



PROBLEMS AND CHALLENGES FACING RECYCLING COMPANIES

MARIN BONCHEV¹, PETRANKA NAYDENOVA-MARINOVA^{2*} AND PETER VELEV²

¹PMB Industries Ltd., 4400, 18 Milyo Voyvoda Str., Pazardzhik, Bulgaria

²Faculty of Chemical Technologies, University of Chemical Technology and Metallurgy, 1756, 8 St. Kliment Ohridski Blvd., Sofia, Bulgaria

*Corresponding author: petrankanaydenovamarinova@gmail.com

ARTICLE INFO

Article History:

Received: 14 January 2026

Revised: 18 June 2026

Accepted: 27 July 2026

Published: 15 September 2026

Keywords:

Circular economy, waste management, sustainability, secondary materials, competitiveness, regulatory requirements

ABSTRACT

This study aimed to identify the key constraints that hinder the efficiency and operational sustainability of waste recycling enterprises. The research used analytical and comparative approaches to assess production dynamics, price indicators, and infrastructure barriers. The results showed significant volatility in the primary polymer market: In 2023, prices for base polymers reached EUR 1,350–1,400 per ton, while in 2020 they were around EUR 900–950. In 2025, prices for secondary materials often matched or exceeded those of primary raw materials: Recycled high-density polyethylene reached EUR 1,170 per ton, recycled low-density polyethylene up to EUR 1,380, and recycled polypropylene up to EUR 1,200. The study found a significant gap between the official recycling rate and actual figures: Individual communities provided only 0–10% of the actual recycling, while the official figure was 50.6%. The study also revealed a lack of national criteria for end-of-waste status, complicating the export of secondary polymers and increasing business costs. The practical significance of the study is that its results make it possible to identify specific regulatory, infrastructure, and economic barriers, the elimination of which will improve the quality of secondary polymers, reduce costs for enterprises, and ensure the competitiveness of Bulgarian recyclers in the European Union market.

© UMT Press

Introduction

Despite the growing importance of polymer recycling in the transition to a circular economy, recycling enterprises in many European countries still face significant technological, regulatory, and economic barriers that limit their efficiency and competitiveness. Understanding these constraints is essential for improving waste management systems and strengthening the role of secondary raw materials in the European market.

The Bulgarian recycling industry plays a key role in shaping the country's environmental policy and fulfilling its obligations to the European Union in waste management. As European countries transition to a circular economy model, the need to increase the efficiency of collection, sorting, and resource

reuse is growing, placing new demands on recycling companies (Zhikeyev *et al.*, 2024). In waste management, discrepancies between regulatory expectations and actual system capacity lead to uneven collection, poor sorting quality, and resource losses. Todorova *et al.* (2025) showed that even cities with similar characteristics achieve very different recycling outcomes due to variations in separate collection, data accuracy, public participation, and technological readiness. Complementary findings by Pozzetto and Leoni (2025) indicate that weak infrastructure, low citizen engagement, high transport costs, and limited incentives for modernisation reduce material recovery efficiency and hinder recycling companies' performance.

Growing waste volumes, uneven collection, and varying recycling performance across regions lead to unstable resource flows, differing enterprise efficiency, and unequal access to infrastructure. Blagoev and Karev (2024) addressed these issues by studying the territorial distribution of enterprises and key economic indicators of recycling companies in the South-Central region of Bulgaria. The authors found significant differences between individual activities: a decrease in the number of waste collection companies, a sharp increase in waste processing structures, significant fluctuations in turnover, a decrease in investment in long-term assets, and different employment dynamics, with collection in decline while recycling operations grow. Resnick (2024) investigated how waste collection and recycling practices are organised in urban environments, focusing on the interaction between official environmental initiatives and the activities of informal collectors. The author showed that Zero Waste programmes rely heavily on the work of people who ensure resource recovery, yet remain excluded from official decisions and face prejudice, unstable access to materials, and spatial constraints.

Insufficient integration of sustainable practices into corporate governance and low employee awareness of sustainable development principles create a situation in which companies struggle to transition to more environmentally friendly models. The issue of implementing such approaches was studied by Dimitrov (2023), who, based on a survey of Bulgarian enterprises, showed that even certified companies demonstrate varying levels of readiness for sustainable transformations, are characterised by limited internal coordination, uneven requirements for suppliers, and insufficient staff participation in the implementation of environmental initiatives.

Low public awareness of circular economy principles and uneven participation across consumer groups in resource reuse processes mean the potential to transition to more efficient waste management models is only

partially realised (Mikhno *et al.*, 2023). A study by Pantcheva (2023) showed that although a significant part of Bulgarian consumers demonstrate environmentally friendly attitudes, most lack information, lack infrastructure for separate collection, and lack adequate incentives for sustainable behavioural change. The author showed that greater environmental responsibility increases readiness for sustainable choices and participation in recycling. At the same time, income plays little role, and women are more inclined to environmental actions than men.

Bulgaria is experiencing increasing difficulties in implementing the National Recovery and Sustainability Plan, which complicates the modernisation of industrial practices and the digital transformation of enterprises. Christova-Balkanska (2024) thoroughly investigated the consequences of an unstable economic environment, low investment efficiency, delays in project implementation, poorly formulated evaluation indicators, and the risk of irrational use of financial resources. The work also emphasises the impact of the energy crisis, inflationary pressure, and structural imbalances that hinder enterprise development and slow the implementation of strategic reforms. The growing volume of solid waste and the limited effectiveness of current management instruments indicate that implementing circular economy principles requires rethinking organisational, technological, and regulatory practices (Burlakovs *et al.*, 2020). Rodrigues *et al.* (2024) showed that recycling outcomes depend on reliable statistical data, process structuring, reducing mixed waste, and public participation, while inconsistent measurement methods and the lack of integrated assessment tools hinder accurate decision-making.

Further research is needed to determine how changes in the organisation of separate collection, the state of infrastructure, price fluctuations, fraction contamination, investment and personnel factors, behavioural aspects, and the role of informal collectors affect the efficiency of recycling systems and the ability of companies to implement circular approaches.

This study aimed to identify the main factors limiting the performance of waste recycling enterprises. The research objectives were to analyse the dynamics of the secondary polymer market in the European Economic Area and to assess price fluctuations for primary and secondary polymers.

Materials and Methods

This study was of a theoretical and practical nature and covered the time frame of 2020–2025, while the period 2026–2031 was analysed through forward-looking assessment of planned regulatory changes, capacity expansion targets and expected market conditions defined in European Union (EU) strategic documents. The theoretical part was based on Eelager *et al.* (2025), which provided a methodological basis for interpreting the role of circular models in polymer processing and identifying the key principles underlying the effective functioning of the secondary raw materials market.

