained or proscribed in specific products, such as cable protection conduits. This has the effect of reducing opportunities for the use of lower-quality recycled plastic and creating additional uncertainty in the market.

In summary, it can be posited that the contemporary plastic cycle functions more akin to a downward spiral, wherein the quality of the material deteriorates with each recycling cycle (downcycling), as opposed to a closed loop wherein the material retains its value. Mechanical recycling generally does not permit the production of materials suitable for food contact. Consequently, the development of chemical recycling technologies is regarded as the primary long-term solution, as these would facilitate the restoration of plastic in a manner that permits the production of high-quality raw materials. It has been demonstrated that reuse systems are not a complete solution to the problem. Notwithstanding the fact that plastic products may be reused on multiple occasions, they must nevertheless undergo reprocessing in order to render them suitable for food contact. If this is done solely through mechanical means, the problem of targeted reprocessing remains unresolved.

In Latvia, policy measures for plastic waste recycling in recent years have been linked to a broad-based national waste management project launched approximately five years ago, which covered all types of waste and related behavioural patterns. This has been one of the most significantly targeted funding mechanisms for developing recycling to date, complementing earlier infrastructure investments funded by the EU. The project has necessitated close collaboration with recycling companies. A number of studies have been commissioned by the Ministry of Climate and Energy with the objective of identifying the most suitable solutions for plastic waste recycling. The results of the study have been presented to the government to inform future policy decisions.

Concurrently, a number of systemic challenges have come to the fore in the implementation of these policies. The fundamental problem is the substandard quality of sorted waste, both in mixed waste and in materials already collected by type. This indicates the necessity to concentrate policy measures more rigorously on modifying consumer behaviour and primary sorting. Despite the technological capacity for recycling being partially in place, in the form of both mechanical recycling methods (one of which is integrated with chemical solutions), several planned technological developments, such as the construction of a pyrolysis plant, have not been realised, despite private-sector initiatives.

In recent years, there has been a shift in policy focus towards alternative waste management solutions, particularly waste incineration and energy production. This has resulted in a shift in both public attention and policy discussions away from recycling. This may have ramifications for the priority accorded to the development of recycling at the policy level.

The implementation of policy measures has been disparate across specific waste streams. Despite the existence of studies addressing non-household plastic waste, including agricultural plastics, and the mapping of stakeholder attitudes, there are currently no specific regulatory requirements for their collection or management. The future regulatory steps are to be focused on the construction sector, where, in accordance with EU guidelines, stricter measures are planned for the separate collection of various waste types, including plastics.

Lithuania, like other EU member states, is guided by the Packaging and Packaging Waste Regulation (EU) 2025/40, which calls for a strong focus on the packaging life cycle, including design, labeling, and waste management. A goal has also been set to make packaging recyclable and to increase the use of recycled plastic in packaging. (European Commission a) Lithuania does not impose an incineration tax but operates a deposit-refund system for beverage bottles and voluntary systems for the recycling of other types of plastic. (European Agency a, 2025) At the national level, Lithuania has improvement tools aligned with EU targets, as evidenced by the audit of the National Waste Generation and Management Plan 2021–2027. The audit highlights that sorting of municipal waste remains inadequate, and the costs associated with management are borne by the population; like-kind waste is not weighed (meaning the applicable waste management fee is not incentivizing), and the conditions and convenience of sorted waste collection are not guaranteed for the entire population. In addition to these shortcomings, the audit identified priorities that require greater attention and solutions: proper sorting of municipal waste; increasing the capacity for recycling secondary raw materials through investment in modern and efficient technologies; reducing the proportion of secondary raw materials from municipal waste sent to incineration. (Valstbės Kontrolė, 2023)

The recycling systems in place **in Poland** for plastic waste and packaging are significantly influenced by the policies and strategic documents of the European Union. The European Union's waste directives, which stipulate the reduction of waste, the promotion of recycling, and the gradual reduction of landfill disposal, have been the primary catalyst for Poland's reform of its waste management system since its accession to the European Union. At the national level, the management of plastic waste is regulated by several laws, including the Waste Act, the Act on the Management of Packaging and Packaging Waste, and the Act on Ensuring Cleanliness and Order in Municipalities. These legislative acts define the role of local governments in organising the waste management system. The latter allocates the responsibility for the organisation of waste collection, transport, and processing to local governments, and authorises them to establish waste management fees (Ciuła et al., 2023).

The overarching strategic framework for policy measures is the National Waste Management Plan 2028, which covers the period 2023–2028 and sets targets for reducing waste generation, increasing recycling, and developing the circular economy. Furthermore, the National Waste Prevention Programme 2028 is being implemented, with a focus on waste prevention and enhancing resource efficiency. In addition to strategic documents, economic policy instruments are also being used to reduce plastic waste. For instance, Poland introduced a tax on plastic carrier bags with the aim of reducing the consumption of single-use plastic bags. In addition, a fee has been implemented for single-use plastic products, with effect from 2024. The objective of this measure is to reduce the volume of plastic waste entering the environment. As stated by the European Environment Agency in 2025, another significant institutional mechanism is the Extended Producer Responsibility (EPR) system, which is undergoing continuous development. At the national level, the objective is to attain a point whereby plastics that are challenging to recycle would be subject to elevated fees. Furthermore, Poland has announced its intention to implement a Deposit Return System (DRS) that will encompass plastic bottles, metal cans, and reusable glass bottles. The objective of this initiative is to enhance the collection rate of packaging and to optimise the quality of recycling. (European Environment Agency, 2025)

In Germany, the policy framework governing the recycling system for plastics and plastic packaging is based on the principles of the circular economy and long-term environmental policy. The management of waste is organised in accordance with the waste hierarchy, which prioritises the prevention of waste, followed by the reuse of products and the recycling of materials, with waste disposal being considered as a last resort. This principle has been fundamental to Germany's waste policy for decades, guiding the systematic development of plastic waste management. Germany was among the first countries in Europe to place plastic packaging waste management at the centre of its policy (Packaging Ordinance) as early as 1991. Consequently, packaging waste was designated as a distinct waste category, thereby establishing the principle of producer responsibility. The objective of this initiative was to motivate producers to reduce the volume of packaging and enhance its recyclability. As posited by Lazarevic et al. (2010), the implementation of the mandatory Extended Producer Responsibility (EPR) system has facilitated an enhancement in collection rates and the establishment of economic incentives for the design of recyclable packaging (Lorang et al, 2022).

In consideration of the policy framework, the circular economy for plastics is also influenced by Germany's national circular economy strategy. The latter's stated objectives are to analyse production and consumption throughout the entire life cycle and to promote resource efficiency. The strategy is centred on the conservation of resources, the reinforcement of circular economy principles, and the augmentation of the efficiency of material and energy utilisation. Furthermore, a range of initiatives aimed at reducing plastic waste and enhancing awareness have been integrated into policy measures. For instance, the roundtable entitled "Pack mer's – Ecological and Sensible Use of Packaging," which was established in the state of Bavaria, focuses on reducing the use of plastic packaging and promoting packaging-free shopping. Initiatives of this nature bring together policymakers, businesses, and research institutions with the aim of developing more environmentally sustainable packaging solutions. As stated by the European Environment Agency (2024), the Pfand deposit-refund system, which was introduced in Germany in 2003, also plays a significant role in the policy framework. This system enables consumers to return plastic bottles and receive a refund of the deposit paid for them, which has had a substantial impact on the collection and recycling rates of plastic bottles. (Basedow et al, 2025).

4.2 Economic Factors

From the perspective of national-level and market-size considerations, the small size of the **Estonian** market is one of the key economic constraints on the development of plastic waste recycling. For example, it has been estimated that agricultural plastic from Estonia alone is not sufficient to make the launch of a new recycling plant economically viable, even if all agricultural plastic were collected—there would still be a shortfall in volume, and the purchase of additional raw materials would be unavoidable. According to an analysis by the Environmental Agency, significant volumes of plastic waste are already being imported and exported today. For example, agricultural plastic collected in Estonia is predominantly transported to Lithuania, where it is sent for recycling. At the same time, there is a company operating in Estonia that processes agricultural plastic but imports raw materials from Scandinavia, as the material available there is cleaner and of higher quality. Although legislation stipulates that 100% of agricultural plastic must be directed to recycling, this is not always economically feasible in practice. If the plastic reaches the processor heavily soiled or damaged, the cleaning costs are so high that recycling becomes unprofitable. Cleanly collected material, however, is clearly more cost-effective. Additionally, there are issues with collection quality—based on previous observations; some agricultural plastic has been landfilled because it was not in a suitable condition for recycling. This indicates that the efficiency of the collection system and user awareness directly impact economic viability.

From a broader perspective, the size of Estonia’s plastic waste market and material flows significantly shape the economic viability of recycling. In 2023, approximately 80,000 tons of separately collected plastic waste were generated in Estonia, of which about 21% was recycled as material. At the same time, approximately 45% of plastic waste was directed toward energy recovery. This indicates that a significant portion of plastic waste does not enter the material cycle and that there is potential to increase recycling. (Keskkonnaagentuur, 2025)

From the perspective of raw material availability and price levels, there were approximately 15 companies engaged in plastic waste recycling operating in Estonia in 2023, which processed a total of about 16,646 tons of plastic waste.

At the same time, the estimated maximum recycling capacity of Estonian recycling plants is approximately 22,000 tons per year, which means that part of the existing technological capacity is currently unused. Considering that approximately 6,000 tons of plastic waste were imported into Estonia, there is reason to assess recycling from this perspective as well: to what extent can the volume of locally recycled plastic be increased? (Keskkonnaagentuur, 2025)

From another perspective, the price of secondary raw materials can be significantly higher than the purchase price of virgin raw materials. For example, recycled LDP or LLDP pellets cost approximately 40% more than virgin plastic. Additionally, the price difference for end products is significant: prices per ton can vary by about 25–30%. Considering that material accounts for approximately 50% of the cost of many plastic products, this means that a product containing recycled raw materials may be 15–

25% more expensive. This price difference reduces market acceptance, particularly in price-sensitive sectors.

Although some manufacturers consciously market products with recycled content (e.g., about 10% of production), demand is limited—the environmental argument appeals to only a small portion of customers, and most purchasing decisions are still driven by price. This is not solely related to the economic cycle but reflects broader market behavior—the environmental argument alone does not outweigh the price premium. The same applies to the agricultural sector: farmers make decisions rationally. Although they understand the environmental arguments for recycled material, cost-effectiveness and product performance are valued more highly. There is also a perception that using recycled pellets may require additional energy and processing, which calls into question its actual environmental benefits.

Regarding niche products, the use of secondary plastics is clearly on the rise in certain segments. For example, in the production of plastic pallets, the proportion of recycled material has increased in recent years, and in some countries (e.g., Germany and Belgium), pallets are already being produced from 100% recycled plastic. These may not fully compete with products made from virgin materials in all respects, but they fulfill their function and find a place in the market. An important price signal also comes from reuse: used plastic packaging can be at least twice as cheap as new. Thus, market logic works well where recycling reduces direct costs and does not require complex reprocessing.

The most significant contradiction from an economic perspective is that high-quality, food-grade recycled plastic is more expensive than virgin raw material, while there is insufficient demand for lower-quality secondary materials or their use is restricted by regulations. The small size of the Estonian market, material quality issues, a price-sensitive consumer base, and cross-border waste flows create a situation where the development of recycling depends largely on regional cooperation and export capacity. Without large volumes, a high-quality collection system, and market-based incentives, realizing new recycling opportunities is economically risky. In summary, economic factors indicate that the development of plastic waste recycling does not depend solely on technological capacity or regulatory goals, but primarily on market volume, material quality, pricing structures, and the actual willingness of consumers and businesses to pay.

In Latvia, the economic factors influencing plastic waste recycling are characterized by a balance between price and quality, whereby the decisive factor is not only the cost of the material but also its suitability for industrial use. Although there is a widespread perception in the market that plastic products made from secondary raw materials are more expensive, it is emphasized that the lower quality of recycled material compared to virgin material is a more significant factor for companies. This means that when using recycled plastic, virgin material often needs to be added, which reduces the economic attractiveness of recycling and makes the production of the final product more complex.

Consequently, companies tend to prioritize raw materials of higher and more consistent quality, even if this means greater reliance on virgin plastic. The use of recycled materials can introduce additional production risks and quality issues that companies seek to avoid. This situation suggests that market-based mechanisms alone may not be sufficient to promote the use of recycled plastics, as quality differences directly affect the competitiveness of products.

In terms of volume, there is no clear perception in Latvia that the quantities of plastic waste are a limiting factor; rather, plastic flows are generally viewed as substantial in the European context. At the same time, it is noted that market conditions and pricing may direct material flows between countries; for example, in certain cases, the Lithuanian market is preferred due to more favorable conditions.

In Lithuania, EU structural funds are being used to expand the plastic recycling infrastructure. For example, a call for proposals has been launched for 16.8 million euros from the Cohesion Fund to develop plastic recycling capacity by the end of November 2028 (EU investments). At the same time, the “polluter pays” principle related to extended producer responsibility has been expanded, requiring manufacturers and importers to register and report in a unified information system, where obligations can be fulfilled either individually or collectively through licensed organizations (Environmental Protection Agency, 2025).

The audit of the waste generation and waste management plan (Valstbės Kontrolė, 2023) highlights the low market value of secondary raw materials recoverable from mixed waste streams as an economic barrier, which reduces the profitability of separating plastics and preparing them for recycling after mechanical processing (Valstbės Kontrolė, 2023). This is also confirmed by Wahlström et al. (2023), who identify fragmented markets, quality fluctuations, and, for some material streams, insufficient publicly available oversight as barriers to the secondary raw materials market. Furthermore, it is noted that “...the scope of supply and demand for secondary materials originating from Lithuania extends up to a 1,000-kilometer radius (Ministry of Economy and Innovation of the Republic of Lithuania, 2021). Thus, Lithuania is similar to other European countries where influencing factors place mixed-collection and contaminated plastics at a disadvantage compared to well-functioning markets such as aluminum or paper. (zu Castell-Rudenhausen et al, 2023)

In Poland, economic factors play a significant role in the dynamics of plastic waste generation and recycling. The country’s economic growth and changing consumption patterns have increased the use of plastic materials and, consequently, the volume of plastic waste. It is estimated that approximately 1 million tons of plastic materials are used in Poland each year, of which about 40% eventually ends up in waste streams. The widespread use of plastics stems from their low cost, good durability, and extensive use in the packaging industry. (Foltynowicz, 2005).

The volume of packaging waste in Poland has increased significantly. For example, the volume of packaging waste increased by approximately 49% between 2000 and 2015 (including municipal waste generation of 293 kg per person per year by 2015), reflecting growth in consumption and the expansion of packaging use (Alwaeli, 2015). While GDP and waste generation followed similar growth trends until 2015, since 2016 waste generation has remained at the same level despite continued GDP growth (European Environment Agency, 2025).

The economic viability of plastic waste recycling is strongly influenced by waste quality, as plastic waste streams are often heterogeneous and contaminated with other materials, which increases sorting and processing costs. However, studies in Poland have found that plastic waste with high calorific value is suitable as an alternative fuel for waste-to-energy production. (Primus & Rosik-Dulewska, 2019) However, the 400 recycling companies, with a total capacity of 2 million tons per year in 2021, indicate that recycling in Poland has developed significantly in recent years (Ciuła et al, 2023).

The plastic recycling system in **Germany** is closely linked to economic factors, including recycling infrastructure, the market value of materials, and international waste trade. The use of recycled materials can bring economic benefits to companies, as the production of new materials is often more expensive than the use of recycled materials (Federal Ministry…, 2023). It is important to note that the economic efficiency of plastic recycling depends largely on the quality of the materials and the accuracy of sorting, including the degree of purity (Lazarevic et al., 2010).

Mechanical recycling has been the most successful recycling method (both technically and economically), often carried out by small and medium-sized enterprises. The primary goal of these companies is to select materials for recycling that enable the production of secondary raw materials of market-competitive quality. One of the most significant cost components of plastic recycling for these companies is product disassembly, which can account for over half of the total post-consumer processing costs, depending in certain cases (e.g., for end-of-life vehicles) on economic incentives. (Woidasky & Stolzenberg, 2009) This means that plastic products with complex compositions or consisting of multiple materials may not be economically viable for recycling.

International trade in plastic waste also influences economic processes. Historically, a large portion of plastic packaging waste was exported to countries such as China or other European nations, as Germany’s domestic recycling capacity was insufficient (Lazarevic et al., 2010). However, China’s ban on plastic waste imports in 2018 significantly altered global plastic waste trade and increased the need to develop Europe’s internal recycling infrastructure, resulting in waste imports from new export markets such as Turkey and Malaysia growing by 247% and 297%, respectively (Lorang et al., 2022). The economic viability of recycling is also affected by the negative market value of plastic waste, which pressures recyclers to prefer incineration (for energy production) or export (Lazarevic et al., 2010).

Table 3. Overview of economic factors by country

COUNTRY	KEY ECONOMIC CHARACTERISTICS	MAIN CHALLENGES	OPPORTUNITIES / DEVELOPMENTS
ESTONIA	Small market; ~80,000 tons collected (2023); 21% recycled, 45% energy recovery; ~15 recyclers; capacity (~22,000 t) underutilized	Insufficient volumes for new plants; reliance on imports/exports; poor collection quality; high costs for contaminated plastics; recycled materials more expensive than virgin	Potential to increase local recycling use; improve collection quality; expand regional cooperation; niche markets (e.g., pallets)
LATVIA	Market driven by balance of price and quality; sufficient plastic volumes	Lower quality of recycled materials; need to mix with virgin plastic; production risks reduce attractiveness	Improving material quality could increase uptake; potential to strengthen competitiveness of recycled materials
LITHUANIA	Strong policy and funding support (EU funds €16.8M); extended producer responsibility system	Low market value of secondary materials; fragmented markets; quality fluctuations; limited transparency	Infrastructure expansion; stronger regulatory framework; regional market integration (up to ~1000 km supply radius)
POLAND	Large and growing market (~1M tons plastic use annually); ~400 recycling companies; 2M ton capacity	High waste volumes; heterogeneous and contaminated waste; competition from energy recovery	Significant recycling capacity; potential to scale recycling; use of plastics as alternative fuel
GERMANY	Advanced recycling system; strong link to global markets; SMEs dominate recycling sector	High disassembly costs; complex product design; negative waste value; dependence on export markets (historically)	Efficient mechanical recycling; economic benefits of recycled materials; push to expand EU internal recycling after China ban

4.3 Social Factors

Social factors **in Estonia** are primarily reflected in people's daily habits and in how easy or difficult it is to sort waste properly. In the agricultural sector, the collection of various types of plastic waste (e.g., pesticide containers, fertilizer bags, silage film) is often organized through sellers and manufacturers: the farmer must first rinse the containers and consolidate the waste in one location, after which its removal is arranged. The collection round system is convenient for the user and mostly free of charge; however, if the collection option goes unused, the farmer must arrange for waste management on their own. Such organizational solutions directly shape user behavior and the quality of waste collection.

From the perspective of households, the situation is different. Studies of mixed municipal waste show that the proportion of plastics in the population's mixed waste remains high. Based on studies of the composition of mixed municipal waste, plastic waste accounts for an average of just under 18% of the total mass of mixed municipal waste. This indicates that a significant portion of potentially recyclable plastic does not enter the separate collection system but ends up in mixed municipal waste, reducing recycling efficiency, and increasing the need for sorting and post-treatment. (SEI, 2020; Keskkonnaagentuur, 2025) Convenience is considered one of the main reasons for this, as packaging waste collection points are far from home or require a separate trip with a "packaging bag," leading some people to abandon separate collection and dispose of waste in mixed waste. An example of good practice comes from Ireland, where the separate collection system for packaging is supported by technology—a camera system installed in garbage trucks analyzes the collected waste in real time and provides households with feedback on whether the sorting was done correctly. The focus is not on fines, but on recommendations and learning, and the result is a noticeable improvement in sorting quality.

According to the interviewees, consumer motivation is significantly influenced by whether they perceive the purpose and results of separate collection. People want to know what happens to the waste they collect and whether their efforts actually lead to recycling. If the system seems opaque or the outcome is unclear, motivation decreases. Therefore, from a social impact perspective, consistent communication, explanation, and the creation of visible feedback (e.g., where and how the collected materials are directed) are important. It was found that some people act based on intrinsic motivation, while others need a more direct benefit or a clear signal that the action is purposeful. It was found that implementing individual incentive systems in agriculture—where the volumes are large, and waste streams are more clearly distinguishable—could be more realistic. In some European countries, a direct price has also been established for agricultural plastic, which motivates better cleaning and higher-quality collection of the material. Applying this logic could also improve the quality of plastic collected in Estonia in the future and increase the recycling rate.

From a waste manager's perspective, every separately collected waste stream requires additional sorting. As foreign materials end up in the mix, and in the case of plastics, different types must also be distinguished. Unfortunately, sorting relies heavily on manual labor, and there are few high-tech automated solutions, which limit the quality and efficiency of the results. According to companies, Estonia's sorting technology capacity is low, and there is a shortage of modern solutions capable of accurately identifying material types automatically. This, in turn, means that even good consumer behavior may not yield optimal results if the subsequent stages of the system are not sufficiently capable.