The forward-looking assessment for the period 2026–2031 is based on several key assumptions. First, it assumes the gradual implementation of European regulatory instruments such as the Packaging and Packaging Waste Regulation (PPWR), the Ecodesign for Sustainable Products Regulation (ESPR), and the Digital Waste Shipment System (DIWASS). Second, the analysis assumes continued growth in demand for recycled polymers driven by regulatory requirements for recycled content in packaging and increasing corporate sustainability commitments. Third, the scenarios assume gradual modernisation of sorting and recycling infrastructure in EU member states, supported by public investment and extended producer responsibility mechanisms. While regulatory implementation is highly probable given the legally binding nature of EU directives, the pace of infrastructure modernisation and market adaptation may vary across countries. Therefore, the projections for 2026–2031 should be interpreted as scenario-based estimates rather than precise forecasts.

To analyse the dynamics of secondary polymer development in the EU during 2023–2024, the method of trend analysis and comparative analysis based on data was used (Expert Market Research, 2025; Independent Commodity Intelligence Services, 2025). The analysis examined changes in processing volumes, geographical concentration of capacity, fraction purity levels and supply-demand ratios in the High-density Polyethylene (HDPE), Low-density Polyethylene (LDPE), Linear Low-density Polyethylene (LLDPE), and Polypropylene (PP) markets. This allowed tracing the structural changes that occurred under the influence of regulatory requirements and technological constraints.

The study of trade in secondary materials within the EU and exports to Turkey, the United Kingdom, India, Egypt, and Switzerland used interregional comparative analysis based on Eurostat data (2025). The analysis covered key trade indicators, including export volumes (tons), import-export balance, and changes in the geographical structure of flows. This approach made it possible to reflect the role of external markets in the sale of secondary polymer raw materials, identify dominant export destinations, and assess the EU's strategic dependence on third countries.

Cross-border transportation and implementation of the Digital Waste Shipment System (DIWASS) (DIWASS Implementing Regulation, 2025) were studied using regulatory analysis. The regulatory analysis showed how the digitalisation of processes affected the transparency of logistics chains, the speed of administrative clearance, and the ability to control the movement of secondary raw materials in real time. A retrospective assessment of the preparatory procedures for the full launch of DIWASS in 2026 was also included in this block.

The dynamics of virgin polymer price indicators in 2020–2025 were studied using calculative and comparative analysis based on prices of commodity plastics (Oriordan *et al.*, 2025). The analysis relied on market price

ranges (EUR/ton) for HDPE, LDPE, LLDPE, and PP, reflecting the variability of market quotations for the main virgin polymer grades in Europe. This made it possible to determine how fluctuations within these price intervals affected the competitiveness of the secondary polymer market, as well as to assess the conditions under which secondary materials became more economically profitable.

The problems of the functioning of recycling enterprises in the EU countries, including changes in prices for recycled (r)HDPE, rLDPE, rLLDPE and rPP, were investigated using the case-study method based on Oriordan *et al.* (2025) and R. Ren (2025). The case analysis made it possible to determine which market conditions favoured secondary polymers over virgin analogues in price and which factors (contamination, lack of clean raw materials, lack of quality flows) drove increases in recyclate cost.

Regulatory requirements European Parliament and Council Directive No. 94/62/EC “On Packaging and Packaging Waste” (1994), Regulation (EU) No. 2024/1781 of the European Parliament and of the Council “On Establishing a Framework for the Setting of Ecodesign Requirements for Sustainable Products” (2024), Digital Product Passport (DPP) (Buzeti & Tian, 2025) and End-of-Waste (EoW) criteria (European Commission, 2025) were investigated using the method of comparative legal analysis based on the sources. Comparing the requirements of Germany, France, Italy, the Netherlands, and Bulgaria helped identify regulatory fragmentation and clarify how different approaches to impurity limits, certification procedures, and EoW-status criteria affected cross-border trade in polymer materials. The selection of the analysed EU countries was based on several criteria, including their significant role in the European recycling market, the diversity of regulatory approaches to polymer recycling, and the availability of reliable statistical and analytical data. Germany, France, Italy, and the Netherlands represent countries with advanced recycling systems and

strict regulatory standards, while Bulgaria was selected to illustrate the challenges faced by emerging recycling markets within the EU.

The study investigated the functioning of Bulgarian polymer processors using infrastructure and institutional analysis based on data from Todorović (2025), as well as regulatory analysis based on the Bulgarian EPR (2025). The study assessed the collection and sorting infrastructure, the distribution of capacities between urban and rural communities, the risks of contamination of flows, and the difficulties of applying EU-level regulatory requirements to national practice. Particular attention was paid to the lack of national EoW criteria and the dependence on administrative interpretation of Regulation (EU) No. 2024/1157 of the European Parliament and of the Council “On Shipments of Waste” (2024) across different regions of Bulgaria. The final methodological step involved constructing a matrix of strategic adaptation pathways for Bulgaria, generated using the structural logic modelling method based on Hsu *et al.* (2020) and Paliova (2024). The aim was to identify the steps Bulgaria needs to meet the requirements of the PPWR, ESPR, EoW, and DIWASS in the period 2026–2031.

Results

Functioning of the Secondary Polymers Market in the European Economic Area

The circular economy is based on preserving the value of resources, minimising waste, and returning materials to production cycles through reuse, recovery, and recycling. In contrast to the linear model, in which material flows end at the disposal stage, the circular approach creates closed loops that extend product life cycles and reduce dependence on virgin raw materials. In the polymers sector, this means the need for high-quality separate collection, ensuring the purity of polymer fractions, the ability of companies to work with different types of plastics—primarily HDPE, LDPE, LLDPE, and PP—and the presence of a stable and predictable market for secondary materials (Eelager *et al.*, 2025).

The practical importance of the circular economy in polymer recycling is increasing in 2025, driven by regulatory changes in the EU. The introduction of the European Parliament and Council Directive No. 94/62/EC (1994) has significantly increased the targets for the use of secondary raw materials in packaging, especially for HDPE and PP. To meet these requirements, the European Union needs to expand its solid polymer recycling capacity by at least two million tons by 2030 and an additional 5.7 million tons by 2040, underlining the strategic role of recycled plastics in the transition to a circular economy. At the same time, regulatory efforts aim to improve the quality of secondary raw materials, develop advanced sorting technologies, increase waste collection, and control imports of low-quality materials (Independent Commodity Intelligence Services, 2025).