In Latvia, the social factors influencing plastic waste recycling are characterized by a generally well-developed collection system, the effectiveness of which, however, depends heavily on user convenience and public awareness. Based on interviews, the collection infrastructure is sufficiently extensive, particularly in cities and towns, and the coverage of plastic waste collection points is considered high. At the same time, there are accessibility issues in rural areas, as collection points are often located in village centers (e.g., near schools or local government offices), which requires residents to travel and reduces the system's user-friendliness. Although digital solutions (e.g., map apps for locating collection points) are available and smart trash bins are being tested, convenience remains one of the main factors influencing behavior.

Resident participation in recycling is, however, relatively high and on the rise, reaching an estimated 79% of the population. Nevertheless, societal perceptions of the role of plastic use and recycling are considered a significant problem. It was noted in interviews that recycling is often seen as a sufficient solution that allows for continued unrestricted consumption of plastic, while the principles of reduction and reuse have not yet taken sufficient root. This points to the need to focus social measures more on raising awareness and changing behavior, rather than solely on developing collection systems.

Trust and communication regarding the functioning of the waste management system also represent a significant social challenge. A discrepancy was highlighted between residents' behavior and waste management practices—although people sort their waste, there is a widespread perception that waste management operators may later mix it back together, citing better logistical solutions or cost-effectiveness as justification. This creates skepticism among residents and may reduce their motivation to sort out waste.

In Lithuania, the proportion of residents sorting household waste has risen over the years to 60% (2021), and awareness of waste management had increased to an estimated 80% by 2021. While the volume of mixed municipal waste decreased by 25%—a trend attributed to "...the introduction of a deposit-refund system for packaging and the expansion of sorting infrastructure"—the proportion of secondary raw materials in mixed municipal waste remained unchanged. The quality of the plastic waste generated is also extremely inconsistent (Ministry of Economy and Innovation of the Republic of Lithuania, 2021). Therefore, Lithuania still faces the challenge of improving sorting efficiency and raising awareness, as well as making sorting more convenient at waste generation points. (State Audit Office, 2023; Ministry of Economy and Innovation of the Republic of Lithuania, 2021) At the same time, according to a study published in 2024 (Daugėlaitė & Kruopienė), the recyclability of single-use take-away plastic packaging was primarily hindered by three factors: color, structure (composite), and degree of soiling (expanded polystyrene) in the case of packaging. This further highlights the need to either raise public awareness regarding the contamination of used and recycled plastics and/or enhance the capabilities of waste management operators through technological advancements.

The effectiveness of plastic waste recycling **in Poland** depends largely on residents' behavior and waste sorting habits, as consumers' environmental awareness and willingness to sort waste directly influence recycling rates. Studies show that the quality of waste sorting also depends on the type of housing. A study conducted in the Silesia region showed that plastic waste sorting is significantly cleaner in single-family homes than in apartment buildings—with contamination rates of 8.1% and

23%, respectively. Based on the contamination rate and the contents of the yellow bags/containers, 57% and 49%, respectively, were suitable for mechanical recycling. (Hryb & Wandrasz, 2025). In Poland, a color-coded container system is used for plastic waste collection, where plastic waste is typically collected in yellow containers or bags, similar to Germany and Estonia. The system allows residents to separately collect plastic, metal, and multi-material packaging (Alwaeli, 2015). Economic incentives are also increasingly being used to influence consumer behavior; for example, the introduction of a deposit-return system launched in 2025 increases the collection rate of plastic bottles and improves the quality of recycling (Pionotek et al., 2024, European Environment Agency, 2025).

Despite the existence of a collection system, a relatively small proportion of waste is collected separately in Poland; for example, by 2015, only approximately 27% of municipal waste was collected separately (Alwaeli, 2015). In 2019, paper and cardboard packaging dominated packaging waste, but recent data indicate a strong need to accelerate the recycling of plastic packaging as well. It should be noted here that while the share of municipal waste prepared for recycling was set to increase to nearly 41% by 2022, a five-year extension is being requested for the subsequent targets set by the EU. (European Environment Agency, 2025).

Although **Germany** is considered one of the most environmentally conscious countries in Europe (Lazarevic et al., 2010), the functioning of the plastic recycling system is influenced by several social factors, particularly the population’s environmental awareness and active participation in waste sorting (Picuno et al., 2021). In households, plastic packaging waste is typically collected through a yellow bag or bin system designed specifically for packaging waste (Basedow et al., 2025), which is also in use in certain regions of Estonia (yellow bag). This system allows plastic waste to be collected separately at the point of generation, which improves recycling opportunities and reduces material contamination. Additionally, in Germany, attention is being paid to raising public awareness regarding the reduction of plastic consumption and the principles of the circular economy. For example, national and regional programs include the creation of educational materials, campaigns, and digital tools that help consumers make more environmentally friendly choices (European Environment Agency, 2024).

Scientific literature has also described social and occupational health issues related to plastic waste management, as plastic waste often contains organic residues that can serve as a breeding ground for microorganisms. Consequently, employees at waste management facilities may be exposed to fungi, bacteria, and endotoxins, particularly at those facilities where manual waste sorting is used in addition to technological advancements (e.g., NIR). (Hebisch & Linsel,

Table 4. Overview of social factors by country

COUNTRY	KEY SOCIAL CHARACTERISTICS	MAIN CHALLENGES	OPPORTUNITIES / GOOD PRACTICES
ESTONIA	Behavior influenced by convenience and system design; agricultural collection systems relatively well-organized; households generate high share of plastic in mixed waste (~18%)	Low convenience of collection points; high share of unsorted waste; low trust and limited feedback; reliance on manual sorting and limited technology	Improve accessibility of collection; introduce feedback systems (e.g., digital tools); incentive schemes for agriculture; invest in sorting technology
LATVIA	High participation (~79%); well-developed urban collection infrastructure	Limited rural access; perception that recycling alone is sufficient; distrust in waste system (fear of re-mixing)	Expand rural access; improve communication and transparency; use digital tools and smart bins; focus on behavior change beyond recycling
LITHUANIA	Increasing awareness (~80%) and sorting (~60%); deposit system contributes to reduced mixed waste	Inconsistent sorting quality; contamination issues; convenience gaps; material-specific challenges (e.g., packaging design)	Expand infrastructure; improve awareness on contamination; enhance sorting convenience; technological upgrades in waste management
POLAND	Behavior strongly influences outcomes; established color-coded collection system; incentives (deposit system) emerging	Low separate collection rates (~27%); higher contamination in apartments vs houses; need to improve sorting habits	Expand incentive systems; improve sorting quality; target housing-specific solutions; increase recycling of plastic packaging
GERMANY	High environmental awareness; established separate collection systems (e.g., yellow bin); strong public engagement	Ongoing need for participation; occupational health risks in manual sorting	Advanced awareness campaigns; digital tools; strong collection systems; focus on reducing plastic use and improving circular behavior

4.4 Technological Factors

The technological possibilities and limitations of plastic waste recycling in **Estonia** are primarily shaped by the diversity of waste streams and their small volumes. An analysis of plastic waste recycling capacity completed by the Environmental Agency in the summer of 2025 emphasizes that there are many applications and types of plastics, and it is not practical to recycle all types of plastics in Estonia. At the same time, the capacity for certain plastic streams already exists (particularly in mechanical recycling), and there is also room for development in the future, including in chemical recycling solutions. The need for technological development is also highlighted by a study on the composition of mixed municipal waste: plastics account for over 20% of mixed municipal waste, and it contains materials that could be recycled. Therefore, in addition to technology, the capacity for separate collection and post-sorting is also crucial for accessing valuable streams.

Discussions confirmed that **mechanical and chemical recycling** are not viewed as competing with each other, but rather as complementary. Mechanical recycling is suitable for certain types of plastic and high-quality streams, but for food-contact packaging, for example, technological limitations are more significant. Currently, the use of recycled PET material is most widely permitted in new food-contact packaging; for many other plastics, meeting food-contact requirements through mechanical recycling is challenging. Therefore, chemical recycling (e.g., pyrolysis) is seen as a potential future solution specifically for food-contact applications, as it allows for the restoration of material quality to a higher level.

At the same time, it is emphasized that chemical recycling is not a universal solution, as different plastics have varying yields and suitability, and the success of the process depends on the input material. If the input is mixed or has the wrong composition, the output (e.g., pyrolysis oil) may remain unstable, and meeting quality requirements may prove difficult.

Regarding bottlenecks, the availability of suitable input streams was highlighted in the context of chemical recycling technologies, making separate collection essential to ensure that suitable plastics reach the chemical process. Several technological issues were described regarding silage film: first, silage film is often heavily contaminated (soil, organic matter, manure), making it difficult to clean sufficiently; second, its physical properties (elasticity) pose a problem during shredding: the material tends to wrap around the shredders and hinders reliable pre-processing. Although some solutions are being explored (e.g., changing collection methods, pre-cleaning, more suitable shredders), the technological handling of silage film remains complex.

At the same time, it is noted that improving collection and pre-processing is partly behaviorally controllable: if silage film is removed and collected before it ends up in manure and soil (e.g., removing the film on an asphalt pad), the material remains significantly cleaner. Such “cleaner collection” practices could reduce the need for subsequent washing and cleaning and improve the technological profitability of the entire chain, especially if accompanied by incentive-based compensation.

Interviews highlighted that one bottleneck is the technological capacity for sorting. In Estonia, some sorting plants already have laser and optical solutions, but overall, the level of automated sorting is considered modest, and dependence on manual sorting is high. This directly affects how clean and uniform the fractions ultimately are when they reach recycling. The use of automated infrared-based sorting systems allows for sorting 5–20 times more units per hour with a significantly lower mis-sorting rate than manual sorting (Keskkonnaagentuur, 2025). As a comparison, the example of the Swedish company Site Zero was highlighted, where waste is crushed, material types are identified using infrared rays, and the material is run through the sorting line multiple times to increase accuracy. This suggests that consumers are not expected to possess the knowledge and skills to accurately distinguish between material types; instead, machines do this work for people. This approach is crucial because even experienced sorters often cannot reliably distinguish between different types of plastic. Therefore, a technological leap in sorting capabilities is seen as the key solution and should be encouraged.

The interviews also addressed the topics of product passports and digital traceability, which may be particularly important where obligations regarding the content of recycled plastic arise and the entire supply chain must be traceable. In this case, smart solutions are needed to ensure information flows through the chain without excessive bureaucracy, for example for large and individually handled products (e.g., batteries). An alternative technological approach mentioned is a digital watermark that could be read by machine sorting even on small surface areas (e.g., 1×1 cm). However, such solutions require that the entire system—packaging design, printing technology, and sorting lines—be compatible, as the weak point of optical/infrared-based sorting sensors is dark and especially black colors, which absorb radiation and do not reflect enough light back. This means that packaging with black backgrounds or black trash bags are difficult to correctly identify and sort out during machine sorting. Consequently, packaging design (e.g., transparent or light-colored materials, less printing, and fewer dark surfaces) becomes a key prerequisite from the perspective of the technological cycle.

Pyrolysis is seen as one possible solution, but realistic obstacles are also highlighted. First, there is the issue of stability and output quality: trials have been conducted for years, but several stakeholders describe that fluctuations in product quality and “getting the formula right” have been challenging. Second, the issue of scale arises: Estonia’s waste volumes may be too small for a pyrolysis plant, which would mean dependence on imports. Therefore, it was concluded that waste streams could be consolidated on a broader scale (e.g., a pan-Baltic solution) and the plant’s location selected in such a way that logistics and the onward transport of the output (oil/gas) would be feasible (e.g., proximity to a port, possibility of pipeline transport).

Latvia’s plastic waste recycling technology is characterized by a relatively high level of technological advancement, particularly in sorting processes, where there has been a clear shift from manual labor toward automated solutions. Based on interviews, the system no longer relies predominantly on human labor; instead, semi-automated solutions are used, supplemented by optical and infrared-based sorting technologies. Some larger companies have also adopted digital solutions, indicating a high level of technological infrastructure. Although automated sorting is combined with manual labor in certain cases, this is no longer the dominant practice.

There are two major companies operating in the field of plastic waste recycling, both of which use mechanical recycling technology. One company has additionally integrated chemical recycling solutions. Although Latvia’s recycling capacity exceeds domestic demand—having expanded to serve the Baltic region as well—there are no pyrolysis solutions. Furthermore, the national focus is on waste incineration technologies, which runs counter to the idea of developing pyrolysis.

According to a report by the EEA (European Environment Agency, 2025), achieving the EU's packaging waste recycling targets in **Lithuania** is a complex challenge—between 2010 and 2022, the recycling rate remained at 58%, while the rate for plastic waste fell to 44%. Consequently, various measures have been implemented, such as increasing landfill taxes, applying higher tax rates to non-recyclable packaging, and focusing on the implementation of extended producer responsibility, etc. (European Environment Agency a, 2025) One significant problem is that inadequate sorting and insufficient recycling capacity are linked to the limited capacity of mechanical and mechanical-biological treatment facilities (Ministry of Economy and Innovation of the Republic of Lithuania, 2021) and the fact that the price of secondary raw materials is too low to make recycling attractive. (State Audit Office, 2023) There is also a strong dependence on plastic waste infrastructure (collection and treatment) (Ministry of Economy and Innovation of the Republic of Lithuania, 2021).

According to a study on plastic waste in **the Baltic States** (Lyshtva, et al, 2025), different types of plastic waste are generated in roughly equal amounts across the three countries. Based on polymer types, the study initially examined the proportion of HDPE containers, LDPE films, PP containers, rigid packaging, PP films, PET bottles and rigid packaging, PS foam, PS containers and rigid packaging, and other plastics in municipal waste streams. LDPE films were the most prevalent in all three countries (7.24% of total mass in Estonia, 14.19% in Latvia, and 20.88% in Lithuania), followed by products made of PP materials; PET bottles and PS waste were found in smaller quantities. Additionally, it was found that plastic waste reaching waste management facilities is characterized by a high proportion of contamination, deformation, or fragmentation, which hinders their recycling. It was also noted that label-based marking reduces the recycling rate due to label damage, and technological developments are needed to make different types of plastics easier to identify. Manual separation of plastic types is not recommended, as "... This process, which relies heavily on the experience of the technicians, does not always provide reliable classification by polymer type". (Lyshtva, et al, 2025)

The technological infrastructure for plastic waste management in **Poland** encompasses both mechanical and chemical recycling, as well as energy production. Mechanical recycling is the primary technology used in plastic waste management, during which plastic waste is sorted, washed, crushed, and processed into pellets for use in the production of new plastic products. In addition to mechanical recycling, **chemical recycling technologies** are also being developed to break down plastic polymers into monomers to produce new plastics. (Adamy et al., 2018) However, chemical recycling is not yet widely used in Poland, and its implementation is still in the development stage (Hryb & Wandrasz, 2025).

In addition to recycling, plastic waste is also used for energy production, including from sorted waste (packaging waste from yellow bags/containers) that cannot be recycled (Hryb & Wandrasz, 2025), as waste-to-energy plants allow plastic waste to be used as an alternative fuel to reduce the use of fossil fuels (Primus & Rosik-Dulewska, 2019).

In Germany, technological solutions play a significant role in the plastic recycling system, as recycling efficiency depends largely on the technology used for sorting and processing materials; furthermore, not all plastic waste is currently suitable for recycling. For example, plastics may be mixed and contaminated with other materials, which complicates their recycling (Lorang et al., 2022).

One key technology is NIR-based sorting, which enables the differentiation of various polymers based on wavelength (Basedow et al., 2025), allowing for the automation of the sorting process and improving the quality of recycled materials. In addition, new technologies are being explored, such as sorting based on fluorescent markers, which allows for the separation of particles with reinforced fibers, thereby improving sorting efficiency. This solution is currently used in PVC sorting. (Woidasky et al., 2020) Furthermore, the use of artificial intelligence in material identification and sorting is being investigated to improve the efficiency of recycling processes and reduce the need for manual sorting (Kwon et al., 2023).

Table 5. Overview of technological factors by country

COUNTRY	KEY TECHNOLOGICAL CHARACTERISTICS	MAIN CHALLENGES	OPPORTUNITIES / DEVELOPMENTS
ESTONIA	Diverse but small waste streams; existing mechanical recycling capacity; emerging interest in chemical recycling (e.g., pyrolysis)	Small volumes limit scalability; low automation in sorting; contaminated streams (e.g., silage film); technological limits for food-grade recycling; unstable chemical recycling outputs	Improve separate collection and pre-treatment; invest in automated sorting (optical/IR); cleaner collection practices; regional (Baltic) solutions for scale; digital traceability (e.g., product passports)
LATVIA	Relatively advanced system; semi-automated and automated sorting (optical/IR); strong mechanical recycling capacity; some chemical recycling integration	No pyrolysis development; policy focus on incineration may limit recycling innovation	High technological readiness; potential to expand regional role; further digitalization and automation
LITHUANIA	Moderate recycling performance; reliance on mechanical and mechanical-biological treatment; infrastructure improvements ongoing	Insufficient sorting quality; limited recycling capacity; low value of secondary materials; dependence on waste infrastructure	Policy measures (taxes, EPR) to improve system; potential to expand capacity and improve sorting technologies
POLAND	Broad system including mechanical recycling, developing chemical recycling, and energy recovery	Chemical recycling still underdeveloped; reliance on energy recovery; mixed and contaminated waste streams	Large-scale infrastructure; potential to expand chemical recycling; integration of recycling with energy systems
GERMANY	Advanced technological system; widespread use of automated sorting (e.g., NIR); innovation in AI and marker-based sorting	Mixed and contaminated plastics remain difficult to process; not all plastics recyclable	High-tech sorting (AI, fluorescent markers); strong automation; continuous innovation improving efficiency and material quality

4.5 Legal Factors

The legal framework is increasingly shaped by European Union guidelines and regulations that link the economic viability of recycling to specific obligations, including **in Estonia**. In several sectors, the obligation to use recycled plastic in plastic products has already been established, and similar requirements are gradually being extended to other legislation. This means that the legal framework is no longer limited to the organization of waste management alone but is beginning to directly influence the demand for recycled materials and, consequently, investment decisions. For example, according to the Packaging and Packaging Waste Regulation, plastic packaging must contain a significant proportion of recycled plastic starting in 2030. Depending on the type of packaging, the required proportion of recycled plastic will remain at approximately 30–35% and will gradually increase to about 65% by 2040. Such requirements will create additional market demand for recycled plastic material and influence both packaging design and the development of recycling infrastructure. (Keskkonnaagentuur, 2025)

One complex area is bioplastics; a compostable trash bag was cited as an example, which consists of thermoplastic starch and contains 20–30% lignin. The purpose of such a product is not traditional recycling but rather composting together with biowaste—this is one of the few applications where compostability can be justified for plastics. At the same time, legal and market-based issues may arise regarding how different countries (especially export markets) recognize this material composition and its impact on compostability or safety. Since the technology and product are still in the development or early implementation phase, it is possible that regulatory interpretations, certification, and market access requirements will become a significant bottleneck. On the other hand, the use of compostable bags is questionable from the perspective of waste management operators, as the compost produced there is highly sensitive to different materials, and foreign objects—including compostable bags—are removed before the biowaste composting process.

From the perspective of businesses, one of the strictest legal restrictions relates to the regulation of materials that encounter food. The requirement that materials must be traceable and safe for human health means in practice that mechanically recycled post-consumer plastics are not permitted and cannot be used due to the risks involved, as there is no certainty regarding the previous use of the packaging (e.g., whether the same packaging previously contained food or chemicals). If the previous use cannot be verifiably proven to be part of a “clean food chain,” a legal and quality management barrier arises that prevents the material from being reintroduced into food packaging.

At the same time, it is noted that technological solutions can help overcome this barrier in certain cases if waste plastic can be processed into plastic suitable for the food industry. Such technology, using milk cartons as feedstock, has already been introduced to the public. However, the reliability of controls remains a critical issue—how to ensure that the wrong container (e.g., a milk carton that has held gasoline) has not entered the collection stream, to guarantee the safety required by legislation.

In addition to direct legal requirements, companies’ options are also shaped by standards and certifications, which may even be stricter than general regulations. An example cited was a situation where food industry standards do not permit the use of trays containing recycled plastic in logistics or production, even if the use of secondary plastic would be sensible from a circularity perspective. Under such conditions, the food chain must be treated separately, and recycled plastic should instead be directed toward applications where safety and certification requirements are not as restrictive (e.g., trash bags, peat bags, certain industrial products). At the same time, it is emphasized that recycled material has many suitable applications in the economy, such as trash bags and other non-food-contact products, as well as robust plastic products (e.g., pallets), where the content of secondary raw material can perform its function well. Regulation through legislation and standards should support the targeted and safe diversion of materials to suitable uses.