The development of the secondary polymer market is showing significant dynamics: In 2023, 13.3 million tons of HDPE and PP entered the European market, and 14.64 million tons in 2024, with Spain, Germany, and Italy providing half of the solid HDPE recycling capacity, and PP recycling was concentrated in Germany, the Benelux countries and Spain. The LDPE and LLDPE segments are projected to grow between 2025 and 2031. However, growth is constrained by limited domestic recycling capacity and the introduction of new export bans, including a ban on the export of Recycled Low-density Polyethylene (R-LDPE) to non-Organisation for Economic Cooperation and Development (OECD) countries (from November 2026) (Expert Market Research, 2025).

The importance of circular approaches varies across polymer types. The HDPE market is growing rapidly, driven by increasing demand for rHDPE from the construction sector and packaging manufacturers responding to regulatory requirements and consumer expectations. Companies are investing heavily in technologies to produce bottles and containers with high recycled-material content. LDPE and LLDPE are increasingly needed for flexible

packaging, but their market is experiencing instability due to export restrictions and insufficient recycling in Europe. PP shows high potential for closed-loop recycling, but faces difficulties in producing food-grade recycled PP, which requires improved sorting and recycling of mixed streams. The quality of recycled PP remains a key challenge, as high-tech applications require clean and stable recycled raw materials (High-density polyethylene, 2025).

However, despite market growth, the structure of the European recycling system faces serious challenges. Recycling capacity is growing more slowly than demand for recycled polymers; some companies risk bankruptcy due to high costs and falling margins; and technological limitations in sorting and material contamination remain significant barriers. The EU currently uses less than 10% of recycled plastics in new products, indicating limited integration of circular principles in practice. The geographical concentration of recycling capacity—primarily in Spain, Germany, Italy, and the Benelux countries—creates uneven access to markets, complicates cross-border flows, and determines the pace of development of other countries within the European Economic Area (Amadei *et al.*, 2025).

The movement of secondary raw materials in the European space in 2025 is shaped by a complex system of internal flows, active trade relations, and strict regulatory requirements aimed at expanding circular models. The volume of trade in secondary materials within the EU and between the countries of the European Economic Area (EEA) is growing, which allows reducing dependence on primary raw materials and supporting production chains in the context of the transition to a circular economy. In 2023, the total volume of trade in secondary materials within the EU reached about 40 million tons. In 2024, the main external export destinations were Turkey (12.3 million tons), the United Kingdom (3.8 million tons), India (3.1 million tons), Egypt (1.8 million tons), and Switzerland (1.6 million tons) (Eurostat, 2025). Domestic flows include

active recycling of metals, paper, polymers, and construction waste, but secondary markets remain uneven and fragmented. The main barriers to the movement of materials remain the lack of harmonised technical requirements, varying levels of trust in the quality of secondary raw materials and limited data transparency, which complicates effective decision-making and creates additional transaction costs for market participants (European Environment Agency, 2023).

Logistical factors significantly determine the intensity and direction of secondary raw material flows across Europe. Processing and sorting capacities, infrastructure quality, warehouse availability, and the ability to quickly clean materials determine the cost and speed of material flows (Radkevich & Shipilova, 2019). Regulatory procedures play an important role, as cross-border transport requires classification, documentation, and compliance with environmental standards. From 2026, the implementation of the DIWASS digital system (DIWASS Implementing Regulation, 2025) will completely change procedures for registering intra-EU shipments, ensuring transparency and traceability while reducing the administrative burden. Within logistics, the importance of “digital product passports” and systems for tracking the purity and origin of the material is growing, becoming necessary elements to meet the European Parliament and Council Directive No. 94/62/EC (1994) requirements for transparency and quality of recycled polymers. Economic factors—fluctuations in the prices of primary resources, energy resources, and logistics costs—create regional disparities and influence where material flows are directed (Skorokhod *et al.*, 1994).

The export and import of polymer waste in Europe is increasingly regulated by the WSR, which makes movements dependent on the status of the country—a member of the OECD or not (Dinzhos *et al.*, 2020). Trade with OECD countries is available, but requires prior written approval, detailed documentation, and proof of environmental compliance. Exports to non-OECD countries are permitted only

until November 2026, after verification of their ability to ensure environmentally safe recycling, and will be prohibited thereafter until at least 2029. These requirements reduce Europe’s dependence on external markets and direct secondary polymers to the EU’s domestic markets, stimulating the development of local recycling capacities (Tudball, 2025).

The example of Bulgaria shows how national specificities reinforce common European barriers. The country faces difficulties in selling secondary plastics due to insufficient implementation of EU directives, uneven quality of collection and sorting, limited infrastructure, and difficulties in obtaining documents confirming the quality and status of secondary raw materials. The most acute problem is the inability to export some polymer fractions without granting them “end-of-waste” status, while there is no common EU-level criterion for determining when a material ceases to be considered waste. This creates significant disparities between countries and complicates the movement of secondary raw materials in the EU internal market (Bulgaria EPR, 2025).

The introduction of a ban on R-LDPE exports to non-OECD countries from November 2026 will further change the structure of flows: Significant volumes of this raw material will remain within the EU, which will, on the one hand, increase the availability of the material, and on the other hand, put pressure on processing capacities and require investments in additional cleaning, sorting, and granulation lines. This will strengthen the internal circulation of secondary raw materials but will also increase companies’ requirements for quality and economic sustainability (Tudball, 2025).

In 2020–2025, the primary polymer market in Europe was characterised by high volatility due to the impact of the energy crisis, rising petrochemical raw material costs, geopolitical risks, and changes in EU regulatory requirements within the framework of the transition to a circular economy. The largest price peaks were observed in 2022–2023, when the cost of basic polymers (HDPE, LDPE, LLDPE, PP) reached

five-year highs. In 2024–2025, prices began to decline, but remained higher than pre-crisis levels in 2020. This dynamic directly affects the profitability of processing enterprises, as secondary polymers compete with primary polymers in price and market demand (Table 1).

Analysis of price dynamics shows that in 2020–2025, primary polymers in Europe fluctuated significantly, reaching both historical highs and lows. The lowest prices were recorded in 2020: HDPE and PP fluctuated within ~900 EUR/t, and LDPE and LLDPE ~900–950 EUR/t. The highest indicators were observed in 2023, when HDPE and PP increased to ~1,350–1,400 EUR/t, and LDPE and LLDPE to ~1,200 EUR/t. In 2024–2025, prices decreased somewhat, but never returned to 2020 levels. Such fluctuations directly affect the economic efficiency of polymer recycling. During periods of high primary-material prices, the secondary polymer market becomes more competitive, while declines in primary-material costs make recycling less profitable.

For comparison, secondary markets recorded the following ranges: rHDPE (EUR 930–1,170), rLDPE (EUR 920–1,380), rLLDPE (EUR 850–1,300), and rPP (EUR 990–1,200). Thus, minimum prices were sometimes similar, but maximum levels for secondary polymers often exceeded those of their primary counterparts, especially in the packaging materials segment. Therefore, the gap between price peaks and troughs is a key factor in recycling companies' ability to adapt to market conditions and remain economically viable.

The likelihood that secondary polymer prices will remain competitive relative to virgin polymers depends on several structural factors, including regulatory requirements for recycled content, market demand for sustainable materials, and technological improvements in recycling processes. EU policies promoting circular economy principles are expected to support stable demand for high-quality recyclates. However, fluctuations in energy costs, global petrochemical prices, and the availability of clean waste streams may influence the future competitiveness of secondary materials.

A possible market scenario should also consider situations where the price of virgin polymers falls below the price of secondary materials. In such conditions, recycling enterprises may face reduced competitiveness, as manufacturers may prefer cheaper primary raw materials. This situation may lead to lower demand for recyclates, pressure on recycling margins, and potential underutilisation of recycling capacities. Therefore, maintaining the economic viability of recycling in such scenarios may require regulatory instruments, including minimum recycled content requirements, financial incentives, and strengthened extended producer responsibility mechanisms.

Practical Difficulties of Processing Companies in Europe and the European Union

In 2020–2025, Europe saw a significant increase in the cost of secondary polymers HDPE, LDPE, LLDPE and PP compared to virgin raw materials, which put significant pressure on the business

Table 1: Price ranges for virgin HDPE, LDPE, LLDPE, and PP in Europe in 2020–2025 (EUR/ton)

Year	HDPE	LDPE	LLDPE	PP
2020	~900–1,000	~900–950	~900–950	~900–1,000
2021	~1,000–1,100	~950–1,050	~950–1,050	~1,000–1,100
2022	~1,100–1,300	~1,000–1,150	~1,000–1,150	~1,100–1,300
2023	~1,200–1,350	~1,050–1,200	~1,050–1,200	~1,200–1,400
2024	~1,206–1,339	~980–1,050	~940–1,047	~900–1,200
2025	~930–1,100	~920–1,011	~941–1,047	~939–1,095

Source: Compiled by authors based on prices of commodity plastics (2025)

models of recycling companies. In 2025, rHDPE prices in Germany ranged between EUR 1,060–1,170 per ton, while rLDPE increased by 6.8% in the packaging segment, reaching USD 1,350–1,380 ($\approx$ EUR 1,250–1,280) per ton; in some EU countries, they remained in the range of EUR 920–1,050. rLLDPE showed even greater variability, ranging from EUR 850 to EUR 1,300 depending on purity, availability, and regional demand. rPP prices in the second half of 2025 were EUR 990–1,200, supported by high energy costs and regulatory requirements, including carbon adjustment mechanisms (Polymer Prices, 2025; Ren, 2025).

During the period under review, secondary polymers were recorded as costing more than virgin polymers. In 2025, high-quality rPP and rHDPE grades in Europe and the USA increased in price by GBP 30–50/ton, exceeding the cost of virgin raw materials due to a shortage of high-quality recyclates and increasing demand for durable materials (Russell, 2025). The largest price gaps were observed for recycled Polyethylene Terephthalate (rPET) and rHDPE: In April 2025, rPET exceeded the cost of virgin PET by EUR 686 per ton, and rHDPE by EUR 542. This is due to the limited availability of high-quality waste, increased sorting requirements and a sharp increase in demand from the packaging industry, which must meet the PPWR targets for the share of recycled materials (Oriordan *et al.*, 2025).

The secondary polymer market in Europe is developing amid significant regulatory heterogeneity, exacerbated by the lack of uniform end-of-waste criteria and differences in national quality standards. The entry into force of the PPWR in February 2025 and the phase-in of its requirements from 2026 form a single framework for packaging design and the mandatory share of recycled materials.

The regulation stipulates that by 2030, packaging must be suitable for reuse or high-quality recycling have minimised void space, be free from prohibited substances (in particular heavy metals and per- and Polyfluoroalkyl Substances [PFAS]), and receive harmonised

labelling for consumers. The requirements for recycled content include 30% recycled content for PET packaging, 10% for other contact packaging, and 35% for all other plastic packaging, with further increases until 2040. Although these requirements are pan-European, their implementation across countries shows significant fragmentation of standards. The lack of EU-harmonised EoW criteria for polymers contributes to national regulatory approaches that differ significantly.

Germany sets extremely high requirements for the purity, traceability, and quality of recycled polymers, effectively equating the final parameters with those of virgin materials. France applies similarly stringent criteria, especially for materials that may come into contact with food products, and requires official EoW certification. Italy has introduced detailed tests for chemical purity and full compliance with environmental standards. At the same time, the Netherlands focuses on pollution control and precise traceability of material flows within closed recycling cycles (De Serio & Mossa, 2016). Against this background, Bulgaria has a less detailed and more flexible system of requirements for the purity of secondary polymers, which on the one hand simplifies domestic recycling, but on the other hand creates problems during export, as materials do not always meet the requirements of countries with stricter standards.

Regulatory fragmentation directly complicates the movement of secondary polymers within the single market. In some countries, the material is recognised as a product, while in neighbouring countries it remains legally considered waste, triggering the requirements of the Waste Shipment Regulation and leading to additional procedures, inspections, and costs (Skakov *et al.*, 2025). Differences in purity criteria, requirements for morphological analysis, certification, and evidence of traceability lead to delivery delays, duplicated documentation, and higher logistics costs. In Bulgaria, these regulatory discrepancies are particularly noticeable: Local companies face

difficulties having their materials recognised as non-waste in Western European countries, leading to export delays, lower profitability, and shrinking sales markets (European Commission, 2025).

Together, these disparities undermine the competitiveness of the European recycling industry. Companies face higher costs to adapt their processes to different national standards, uncertainty about market access, and investors postpone modernisation projects because of the lack of predictable regulatory logic. Market fragmentation also increases the EU's dependence on imports of cheaper polymers from less regulated jurisdictions, which reduces the share of domestic production of secondary materials. This is why the European Commission (2025) and the Joint Research Centre (2025) are preparing common European EoW criteria for polymers, designed to reduce administrative barriers, ensure trade stability, and create a level playing field for all market participants.