In Latvia, the legal factors influencing plastic waste recycling are characterized by the existence of general regulations, but a lack of specific measures to support the development of new and innovative plastic materials. Based on interviews, it is primarily companies themselves that are engaged in the development of composite and alternative plastic materials. An important part of the legal framework is environmentally sustainable public procurement, which formally operates in Latvia, but its practical impact is considered rather modest. The obligation to implement environmentally friendly procurement applies mainly to the public sector (government agencies and state-owned enterprises), while in the private sector, adherence to such principles largely depends on companies' internal rules and voluntary initiatives.

The producer's responsibility system, on the other hand, is well-established legally and, based on official indicators, also highly effective, reaching approximately 92% and ranking among the most effective in the EU. At the same time, a significant gap was highlighted between the formal functioning of the system and its practical implementation—shortcomings are primarily observed in oversight, including the verification of companies' reporting and the alignment of actual activities with the data submitted.

Although **Lithuania** has not introduced differentiated taxation based on the difficulty of recycling as part of its extended producer responsibility scheme, it has nevertheless established a higher tax rate for packaging that cannot be recycled, as well as a packaging fee for legal entities that fail to comply with the requirements. Additionally, packaging producer responsibility organizations are required to finance infrastructure development (European Environment Agency, 2025). Similarly, producers and importers have had a registration obligation (to keep records and submit reports) in the product/packaging/waste accounting information system since the beginning of 2018. In Lithuania, licenses are also issued to packaging waste management organizations. For example, the State Environmental Protection Agency has designated Žaliasis Taškas and Gamtos Ateitis as licensed packaging waste management organizations, which handle, among other things, plastic and PET packaging. (Environmental Protection Agency, 2025) However, since sorting remains insufficient (packaging accounts for 33% of municipal waste), the costs of packaging management are borne by the population (Valstybės Kontrolė, 2023). In addition, it is noted that extended producer responsibility systems could be further developed to apply "... stricter plastic waste regulations…" (Ministry of Economy and Innovation of the Republic of Lithuania, 2021).

The legal framework **in Poland** plays a key role in the development of plastic waste recycling, and European Union directives have set specific targets for waste recycling and reducing landfill disposal. For example, the recycling rate for packaging waste was required to reach at least **65% by 2025** and to increase further in the coming years. In addition, the European Union's Waste Directive requires that **the proportion of waste sent to landfills not exceed 10% by 2035**, which compels member states to develop alternative waste management solutions. However, as previously noted under social factors, Poland intends to request a five-year extension to meet future targets. (European Keskkonnaagentuur, 2025).

Poland has also implemented economic regulatory measures, such as a **landfill tax**, which is approximately **60 euros per ton** and aims to redirect waste toward recycling and energy production. At the same time, the landfilling of high-calorific-value and biodegradable waste is restricted, which encourages alternative uses of waste. Regarding incineration, it should be noted that only incineration plants pay the so-called incineration fee (European Keskkonnaagentuur, 2025).

The plastic waste recycling system in **Germany** is governed by a legal framework that includes both national laws and European Union regulations. One of the most important pieces of legislation is the Packaging Act (VerpackG), which requires manufacturers to register packaging placed on the market and participate in recycling systems. The law also banned the sale of lightweight plastic bags starting in 2022, and beginning in 2023, restaurants and cafes must offer customers the option to use reusable packaging (Federal Ministry…, 2023). The Waste Prevention Program and the Packaging Regulation also set requirements for packaging design and recyclability to encourage manufacturers to use more environmentally friendly materials and reduce the generation of packaging waste. (European Environment Agency, 2024) At the international level, the management of plastic waste is also influenced by EU and Basel Convention regulations, which restrict the export of plastic waste and impose stricter requirements on the cross-border movement of waste (Federal Ministry…, 2023).

Table 6. Overview of legal factors by country.

COUNTRY	KEY LEGAL CHARACTERISTICS	MAIN CHALLENGES	OPPORTUNITIES / DEVELOPMENTS
ESTONIA	Strong EU-driven framework; mandatory recycled content targets (30–65% by 2040); strict food-contact regulations; increasing role of standards and traceability	Limits on using recycled plastics in food applications; uncertainty around bioplastics; certification and traceability barriers; mismatch between regulation and technological capability	Growing demand for recycled materials; potential for chemical recycling solutions; clearer allocation of recycled plastics to suitable (non-food) applications
LATVIA	General legal framework with strong EPR system (~92% performance); presence of green public procurement	Limited targeted support for innovation; weak enforcement and oversight; low practical impact of green procurement (mainly public sector)	Strong EPR foundation; potential to improve enforcement; expand sustainable procurement and support innovation
LITHUANIA	EPR-based system with taxes on non-recyclable packaging; mandatory registration and reporting; licensed waste organizations	Insufficient sorting leads to higher costs for consumers; gaps in monitoring and enforcement; limited differentiation in EPR	Financial instruments to drive recycling; potential to strengthen regulation, monitoring, and stricter EPR measures
POLAND	EU-driven legal targets (e.g., 65% recycling, landfill limits); landfill tax (~€60/t); restrictions on landfilling certain waste	Difficulty meeting future EU targets (seeking extension); reliance on alternative treatments (e.g., energy recovery)	Strong regulatory pressure to reduce landfilling; incentives to shift toward recycling and alternative waste management
GERMANY	Advanced legal system (Packaging Act, EU rules); strict producer responsibility; bans on certain plastics; strong design and reuse requirements	Complex compliance requirements; strict standards for materials and recycling; managing international waste flows	Highly developed circular framework; strong push for reusable packaging and eco-design; alignment with EU and global regulations

4.6 Environmental Factors

The use of plastics and waste management is a significant environmental issue on a global scale. In 2023, over 400 million tons of plastic were used worldwide, of which approximately 54 million tons were produced in Europe. At the same time, only slightly less than 21% of plastic waste was recycled in Europe, including the same percentage in **Estonia**. This indicates that the potential for plastic recycling remains high, and policies and technologies are increasingly focused on expanding material circulation and reducing the use of fossil raw materials. (Keskkonnaagentuur, 2025) The environmental perspective is generally based on waste hierarchy and a comparison of different treatment methods. At the European level, reference is made to a separate comprehensive study, the conclusions of which indicate that the chemical recycling of plastic waste is more beneficial to the environment than incineration or landfilling. Mechanical recycling is still considered the most favorable option, but chemical recycling (including pyrolysis technology) is also preferred over final disposal without material recovery. At the same time, it was emphasized that there are several subtypes of chemical recycling, and their environmental impacts are not uniform; for example, in pyrolysis, the primary input is energy, which makes the process resource intensive.

In the Estonian context, mechanical recycling is often seen as the most sensible solution, as the proportion of the material's own value in the final product is relatively high, and profitable production does not necessarily require very large raw material volumes. At the same time, mechanical recycling is associated with significant water and energy consumption from an environmental perspective, primarily due to the need to clean the input material. In addition, sorting and pre-processing processes also contribute to the environmental burden, as mechanical recycling requires cleaner and better-controlled input raw materials. It is precisely in the quality of the input that a significant systemic limitation lies: Estonian companies engaged in the recycling of mixed plastic waste are forced to import part of their raw material from regions where collection systems yield cleaner material. This demonstrates that environmental outcomes depend not only on technology, but on the functioning of the entire chain—particularly on how cleanly waste is collected and how effectively contamination and mixing can be prevented.

An advantage of chemical recycling (e.g., pyrolysis) is that it is less sensitive to contamination and impurities in the input than mechanical recycling—thus, it can reduce the need for very intensive cleaning. However, this does not mean that input-related problems would disappear: the process is particularly sensitive to PVC and, to some extent, PET, which must be separated, and the yield depends significantly on the type of plastic. From an Estonian perspective, potential is added by the fact that there is experience in oil shale chemistry with similar processes and research capacity (e.g., plastic pyrolysis studies at the Virumaa College of the Technical University). Pyrolysis is therefore seen as a technology that could be better suited to Estonian conditions than some other chemical recycling methods.

When assessing environmental impact and feasibility, the issue of scale also arises. Some recycling technologies (e.g., PET hydrolysis or solvent-based separations) require very large feedstock volumes, as the cost of the input material accounts for a small portion of the process cost and efficient operation demands high throughput. Estonia's waste volumes may be insufficient for such solutions, pointing to the need to consolidate waste streams from a larger region or seek regional solutions. From this perspective, it may be better for the environment if local streams can be processed as close as possible (reducing transport) and technology is selected based on realistic input.

Long-term future scenarios foresee a significant increase in the share of recycled plastic. At the same time, the limitations of the material are emphasized: no plastic can circulate indefinitely—the material degrades, and real-world recycling is often limited to a few cycles. Ultimately, some of the material must be directed either to energy production or to the chemical “back to monomers” stage to restore its original quality. This makes the technology portfolio crucial: mechanical recycling is suitable for certain streams and cycles; chemical recycling helps restore quality, and certain residues inevitably end up in energy recovery.

From a business perspective, it is emphasized that the role of plastic cannot be assessed solely through the lens of pollution or waste. Historically, plastic has partially replaced paper in many applications, partly to reduce pressure on forests, and the advantage of plastic packaging is its low weight: compared to glass or metal, plastic is significantly lighter, which means lower transportation costs and often lower energy consumption in production (plastic processing temperatures are lower than those for glass and metal). Thus, in certain cases, a move “back to glass or metal” may increase the overall carbon footprint when energy consumption, logistics, and material use are taken into account.

It is also noted that many “paper packages” require plastic coating, wax, or other additional materials to achieve moisture and odor barrier. This complicates the separate collection and recycling of the material and raises the question of how “paper-based” we can consider such packaging to be.

In the case of bioplastics and compostable bags, a point of contention arises where the consumer expects that “compostable” means complete decomposition and environmental protection, but operational practices do not support this. In compost production, the mass derived from biowaste must be screened, and foreign matter removed, as the input contains various extraneous objects. The operator cannot wait for the bag to fully decompose, so its journey ultimately ends in the foreign matter's fraction, which is directed either to energy production or to landfill. In practice, this means that a compostable bag, which is more expensive for the consumer, may result in the same treatment pathway in terms of the result if the system is not adapted.

Furthermore, experience with lignin-based or other “natural component” bags shows that their properties can vary from batch to batch (e.g., odor, durability, brittleness), raising questions among consumers about whether and how quickly they compost. Ease of use also affects environmental outcomes: if bags stick together, tear, or do not fit into the handling system, consumers become reluctant to use them, and trust in the system diminishes.

In agriculture, environmental aspects are closely linked to functionality. Silage film must be airtight, UV-resistant, and last for at least a certain period; biodegradable materials may degrade uncontrollably in such an application or leave microplastics in the soil. Additionally, production costs and willingness to pay are limiting factors: even if a suitable biofilm was invented, the market might not be willing to pay that price. It follows that reducing the use of agricultural plastic requires a technological breakthrough.

In the environmental discussion, the view also emerged that where recycling certain streams (e.g., heavily contaminated agricultural plastic) is unreasonably complex or resource-intensive, energy production may be a more practical solution. Citing examples from Sweden and Finland, solutions were described in which agricultural plastic is sent for incineration (in some cases mixed with other fuels), and the contamination problem is “solved” through crushing and mixing. This reflects a contradiction: on the one hand, recycling is encouraged; on the other, overregulation (the obligation to collect, clean, pelletize, and verify use) can make the process so complex that the best environmental outcome is not achieved. This logic emphasizes that the overall goal need not be the production of a “silage-to-bath mat,” but rather finding realistic and effective solutions for each stream separately.

The environmental discussion also touched on the broader issue of resource use. One line of reasoning highlighted that while efforts are made to “extract” mixed-plastic products of highly variable quality, a significant amount of wood is being burned —so in some packaging sectors, there could be a greater focus on utilizing local bio-resources (wood, paper, cardboard) and reducing dependence on fossil-based inputs. At the same time, it is acknowledged that wood- and cellulose-based “true plastic substitutes” are still in the development phase, and plastic remains unavoidable in many areas of food packaging, particularly where there is direct contact with food. A realistic interim goal is seen as reducing plastic use through hybrid solutions (e.g., cardboard support structures), where recycling paper fibers is easier.

In Latvia, the environmental factors affecting plastic waste recycling are primarily addressed at the academic level, while broader public or regulatory debate is limited. Issues concerning the environmental impact of different materials (e.g., plastic vs. paper) or comparisons of mechanical and chemical recycling are based primarily on life cycle assessment (LCA) results, and these topics are generally considered to have already been analyzed and addressed scientifically. From an academic perspective, the development and adoption of new materials that could replace traditional plastic packaging are seen as an important direction. According to the interview, the focus is shifting primarily toward bio-based solutions, such as paper and paper materials with enhanced coatings, as well as wood-based alternatives, including materials made from wood waste. In other words, efforts are being made to find ways to move away from plastic solutions and seek more environmentally friendly alternatives.

At the same time, it was emphasized that recycling is no longer a sufficient solution in the context of the growing waste problem. It was highlighted that waste volumes, including plastic waste, continue to rise, which is why there needs to be a greater focus on reducing waste generation and changing consumption patterns. Recycling is viewed more as an earlier stage that should have been implemented more widely 10–15 years ago, and the current focus should shift toward waste reduction and systemic change. In the context of environmental factors, the importance of eco-design and extending value chains is also highlighted, encompassing improvements in product quality, extended product lifespans, and, in general, more efficient use of resources. It is also recognized that both corporate social responsibility frameworks and the legal environment can play a significant role in guiding companies toward more environmentally friendly solutions.

In Lithuania, attention has been drawn to the fact that waste storage places an environmental burden on the environment—including the generation of emissions—simply because nearly 17 tons of waste destined for landfills, which could serve as potential secondary raw materials, are not being recycled. Statistics from the documentation submitted to the supervisory authority also point to a problem where not all parties submit the necessary documentation to the State Environmental Protection Agency. Consequently, it has been acknowledged that the assessment and resolution of environmental issues are incomplete. Furthermore, the agency responsible for national environmental protection has not conducted assessments of packaging-related accounting, which also fails to ensure informed decision-making. (State Audit Office, 2023) Since the Packaging and Packaging Waste Regulation 2025/40 (European Parliament and Council, 2024) aims to reduce the use of virgin raw materials, increase the share of recycled materials, improve recyclability, and restrict certain single-use packaging, it is essential that reporting, monitoring, identifying problem areas, and finding solutions function effectively in Lithuania.

According to a study by Daugėlaitė & Kruopienė (2024), the prospects for recycling plastic packaging are good, and the country also has a recycling plant for (clean) polystyrene foam packaging, which, however, requires large input flows to be cost-effective. They identified incorrect sorting, inadequate labeling (e.g., on the bottom of the packaging), and, more broadly, low consumer awareness (regarding the need to rinse items and the minimum size requirement of 6 cm for recyclable items) as factors hindering recycling. As recommendations, they propose improving recycling infrastructure and implementing recycling planning methodologies (e.g., through the adoption of certified packaging). It is also noted that although chemical recycling involves high energy costs and problematic byproducts, it would nevertheless enable the recycling of soiled and multilayer plastics. The potential for reducing environmental impact is believed to be achieved through packaging design that influences emissions related to production and transport. (Daugėlaitė & Kruopienė, 2024)

Since plastics degrade very slowly in the environment and can pose long-term environmental risks, including the formation of microplastics and damage to ecosystems, their environmental impact is one of the main reasons why the development of plastic recycling has become a political and economic priority (Mierzwa-Hersztek et al., 2019). Given that plastic recycling rates in **Poland** have been below the European average (in 2022, the plastic recycling rate in Europe was approximately 27%, while in Poland it was approximately 21%) (Hryb & Wandrasz, 2025), further developing recycling capabilities is a key issue. Historically, the disposal of plastic waste in landfills must be drastically reduced to prevent methane emissions and soil and groundwater contamination (Alwaeli, 2015). Therefore, increasing the recycling of plastic waste is important both for reducing environmental pollution and for increasing the use of secondary raw materials.

The development of plastic recycling in **Germany** is closely linked to environmental protection goals, helping to reduce the use of natural resources, energy consumption, and the amount of waste sent to landfills (Federal Ministry…, 2023), especially given the global trend of increasing plastic consumption, which, for example, stood at 143 kg per person in Germany in 2017 (Schmidt et al., 2026). At the same time, the potential for recycling is limited because the quality of plastic materials deteriorates with each subsequent recycling cycle (mechanical properties), failing to meet the expectations of an equivalent product (Schmidt et al, 2026). Therefore, in developing a circular economy for plastics, it is important not only to increase recycling but also to reduce plastic consumption and use alternative material.

Table 7. Overview of environmental factors by country.

COUNTRY	KEY ENVIRONMENTAL CHARACTERISTICS	MAIN CHALLENGES	OPPORTUNITIES / DEVELOPMENTS
ESTONIA	Mechanical recycling preferred; growing interest in chemical recycling (e.g., pyrolysis); environmental outcomes depend on full value chain (collection → sorting → processing)	High energy and water use in mechanical recycling; poor input quality; small scale limits advanced technologies; challenges with contaminated streams (e.g., agricultural plastics, silage film)	Cleaner collection systems; regional solutions for scale; leveraging expertise (e.g., oil shale chemistry); optimized technology mix (mechanical + chemical + energy recovery)
LATVIA	Environmental discussion mainly academic (LCA-based); focus shifting toward bio-based and alternative materials	Limited broader policy/public debate; recycling alone insufficient as waste volumes grow	Development of alternative materials (wood, paper-based); stronger focus on waste reduction, eco-design, and circular economy practices
LITHUANIA	Policy focus on reducing landfill and increasing recyclability; some recycling infrastructure (e.g., polystyrene plant)	Insufficient monitoring and reporting; low sorting quality; contamination; high energy demand of some recycling technologies	Improved infrastructure; better sorting and labeling; stronger monitoring; packaging design improvements to reduce environmental impact
POLAND	Environmental pressure driven by low recycling rates (~21%); strong need to reduce landfill use and pollution	High environmental risks (microplastics, emissions); reliance on landfill and energy recovery; below EU average recycling performance	Expansion of recycling capacity; increased use of secondary raw materials; stronger environmental policies to reduce landfill use
GERMANY	Advanced system focused on reducing resource use, emissions, and landfill; strong integration of recycling into environmental policy	Material degradation limits infinite recycling; increasing plastic consumption; not all plastics recyclable	High recycling efficiency; emphasis on reducing consumption; development of alternative materials and circular economy solutions

4.7 The Possibility of Recycling Agricultural Plastic: The Finnish Example

The business model for the collection and recycling of agricultural plastic established in Finland was initiated voluntarily by plastic manufacturers. This was driven by plastic manufacturers' desire to preempt future regulatory pressure, and the primary goal was to demonstrate that the sector can take responsibility for collection on its own, thereby strengthening the sector's reputation and control over solutions. As a non-profit organization, it most closely resembles the producer responsibility business model for packaging, where a recycling fee is added to the price of the plastic product and the end-user essentially pays for the service at the time of purchase, allowing the agricultural producer to organize collection free of charge. Fees began to be collected four months before the actual start of collection to generate cash flow before costs are incurred, with collection costs covered by producers. The approach is based on the principle of a reasonable price to encourage participation, as an excessively high fee would reduce the system's effectiveness.

The technologically simple and user-friendly collection process works as follows: the need for collection is reported via a mobile app—the customer registers and submits an order, and the order is automatically forwarded to the contractors' system. Collection routes organized using three large trucks are planned manually, after which plastic waste is collected from farms and transported directly to storage. Since the company's previous plastic recycling partner went bankrupt, there was a disruption in the system; as a result, the plastic is currently being stored on the company's own premises, but new partners are being sought in Finland and abroad. From both an economic and a circular perspective, the company prefers to keep the cycle domestic, as exporting plastic increases costs on the one hand and complicates logistics on the other. Another significant risk for the company is dependence on the volume of material flow, as sustainability cannot be guaranteed with a limited volume.

The company considers the biggest challenge to be consumer-side sorting of agricultural plastic, where white and colored plastic film must be separated, and no nets are allowed to mix in. The main reason for this challenge is consumers' low awareness of the benefits of recycling, and incineration is mistakenly considered a circular activity. The company considers the level of awareness to be inconsistent, as agricultural producers are, for example, aware of the presence of microplastics in soil. On the other hand, consumer habits—where people are accustomed to burning—are a problem. Therefore, the company representative acknowledges that since changing behavior takes time, the workload associated with additional sorting will increase. At the same time, it is acknowledged that with even more specific sorting—including the removal of plastic film by consumers—sorting would become so complex that it would begin to hinder consumer participation in achieving recycling goals. Although disseminating additional information for the purpose of raising awareness is considered challenging, the company acknowledges that overall understanding has improved over time and believes that, with time and simple, clear communication, consumer knowledge will increase and habits will become more environmentally friendly.

More generally, the company found that additional sanctions could also be beneficial, particularly in cases where farmers neither recycle nor incinerate plastic but instead burn the plastic waste they generate themselves to avoid costs. Therefore, stricter penalties could motivate a change in behavior. It was also suggested that legislation could promote the use of recycled materials, which in turn would increase the value of secondary raw materials. A company representative noted that regulations should also create an economic incentive where the price of recycled plastic products would be equal to or lower than that of plastic made from virgin raw materials. On the other hand, since recycling requires investments with a payback period measured in years, investors are cautious about implementing new technological processes. A sufficient scale is needed to reduce costs and increase environmental efficiency. A market for circular products is also needed. From a transportation perspective, it was found that the business model of large central European plants is likely too risky, which in turn reduces the environmental benefits achieved through transportation.