Regulatory fragmentation in the European Union significantly weakens the competitiveness of the recycling industry and complicates cross-border trade in secondary polymer materials. The “detailed regulation + fragmented implementation” model results in secondary raw materials falling under different requirements depending on the Member State, despite a common European legal area. This creates significant barriers for businesses, especially small and medium-sized ones, which face inconsistent rules, additional costs, and unpredictable administrative procedures (David *et al.*, 2025).

The most problematic countries for the export and import of secondary polymers remain Germany, Spain, and Belgium, where high domestic environmental standards are combined with strict application of national control procedures. Germany has some of the strictest standards regarding polymer purity, impurity content, and compliance of recycled materials with packaging legislation. France and the Netherlands also have increased requirements for certification and testing, while Bulgaria has a

more flexible approach but limited technological and infrastructural capabilities, making it difficult to achieve standards acceptable to Western European markets.

As a result, the same batch of polymers can be considered “secondary raw material” in one country and “waste” in another, automatically triggering the procedures of the Waste Transboundary Movement Regulation and increasing the risks of delays, fines, and additional inspections (Pierri *et al.*, 2024). A key regulatory barrier is the requirement for material traceability, which has been strengthened with the adoption of Regulation (EU) No. 2024/1781 of the European Parliament and of the Council (2024), which introduces the DPP. The DPP requires each batch of polymers to have a unique digital identifier containing complete data on composition, the proportion of secondary raw materials, the presence of hazardous impurities, environmental performance, and recommendations for final disposal. Such passports require integration with national registries, customs databases, and control systems, which vary between countries and increase the administrative burden. Blockchain, IoT, and digital labelling are intended to increase transparency, but for many companies this means a significant increase in the costs of digitalisation and supply-chain auditing (Buzeti & Tian, 2025).

Regulatory differences are exacerbated by different purity criteria and requirements for achieving EoW status. Germany, France, and the Netherlands set high purity thresholds for recycled polymers, effectively equating them to virgin materials, while Bulgaria and some other South-eastern European countries allow higher impurity levels due to limited technological capabilities. The lack of a single EoW criterion for plastics at the EU level creates legal uncertainty: Companies must re-certify for each cross-border movement, and different interpretations of the material's status at customs create risks of shipments being stopped or reclassified as “waste”. The issue of impurities is particularly complex: The more than 13,000

compounds used as additives in plastics—from PFAS to phthalates, Ultraviolet (UV) stabilisers and brominated flame retardants—often make it impossible to achieve the purity required for high-quality recyclates to enter the market (Independent Commodity Intelligence Services, 2025).

Sorting and bringing polymers to a level sufficient for EoW remains one of the biggest challenges. Many waste streams are mixed, contain impurities, multilayer structures, or food contamination, which dramatically reduces the quality of the secondary raw materials (Chernets *et al.*, 2008). Inconsistent separate collection systems, insufficient infrastructure, and varying output-stream quality mean that a significant part of plastic waste never reaches the recycling stage (Paton *et al.*, 2005a, 2005b). Even with optical sorting, Artificial Intelligence (AI) markers, or near-infrared technologies, many small and medium-sized enterprises cannot invest in such systems, widening the gap between countries with developed infrastructure and those with weaker capabilities (European Chemical Regions Network, 2025). The European Parliament and Council Directive No. 94/62/EC (1994) further affects classification and traceability by setting mandatory quotas for secondary raw-material content and requirements for packaging design. PPWR mandates that packaging be designed for recyclability on a large scale, with performance grades (A to D) assessing actual recyclability. From 2030, only packaging with performance grade A or B ($\geq 80\%$ – 95% recyclable) can be placed on the EU market. This classification determines whether materials qualify for recycling streams, affecting how recyclates are classified and accepted.

The increasing regulatory pressure is particularly noticeable “up the chain”, as manufacturers and processors become increasingly demanding of suppliers under the influence of internal quality management procedures. Companies are forced to implement continuous process improvement, which is the basis of ISO 9001:2015 (2015), starting from the collection and pre-sorting stages. In this

context, the role of material purity control, accurate polymer classification, complete batch documentation, and the implementation of digital tools (digital product passports, labelling, blockchain-based proof of origin) is increasing. At the same time, the operating environment is becoming more complicated in terms of occupational safety (Radkevich *et al.*, 2022). The processing industry uses dangerous equipment, which requires constant external auditing and closer attention to the condition of production sites. Even with compliance with occupational safety requirements, “blind spots” often arise that are revealed during third-party inspections. Investments in safer early stages of the process can reduce overall risks and long-term costs.

The greatest uncertainty arises in cross-border transportation. The Regulation (EU) No. 2024/1157 of the European Parliament and of the Council (2024) is interpreted differently not only between countries, but sometimes even between regions of the same country. Errors in preparing transport documents often lead to long delays, fines, additional checks, or even temporary withdrawal of documentation. Individual cases are complicated because the list of “hazardous materials” can change, and goods that did not pose a risk can suddenly fall into stricter categories. This forces exporters and importers to constantly monitor changes and participate in specialised seminars (Kehayova & Anastasova, 2024).

The lack of clarity of standards and guidance documents also creates significant difficulties. Regulatory texts contain numerous cross-references, which give rise to contradictory interpretations and complicate the practical implementation of the rules. Even environmental protection specialists or risk management sometimes make mistakes in determining the necessary procedures, which forces companies to involve external experts to coordinate actions and avoid regulatory violations. At the same time, the industry faces systemic problems typical of most European markets: Contamination of secondary raw materials, insufficient investment

in infrastructure, uneven access to modern sorting technologies, variability of demand for secondary polymers, price instability, and low margins of certain types of processing (Tastemir *et al.*, 2025). A significant problem remains the consumer factor—confusion in sorting rules, low level of awareness, inappropriate behaviour, widespread contamination, and greenwashing phenomena.

Material and market barriers include the complex chemical composition of polymers, the presence of hazardous additives, laminated structures, poor traceability of the material history, degradation of properties during reuse, and competition between mechanical and chemical recycling (Bulatov, 2025). The large differences in the quality of secondary raw materials between EU and EEA countries create obstacles to assigning “End-of-Waste” status, which further complicates trade in secondary polymers. Despite this, the industry is moving toward a 100% reuse model due to increasing consumption, resource depletion, and the need to reduce the EU’s dependence on imported raw materials (Kehayova & Anastasova, 2024). Improving standards, implementing design-oriented solutions, expanding the use of innovative digital tools, developing sorting infrastructure, and the emergence of chemical recycling as a complement to mechanical recycling create the prerequisites for improving the quality of secondary polymers and harmonising the market in the future.