During an interview, an R&D institution described that development is proceeding along two parallel lines: mechanical recycling, which is suitable for clean and sorted plastic, and chemical recycling (pyrolysis), which is suitable for contaminated material. Mechanical recycling produces granules, while chemical recycling produces pyrolysis oil. Although both require high-quality input, pyrolysis also allows for the use of lower-quality raw materials. According to the R&D organization, there is an increasing shift toward chemical recycling to expand recycling options.

6. DISCUSSION

This section discusses the key findings of the analysis, highlighting the main challenges and development needs of the plastic waste recycling system across political, economic, social, technological, legal, and environmental dimensions. These key challenges and barriers within the plastic recycling system are critical for understanding the transferability of different recycling practices. Since they are largely systemic rather than case-specific, transferring solutions between countries requires careful consideration of the broader context. This means that legal, political, technological, economic, and social dimensions must all be taken into account to ensure that recycling practices can be effectively adapted and implemented in different settings.

This section highlights the key factors influencing plastic waste recycling, which can also serve as criteria for assessing the transferability of recycling practices.

5.1 Governance and Policy and Regulatory Framework

The development of plastic waste recycling in the EU is largely shaped by a top-down policy framework. While this provides direction, it often lacks flexibility and does not fully account for national conditions. Regulatory inconsistencies and unrealistic targets—such as high recycled content requirements that exceed current technological capabilities—highlight the need for better alignment between policy, technology, and market capacity.

Implementation gaps further limit effectiveness. Low sorting quality, insufficient consumer engagement, and inadequate infrastructure remain persistent challenges. Addressing these requires stronger behavioral measures, including awareness-raising, simplified sorting systems, and improved accessibility of collection.

Economic instruments such as the plastic tax have proven effective but could be better targeted to support recycling infrastructure and innovation. More broadly, public support remains insufficient, particularly for scaling new technologies such as chemical recycling. Increased investment and stronger private-sector involvement are therefore needed.

System inefficiencies persist across the value chain. Underutilized recycling capacity, weak collection systems, and the export of waste indicate structural shortcomings. Improving collection and sorting, introducing stronger incentives (e.g., deposit systems), and promoting local processing are key priorities.

Not all plastics can be recycled economically or technically, requiring prioritization of high-value streams and alternative solutions for lower-quality materials. At the same time, limited transparency in recycling flows undermines trust and policy effectiveness, highlighting the need for better tracking and reporting systems.

A further challenge is “downcycling,” where material quality declines over time. Addressing this requires both technological innovation and improved product design, particularly through design-for-recycling. In addition, certain waste streams (e.g., agricultural or complex plastics) remain insufficiently addressed and may require targeted policies and cross-border cooperation.

Finally, recycling competes with alternatives such as incineration. Where energy recovery is more favorable economically or regulatorily, it can divert materials away from circular use. Policies should therefore clearly prioritize recycling over energy recovery.

In brief, the following governance-related factors are critical:

THEME	KEY POINTS
POLICY FRAMEWORK	EU policy dominates national systems → often rigid, with inconsistent and unrealistic regulations; needs better harmonization, flexibility, and realistic targets
IMPLEMENTATION CHALLENGES	Poor sorting quality, low consumer engagement, and inadequate infrastructure limit effectiveness → require behavioral measures and simpler systems
ECONOMIC & POLICY SUPPORT	Support is insufficient → plastic tax helps but should better fund recycling; more public investment and private-sector involvement needed
SYSTEM INEFFICIENCIES	Underused capacity, weak collection/sorting, and waste export persist → need improved systems, incentives (e.g., deposit schemes), and stronger local markets

RECYCLING QUALITY & TRANSPARENCY	Not all plastics are recyclable; downcycling and limited tracking reduce value → require prioritization, monitoring, and design-for-recycling
TECHNOLOGICAL DEVELOPMENT	Mechanical recycling alone is insufficient → combined mechanical and chemical solutions and stronger innovation support needed
CHEMICAL RECYCLING BARRIERS	High potential but limited by low investment and unclear regulations → requires stable policy support
SPECIFIC WASTE STREAMS	Some plastics are under-addressed → need targeted solutions and cross-border cooperation
POLICY PRIORITIZATION	Incineration competes with recycling → policies should prioritize material recycling over energy recovery

Legal frameworks increasingly shape recycling through market mechanisms, linking regulatory targets to demand for recycled materials and investment decisions. EU requirements, particularly for recycled content, are driving structural changes across the value chain.

However, strict regulations (especially for food-contact materials) limit the use of recycled plastics due to safety and traceability requirements. Overcoming these barriers requires both technological innovation and additional financial support.

Regulatory inconsistencies and unclear restrictions create uncertainty for businesses. Clearer communication, harmonization, and alignment between policymakers and practitioners are needed.

Innovation, particularly in new materials such as bioplastics, is further hindered by fragmented regulations and certification challenges. A more coherent legal framework is required to support market uptake.

Weak enforcement and insufficient oversight reduce the effectiveness of regulations and can shift costs to consumers. Strengthening monitoring and data reliability is therefore essential. At the same time, legal frameworks could better support domestic recycling capacity and reduce reliance on imports.

In brief, the following regulatory factors are critical:

THEME	**KEY POINTS**
ROLE OF LEGAL FRAMEWORKS	EU targets and mandatory recycled content drive demand, investment, and circular economy development
REGULATORY CONSTRAINTS	Strict rules (e.g., for food-contact materials) limit use of recycled plastics → require technological innovation and financial support

REGULATORY CLARITY	Inconsistencies and restrictions create confusion → need clearer communication and alignment between policymakers and practitioners
INNOVATION & NEW MATERIALS	Legal uncertainty (e.g., for bioplastics) and fragmented rules hinder adoption → require harmonized regulations and certification
ENFORCEMENT & OVERSIGHT	Weak monitoring and unreliable data reduce effectiveness and shift costs to consumers → stronger enforcement needed
DOMESTIC CAPACITY SUPPORT	Policies should better promote local recycling capacity → reduce reliance on imports/exports and utilize existing infrastructure

The governance and regulatory challenges outlined above do not operate in isolation — they directly shape the economic environment in which recycling systems must function. Regulatory pressure creates demand for recycled materials, but whether that demand translates into viable markets depends on cost structures, material quality, and the willingness of businesses and consumers to pay. The following section examines these economic dimensions.

5.2 Market and Economic Conditions

Plastic waste generation and recycling are closely linked to economic growth, consumption, and global trade. International market dynamics, including waste trade and price fluctuations, significantly influence material flow and investment decisions.

The viability of recycling depends primarily on market conditions (material quality, volumes, pricing, and willingness to pay) rather than solely on regulatory targets. Policies must therefore align environmental objectives with economic incentives, including support for waste reduction, internal EU recycling capacity, and demand for secondary materials.

Small and fragmented markets, such as Estonia, limit economies of scale and make recycling dependent on cross-border flows. Strengthening regional cooperation and optimizing logistics are essential to improve efficiency and reduce costs.

System performance is also heavily influenced by collection and sorting quality. Poor-quality input increases costs and reduces recycling competitiveness, often diverting materials to energy recovery. Improving collection systems, raising awareness, and prioritizing recycling over incineration are therefore critical.

Market barriers further constrain development. Low or negative material value, price competition from virgin materials, and inconsistent quality reduce demand for recycled plastics. Addressing these issues requires economic incentives, standardization, and stronger market transparency.

At the same time, certain niche applications (e.g., pallets, deposit systems) demonstrate that recycling can be economically viable. Expanding such segments offers opportunities for scaling circular solutions.

In brief, the following market-related factors are critical:

THEME	KEY POINTS
MACROECONOMIC DRIVERS	Plastic waste and recycling are linked to economic growth, consumption, and global trade → international markets and policies shape flows and investments
MARKET DEPENDENCE	Recycling viability depends on material quality, volumes, prices, and willingness to pay → policies must align environmental goals with market logic
SCALE & REGIONAL MARKETS	Small, fragmented markets limit viability → require regional cooperation and cross-border flows for economies of scale
COLLECTION & SYSTEM EFFICIENCY	Inefficient collection and sorting increase costs and divert waste to incineration → need better systems, standards, and awareness
CAPACITY UTILIZATION	Underused recycling capacity and reliance on imports indicate inefficiencies → more local waste should be processed domestically
MATERIAL VALUE & COMPETITION	Low or negative value of plastic waste and competition from incineration weaken recycling → need incentives to increase value and prioritize recycling
MATERIAL QUALITY	Contamination and degradation raise costs and reduce usability → require improved sorting, pre-treatment, and quality standards
PRODUCT DESIGN	Complex, multi-material products increase recycling costs → design-for-recycling is essential
MARKET BARRIERS	Secondary materials face price disadvantages, inconsistent quality, and low transparency → need subsidies, standards, and stronger oversight
DEMAND DYNAMICS	Price sensitivity favors virgin materials → requires financial incentives and measures like green public procurement
NICHE OPPORTUNITIES	Some applications (e.g., pallets, deposit systems) are economically viable → should be expanded and scaled

Economic viability ultimately depends on what people do with their waste. Even well-designed market mechanisms and price signals have limited effect if consumer participation remains low or sorting quality is poor. The social dimension — how people understand, trust, and engage with recycling systems — therefore forms a critical link between policy intent and real-world outcomes.

5.3 Social Factors and Behavior

Recycling effectiveness is strongly influenced by public awareness, attitudes, and behavior. Lack of transparency and feedback reduces participation, while the perception that recycling alone is sufficient limits efforts toward waste reduction and reuse. Awareness initiatives must therefore be combined with practical guidance and systemic improvements.

Trust in the system is equally important. If users doubt that waste is properly processed, motivation declines. Providing clear information and feedback on waste flows can strengthen engagement.

Economic incentives, such as deposit-refund systems, have proven effective in improving both collection rates and quality. Expanding such mechanisms could further enhance participation.

Convenience is another key factor. Easy access to collection points significantly increases sorting rates, while rural areas and apartment buildings often face barriers. Improving accessibility, tailoring solutions to housing types, and introducing flexible collection systems are therefore essential.

In brief, the following societal factors are critical:

THEME	KEY POINTS
AWARENESS & UNDERSTANDING	Recycling effectiveness depends on awareness and attitudes → lack of transparency and feedback reduces participation; awareness must be linked to practical guidance
BEHAVIOR & MISCONCEPTIONS	Belief that recycling alone is sufficient limits waste reduction → communication should emphasize prevention and reuse
TRUST & MOTIVATION	Participation declines if trust in the system is low → transparency and regular feedback are essential to maintain engagement
ECONOMIC INCENTIVES	Financial mechanisms (e.g., deposit-refund systems) improve collection rates and quality → can be expanded to more plastic types
ACCESSIBILITY & CONVENIENCE	Easy and nearby collection increases sorting → rural areas and apartment buildings face greater barriers
COLLECTION SYSTEM DESIGN	Need denser collection networks, housing-specific solutions, and flexible options (e.g., mobile systems) to improve access and participation

Changing behavior, however, is not sufficient on its own. Motivated consumers who sort their waste carefully can still be let down by infrastructure that is unable to process what they deliver. The quality of sorting, processing, and material recovery ultimately depends on the technological capabilities available — and it is here that significant gaps remain across the countries examined.

5.4 Technology and Infrastructure

Recycling efficiency depends on the availability and quality of input materials. Contaminated or mixed waste reduces the effectiveness of recycling technologies, making improved separate collection and pre-treatment essential.

Certain materials—particularly complex, dark, or contaminated plastics—pose technological challenges. Addressing these requires better product design, targeted collection systems, and investments in advanced sorting technologies.

Sorting remains a key bottleneck. Automated solutions (e.g., optical and AI-based systems) can significantly improve accuracy, capacity, and safety, reducing reliance on manual labor.

No single technology can address all plastic streams. Mechanical and chemical recycling should be combined, with materials directed to the most suitable process. Digital tools, such as product passports, can further improve traceability and sorting efficiency but require system-wide coordination.

Technological development is also constrained by scale and market conditions. Small volumes and low material value limit investment, making regional cooperation and harmonization essential.

In brief, the following technological factors are critical:

THEME	KEY POINTS
INPUT QUALITY & VOLUME	Recycling efficiency depends on clean, sufficient input streams → contamination and low volumes reduce effectiveness
MATERIAL & DESIGN CHALLENGES	Complex, dark, or contaminated plastics hinder recycling → require design-for-recycling and improved pre-treatment
SORTING TECHNOLOGIES	Manual sorting is limited → automated solutions (optical, AI-based) improve accuracy, capacity, and safety
TECHNOLOGY INTEGRATION	Mechanical and chemical recycling should be combined and matched to material characteristics
DIGITALIZATION	Product passports and machine-readable labels improve traceability and sorting → require system-wide coordination
SCALE & MARKET LIMITS	Small volumes and low material value hinder investment → regional cooperation and harmonization needed for efficiency

Technological choices also have direct environmental consequences. The energy intensity of different recycling methods, the environmental cost of transport, and the question of what to do with streams that cannot be recycled all point to a broader need to assess the environmental performance of the system as a whole — not just its technical efficiency.

5.5 Environmental Performance

From an environmental perspective, mechanical recycling is generally the most favorable option, followed by chemical recycling, while incineration and landfill should be used only as last resorts. However, environmental outcomes depend heavily on resource use and the suitability of technologies for specific material streams.

The performance of the entire value chain is critical. Clean collection and effective sorting reduce resource consumption and improve recycling feasibility, making input quality a key determinant of environmental impact.

Scale also matters. Small markets limit optimal solutions, increasing the need for regional cooperation while minimizing transport-related impacts.

A combined technological approach is necessary, as material quality declines over time. Mechanical, chemical, and energy recovery processes should therefore be seen as complementary.

Challenges also arise with bioplastics, where system incompatibility can negate environmental benefits. Clear standards, better infrastructure alignment, and consumer awareness are needed.

Ultimately, the greatest environmental gains come from waste prevention, reduced material use, and extended product lifespans. Not all plastics should be recycled—highly contaminated streams may be better suited for energy recovery. This highlights the need for a system-wide, case-by-case approach.

In brief, the following environmental factors are critical:

THEME	KEY POINTS
TECHNOLOGY CHOICE	Mechanical recycling is most environmentally favorable, followed by chemical recycling; incineration and landfill should be last-resort options
INPUT QUALITY & COLLECTION	Clean collection and effective sorting are critical to reduce resource use and enable efficient recycling
SCALE & REGIONALIZATION	Small markets limit optimal solutions → need regional cooperation and waste stream consolidation while minimizing transport impacts
INTEGRATED TECHNOLOGIES	Recycling should combine mechanical, chemical, and energy recovery approaches depending on material quality

BIOPLASTICS CHALLENGES	Environmental benefits depend on system compatibility; require better certification, infrastructure alignment, and consumer awareness
WASTE PREVENTION	Reducing plastic use, promoting reuse, and extending product lifespans have the highest environmental impact
MATERIAL-SPECIFIC SOLUTIONS	Not all plastics should be recycled → heavily contaminated streams may be better suited for energy recovery; case-by-case assessment needed
SYSTEM-WIDE PERSPECTIVE	Environmental outcomes depend on the full system (policy, technology, markets, behavior), requiring a holistic approach

Environmental performance cannot be assessed in isolation from the systemic factors discussed in the preceding sections. The choice of recycling technology, the quality of collection and sorting, the scale of material flows, and the behavior of consumers all directly determine environmental outcomes. A technically superior recycling method achieves little if the input material arriving at the facility is too contaminated to process, or if the volumes are too small to justify the energy investment. This underscores a central finding of the analysis: environmental gains in plastic waste management are not achieved through technology alone, but through the coordinated functioning of the entire value chain.

7. SUMMARY

The use of plastics has grown significantly in recent decades, and as a result, plastic waste management has become a key environmental and circular economy challenge both in Europe and globally. Plastics are widely used in packaging, agriculture, construction, logistics, and consumer goods due to their advantages of light weight, durability, and low production costs. At the same time, the slow degradation of plastics and the formation of microplastics pose long-term environmental risks, making the development of plastic waste recycling a political, economic, and technological priority. At the European Union level, this is supported by waste directives, packaging regulations, and growing requirements for the use of recycled plastic in new products.

The study aims to evaluate the performance and development potential of the plastic waste recycling system using the PESTLE framework. It focuses on identifying value chain bottlenecks, assessing the effectiveness of policy measures, and examining the suitability of technological and market-based solutions. The analysis covers the TREASoURcE project target areas - Estonia, Latvia, Lithuania, Germany, and Poland. It combines expert interviews conducted in Estonia and Latvia with a comparative desk-based review of cases from Germany, Lithuania, and Poland, allowing plastic waste recycling to be examined as an integrated, end-to-end value chain.

When recycling plastic waste, it is important to consider the diversity of plastic types and properties, including physical characteristics, areas of use, and recycling options. Additionally, packaging design, dyes, labels, and multi-layer solutions directly impact the quality of sorting and subsequent recycling. From the perspective of recycling technologies, plastic waste recycling is primarily divided into mechanical and chemical recycling. Mechanical recycling is generally considered the most cost-effective solution, but its effectiveness depends heavily on the purity of the input material. Chemical recycling, including pyrolysis, allows for the processing of more complex and contaminated plastic streams by breaking down polymers into smaller chemical compounds or raw materials. At the same time, these processes are more energy-intensive and require greater technological capacity and input volume. Therefore, in the modern circular economy, these technologies are viewed as complementary rather than competitive.

Cross-national comparisons show that plastic waste recycling systems vary significantly in terms of both technological level and market size. Germany has emerged as one of Europe's leading examples, where packaging legislation, a deposit system, and extended producer responsibility have created a strong foundation. Although there are several country-specific characteristics, all are united by several key factors, such as relatively low consumer awareness, inadequate collection infrastructure and packaging design, the volume of secondary raw materials diverted to energy recovery, etc.

The analysis highlights following **key takeaways:**

- **Political factors** → Plastic recycling is strongly driven by EU policies (e.g., EPR, packaging regulations, recycling targets), but success depends on effective national implementation and market readiness
- **Economic factors** → Small market size and poor input quality limit investment viability; regional cooperation and improved sorting are essential to strengthen the business case for recycling
- **Social factors** → Consumer behavior is critical; low awareness, convenience barriers, and limited understanding reduce participation and lead to high levels of recyclable waste in mixed streams
- **Technological factors** → Advanced sorting technologies (e.g., optical, infrared, digital solutions) are key to improving efficiency; chemical recycling shows promise for complex plastics but faces cost and scale constraints
- **Legal factors** → Regulations shape demand and market development, but strict requirements (e.g., for food-contact materials) limit the use of recycled plastics and increase the need for traceability and quality assurance
- **Environmental factors** → Mechanical recycling is generally most sustainable but depends on clean input; chemical recycling expands options for complex waste, while overall impact reduction also requires waste prevention and alternative materials

Taken together, these findings demonstrate that plastic waste recycling systems are shaped by a set of interdependent factors rather than isolated challenges. The effectiveness of the system depends on how well policy frameworks, market conditions, technological capabilities, and consumer behavior are aligned.

In summary, the development of an effective plastic waste recycling system requires a holistic and coordinated approach. Achieving circular economy objectives is not solely a matter of technological advancement, but of systemic transformation across the entire value chain.

Building on these insights, the analysis identifies the following policy-oriented recommendations:

- **Adopt an integrated policy approach** → Design and implement coordinated policies that address the entire plastic value chain (production, consumption, collection, recycling, and end-use markets)
- **Strengthen collection and sorting systems** → Invest in infrastructure, set clear quality standards, and introduce regulatory requirements to improve separate collection and reduce contamination
- **Create stable market conditions for secondary materials** → Use economic instruments (e.g., subsidies, tax incentives, green public procurement) to increase demand and competitiveness of recycled plastics
- **Support regional cooperation and market integration** → Facilitate cross-border material flows and align regulations at regional level to enable economies of scale, particularly in smaller markets
- **Promote a balanced technology mix** → Support the development and deployment of both mechanical and chemical recycling through targeted funding, while ensuring materials are directed to the most suitable processes
- **Link infrastructure investment with behavioral measures** → Complement technological investments with policies that incentivize proper sorting and participation (e.g., deposit-return systems, pay-as-you-throw schemes)
- **Enhance public awareness and trust** → Implement national communication strategies, ensure transparency in waste management, and provide feedback mechanisms to increase citizen engagement
- **Ensure regulatory clarity and realistic target-setting** → Harmonize EU and national regulations, reduce inconsistencies, and set achievable interim targets aligned with current technological and market capacities
- **Prioritize material recycling in policy frameworks** → Adjust regulatory and economic conditions to make recycling more attractive than incineration and other lower-value recovery options
- **Embed waste prevention and eco-design in regulation** → Introduce measures that reduce plastic use, promote reuse, and require design-for-recycling to improve long-term system performance

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