Features of Bulgarian Polymer Processors under EU Regulatory Requirements

Several infrastructural, technological, and regulatory factors shape the national conditions for Bulgarian recycling enterprises and determine the availability of high-quality secondary raw materials, compliance with European requirements, and industry competitiveness. The infrastructure for the collection, sorting, and pre-treatment of plastic waste in Bulgaria has basic elements mainly in cities, where separate collection systems and a number of sorting stations focused on the

separation of PET, Polyethylene (PE) and PP operate. In urban centres, mechanical sorting lines and advanced enterprises such as Integra Plastics AD operate, while in rural communities, much plastic waste ends up in mixed streams due to a lack of infrastructure and low levels of public participation. This creates significant regional disparities, as shown by cases where individual communities report recycling rates of 0–10%, while official averages are around 50.6% (Todorović, 2025).

Bulgaria has an insufficient number of sorting stations and Material Recovery Facilities (MRFs), and the available capacity is often limited to basic mechanical technologies with minimal use of Near-infrared (NIR) or AI sorting. Manual sorting continues to play a significant role, limiting the ability to obtain high-purity secondary materials. Container coverage for separate collection remains low: Estimates suggest the number of containers should be increased by 2.5–3 times to match the actual volume of waste. An additional constraint is the import of plastic waste, which in many cases is more financially advantageous than processing domestic flows (Zero Waste Europe, 2025).

The problems of infrastructural inadequacy are exacerbated by regulatory barriers. Bulgarian legislation is based on the Waste Management Act (2012), which implements the requirements of Directive No. 2008/98/EC of the European Parliament and of the Council “On Waste and Repealing Certain Directives” (2008), as well as provisions on extended producer responsibility. However, the country does not have its own national EoW criteria for plastics, which creates difficulties in entering the EU markets, where significantly stricter standards apply, in particular in Germany, France, and the Netherlands. The uneven interpretation of the norms adds additional difficulties during cross-border movement: The requirements of the European EVOA Regulation can be interpreted differently even within the same country, leading to delays and the risk of fines in the event of the slightest inaccuracies in the documentation.

Growing regulatory pressure is increasing requirements across the entire secondary-materials supply chain. European manufacturers are becoming increasingly demanding regarding polymer quality and increasingly require the implementation of continuous improvement systems in accordance with ISO 9001:2015 (2015). Bulgarian companies must strengthen process management and ensure higher standards of cleanliness, traceability, and occupational safety. A separate problem remains the constant danger of working with sorting and processing equipment; even with occupational health and safety procedures in place, the need for audits and external controls remains high (Pak *et al.*, 2001, 2018).

At the same time, regulatory texts are often overly complex and overloaded with cross-references, increasing the risk of incorrect implementation. Situations where even consultants misinterpret the norms are typical, which affects the accuracy of risk assessment and investment planning. Increasing regulatory complexity is also a significant driver of rising financial costs for businesses: From 2025, Bulgaria will introduce a new product levy on plastic packaging (approximately EUR1.20/kg), along with fines for failing to meet recycling targets and reporting requirements. Producer Responsibility Organisations (RLOG, 2024) must post significant bank guarantees, which limits the system's financial flexibility and increases barriers to entry.

Additional challenges include contamination of plastic streams, the complexity of processing multilayer materials, the presence of hazardous impurities (PFAS, phthalates, dyes, and UV stabilisers), low traceability of chemical composition, and a constant shortage of high-purity raw materials (Mossa, 2006). Under these conditions, Bulgaria cannot yet ensure the production of high-grade or food-grade secondary polymers on a scale comparable to advanced EU countries. In general, Bulgarian processors' operating conditions are shaped by a combination of infrastructural inadequacy, unstable regulatory interpretations, increasing

pressure from European requirements, high compliance costs, and increased competition from more developed EU markets. The progress towards 100% material reuse, declared in Europe, is difficult to implement under the current conditions, which makes it necessary to invest in modern sorting technologies, strengthen the Extended Producer Responsibility (EPR) system, increase transparency, and modernise the infrastructure at the national level (Bulgaria ERP, 2025).

Bulgaria's adaptation to European environmental and technical standards in polymer recycling requires comprehensive modernisation of infrastructure, management processes, and regulatory mechanisms. Current differences between national systems and EU requirements complicate the production of high-quality secondary polymers, limit export opportunities, and increase processor costs. To address these challenges systematically, national policies must be harmonised with European criteria for polymer purity, traceability, and safety. Table 2 reflects Bulgaria's structured adaptation directions by systematising the key barriers, necessary changes, and expected results of harmonisation.

The analysis of the strategic adaptation pathways presented in Table 2 demonstrated that Bulgaria's successful integration into the European secondary polymers market depends on systemic, multi-layered reforms that address both structural weaknesses and regulatory inconsistencies. The country's current position—characterised by fragmented infrastructure, uneven enforcement, and limited technological capacity—creates substantial barriers to meeting the high-purity, high-traceability, and safety standards expected under EU legislation such as PPWR, ESPR, REACH, and the forthcoming harmonised EU-wide End-of-Waste criteria for plastics.

A key element of Bulgaria's adaptation involves transforming its waste management ecosystem from a predominantly low-efficiency model into a technologically advanced, quality-assured recycling chain. Modernisation of

Table 2: Strategic pathways for Bulgaria’s adaptation to EU requirements for secondary polymers

Key Challenge for Bulgaria	EU Requirement/Standard	Required Change in Bulgaria	Expected Outcome
Low quality of input waste streams	High purity standards for polymers under EoW criteria	Introduction of mandatory pre-washing and advanced cleaning systems	Reduced contamination and stable recyclate quality
Limited technological capacity in sorting facilities	Adoption of NIR, AI, and digital watermarking technologies	National modernisation programme for MRFs supported by EU funds	Higher precision in polymer segregation
Weak control over chemical additives and legacy substances	Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) standards for PFAS, phthalates, UV stabilisers and other hazardous chemicals	Establishment of accredited laboratories for polymer composition analysis	Verified chemical safety of secondary raw materials
Strong regional disparities in waste infrastructure	EU requirement for universal access to separate collection	Expansion of collection points in small municipalities	More uniform feedstock quality across regions
Low market transparency	Traceability principles under ESPR and DPP	Development of a national digital monitoring system for polymer flows	Transparent and verifiable waste-to-product chain
Inefficiency of EPR schemes	Reformed EPR rules under PPWR (from 2026)	Revision of fee structures, elimination of free-riders, mandatory audits of PROs	Increased financial capacity of the recycling system
High logistical costs	EU model of cost-efficient waste transportation	Optimisation of transport routes, creation of regional waste-sorting hubs	Lower processing costs and improved competitiveness
Weak regulatory enforcement	EU trend toward harmonised inspection and control	Strengthening inspections and independent audits	More stable and predictable recyclate market
Low public participation in sorting	EU requirement for minimum household engagement	Awareness campaigns and improved convenience of collection services	Cleaner and higher-quality input materials
Competition from waste incineration	EU preference for recycling over energy recovery	Limiting incentives for WtE and prioritising mechanical recycling	Increased volumes of plastics diverted to recycling

Source: Compiled by authors based on Hsu *et al.* (2021), Paliova (2024), and Bulgaria ERP (2025)

sorting facilities through large-scale deployment of NIR and AI-driven systems, combined with the introduction of digital product passports, will enable Bulgaria to meet the strict purity and traceability requirements that define circular-economy markets in Western Europe. Equally critical is establishing accredited laboratories capable of monitoring chemical composition and identifying hazardous legacy substances. In this area, Bulgaria currently lags far behind countries such as Germany and the Netherlands.

However, the large-scale introduction of NIR and AI-based sorting technologies may be constrained by financial, technological and human resource limitations faced by many Bulgarian recycling enterprises. Small and medium-sized companies often lack the investment capacity and specialised technical staff required to implement advanced sorting systems. Therefore, the modernisation of sorting facilities should be considered as a gradual process supported by targeted public funding, training programmes, and cooperation with European technology providers.

Furthermore, harmonising Bulgaria's Extended Producer Responsibility (EPR) model with EU requirements is crucial to building a financially sustainable recycling sector. By eliminating free-riders, strengthening producer audits, and aligning fee modulation with recyclability performance, Bulgaria can secure stable funding for infrastructure development and reduce dependency on imported waste streams. Expansion of separate collection coverage, especially in rural municipalities, will further improve the availability and purity of recyclable plastics, enabling recyclers to meet high-value market standards. Digitalisation plays a particularly strategic role. A national system for tracking polymer flows—from collection to final recyclate—would not only improve regulatory compliance but also increase market confidence and attract investment from European manufacturers seeking certified, traceable secondary materials.

Finally, aligning Bulgaria's policy framework with EU priorities, particularly the shift away from incineration and toward high-quality mechanical and chemical recycling, will strengthen the long-term competitiveness of the domestic recycling industry. By implementing these reforms, Bulgaria can overcome regulatory and infrastructural constraints, reduce market fragmentation, increase the supply of high-quality recyclates, and fully align with evolving EU single-market standards for secondary raw materials.

The practical implementation of these modernisation measures depends on the availability of financial resources, qualified personnel, and institutional capacity. While EU structural funds and green transition programmes may support technological upgrades, limited investment capacity and a shortage of specialised technical staff may slow the modernisation of sorting facilities in Bulgaria. Therefore, implementing these measures requires phased investment strategies, targeted training programmes, and stronger cooperation between government institutions, industry, and academic organisations.

Discussion

Waste management challenges remain among the most challenging for modern economies, encompassing interconnected environmental, technological, and institutional dimensions. The development of circular models depends not only on the availability of effective technologies, but also on how well regulatory requirements are aligned, whether market mechanisms can ensure stable flows of secondary raw materials, and whether incentives exist to modernise production. A comparison of this study with the work of Li *et al.* (2024) showed that although both works analysed problems in waste management, they revealed them in different dimensions. This study, by contrast, revealed the problem through an economic-regulatory lens, focusing not on toxic impacts but on market organisation,

institutional fragmentation, and the lack of controlled flows of raw materials. Despite the difference in focus, both works agreed that any recycling system cannot be effective without clear infrastructure and formalised control.

A further connection appeared in a comparison with Singh and Walker (2024). The authors shifted the discussion to the global level: They criticised the international system of plastic management, highlighted the lack of coordination among regulators, and noted the insufficiency of technological solutions on a global scale. This study partly echoed these findings but was limited to analysing the specific regional context and institutional barriers that shaped the inefficiency of the recycling system at the local level. A similar logic emerged in the comparison with Li *et al.* (2024): the authors also emphasised systemic gaps but focused on toxicological risks, while this study outlined primarily economic, organisational, and technological barriers. In both cases, the issue was the inconsistency of mechanisms and the lack of a coherent policy, but in different projections—ecological and institutional.

A comparison with Krasnikova *et al.* (2025) revealed another layer on market risks. Krasnikova *et al.* (2025) emphasised the pan-European production and logistical challenges, while this study detailed specific national barriers that hindered the development of the Bulgarian processing segment. The study by Song *et al.* (2021) logically continued this discussion, as it focused on the physical and technological aspects such as complex polymer structures, impurities, and low quality of streams. This study combined these observations with an analysis of the infrastructural and regulatory reasons underlying the low technological performance. Similarly, Hou *et al.* (2025) discussed the inefficiency of resource systems within the coal industry, which allowed us to see a broader phenomenon: Technological and managerial gaps inherent in different sectors. This study demonstrated a similar logic, but in the polymer sphere and in the context of regulatory fragmentation.

Gradually, the discussion moved to a more strategic level which is a comparison with Bleischwitz *et al.* (2022). There, the analysis covered the global architecture of the circular economy, while this study showed how these global structural imbalances manifested themselves at the level of an individual European country. Against this background, the work of Nguyen *et al.* (2025) complemented the comparative picture: The authors described imbalances in waste trade between EU countries, while this study recorded how these transnational disparities materialised in the form of local barriers, which from the lack of end-of-waste criteria to price pressure on secondary materials.

A comparative analysis of this study with the work of Deng *et al.* (2024) showed that both works. However, they converged on one key observation: Market fluctuations and regulatory instability became one of the main factors undermining the sustainability of the recycling system. In Deng *et al.* (2024), this was manifested through macroeconomic shocks that reduced investment activity and effectively “froze” the development of secondary markets. This study revealed this problem from another side: Not only economic shocks, but also the blurring of norms, the lack of quality flows, and a significant gap between declared and actual recycling indicators created an environment in which the effective functioning of polymer recycling became unlikely.

Continuing the topic of regulatory instability, a comparison with Sobrino-García (2024) expanded the discussion to management decisions. Sobrino-García (2024) showed that even within a single country, Spain, the effectiveness of the waste management system depended on local administrations’ ability to implement national and European legislation correctly. In this context, the work demonstrated how legal inaccuracies, weak control, or insufficient integration of municipal regulations with EU requirements directly affected practical results. This study extended this view to the level of international asymmetry: The fragmentation

of regulators in Bulgaria and the lack of unified End-of-Waste criteria also demotivated the industry, not at the local level, but at the interstate level. Thus, it was a common problem specifically the imbalance of the regulatory field, but with a different focus: Legal-administrative in Sobrino-García and institutional-market in this study.

Comparison with the work of Lallana *et al.* (2024) deepened this topic, showing that regulatory fragmentation is not only an administrative problem, but also a strategic barrier to the functioning of European extended producer responsibility systems. Lallana *et al.* (2024) highlighted the uneven conditions faced by countries with different levels of political and technological capacity. This study illustrated how such an asymmetry translated into specific Bulgarian realities: Difficulties exporting secondary raw materials, dependence on low-profit local markets, and a lack of incentives for modernisation. Although the emphases differed, both works shared the idea that without uniform rules of the game, implementing a circular economy remains more conceptual than real.

Compared to del P Pablo-Romero *et al.* (2024), this logic was complemented by another dimension: The connection between regulatory changes and their energy and environmental consequences. The authors showed that waste management policies can significantly affect emissions, the burden on energy systems and the resilience of communities. This study did not focus directly on energy aspects. However, the parallel was obvious: In both polymer recycling and general waste management reforms, a lack of clarity and logical interaction between regulations led to weak practical results. This is the commonality in principle, while the difference lies in the subject matter focus.

Comparison with the studies by Anwar *et al.* (2024) and Shahid *et al.* (2024) allowed the discussion to move from the regulatory to the technological level. Anwar *et al.* (2024) emphasised the energy and technological challenges of metallurgical recycling, while Shahid *et al.* presented a similar picture for

multilayer plastics: Technical unsuitability of the material, high process energy intensity, and a lack of viable methods for layer separation. This study, in turn, showed that even where technologies formally exist, their effectiveness is limited by low-quality flows, market fragmentation, and lack of incentives for investment. That is, all three works converged on one thing, which technological solutions only make sense in an environment that supports them economically and institutionally.

The comparative review demonstrated that despite the diversity of approaches—from toxicological and environmental to technological, economic, and regulatory—all the analysed studies converged on one key point: Systemic policy incoherence and institutional fragmentation remained the main barriers to effective waste recycling. Taken together, the analysis confirmed that technological solutions alone are not enough to form a viable recycling model. A holistic institutional architecture is needed that can ensure transparency, stability, and integration of all elements of the system.

Conclusions

The study provides an analytical assessment of the systemic barriers that hinder the efficiency of processing enterprises in Europe and, in particular, in Bulgaria during the period 2020–2025, based on comparative and secondary data analysis. The results indicate that price volatility, uneven infrastructure provision, a fragmented regulatory field, and significant logistical constraints shape the secondary polymer market. The increase in prices for primary polymers in 2022–2023, when HDPE and PP reached 1,350–1,400 EUR/t, and LDPE and LLDPE were about 1,200 EUR/t, increased the competitiveness of secondary raw materials.

However, in 2024–2025, despite a partial decrease in the cost of primary products, prices for secondary materials often remained the same or even higher: rHDPE cost up to 1,170 EUR/t, rLDPE up to 1,380 EUR/t, rLLDPE up to 1,300 EUR/t, and rPP up to 1,200 EUR/t. Combined

with high stream-purity requirements, the dominance of mixed fractions, and rising sorting costs, this puts significant pressure on processors' economic sustainability. The European market in 2023–2024 demonstrated high volumes of secondary raw materials turnover (up to 40 million tons per year), and the main external export destinations such as Turkey (12.3 million tons), the United Kingdom (3.8 million tons), and India (3.1 million tons), confirmed the EU's strategic dependence on third countries.

The introduction of DIWASS in 2026 should reduce administrative barriers, but it will also make it more difficult to comply with traceability and digital documentation requirements. The lack of unified “End-of-Waste” criteria has become one of the most significant barriers in the recycling industry. The high standards of Germany, France, and the Netherlands effectively equate the quality of secondary raw materials with that of primary raw materials, while Bulgaria has more flexible requirements, making it impossible to export a significant share of its products. This is especially critical given the country's structural infrastructural weakness: Real recycling rates in some communities are only 0–10%, while the official rate is 50.6%, and the lack of sorting stations and limited use of NIR technologies create low-quality input flows. The study is limited because it relies only on analytical and comparative data, without direct measurements of polymer-stream quality at enterprises. Future research should conduct empirical assessments of fraction purity, test the technological efficiency of sorting lines, and analyse the impact of harmonised “End-of-Waste” criteria on the possibility of exporting secondary polymers.

Acknowledgements

We would like to thank the journal's editorial team and administrative editors for their professional support, efficient handling, and assistance in processing this article.

Conflict of Interest Statement

The author declares that they have no conflict of interest.

Author Contributions Statement

MB was responsible for the conceptualisation, methodology, and data curation of the study. They also wrote the original draft and contributed to the manuscript's review and editing. PN conducted the research, performed the formal analysis, created visualisations, and contributed to the writing of the original manuscript. PV supervised the research, managed the project, and reviewed and edited the manuscript.

Data Availability Statement

The author declares that they have no conflict of interest.

Declaration of AI-usage

No Artificial Intelligence (AI) tools or technologies were used in the conduct of this research.

References

- Amadei, A., Venturelli, S., & Manfredi, S. (2025). *Plastics materials flows in the EU-27 and their environmental impacts*. Publications Office of the European Union. <https://publications.jrc.ec.europa.eu/repository/handle/JRC142860>
- Anwar, M. A., Suprihatin, N., Sasongko, N. A., Najib, M., & Pranoto, B. (2024). Challenges and prospects of multilayer plastic waste management in several countries: A systematic literature review. *Case Studies in Chemical and Environmental Engineering*, 10, Article 100911. <https://doi.org/10.1016/j.csee.2024.100911>
- Blagoev, D., & Karev, K. (2024). Analysis of the territorial distribution of the companies in the recycling industry in the South-Central region of Bulgaria. In *Industrial Growth*

- Conference 2024* (pp. 60–71). Azbuki. <https://doi.org/10.53656/igc-2024.03>
- Bleischwitz, R., Yang, M., Huang, B., Xu, X., Zhou, J., McDowall, W., Andrews-Speed, P., Liu, Z., & Yong, G. (2022). The circular economy in China: Achievements, challenges and potential implications for decarbonisation. *Resources, Conservation and Recycling*, 183, Article 106350. <https://doi.org/10.1016/j.resconrec.2022.106350>
- Bulatov, N. (2025). Intelligent systems for modelling of a tubular conveyor for collection and sorting solid waste. *Journal of Environmental Accounting and Management*, 13(1), 91–105. <https://doi.org/10.5890/JEAM.2025.03.008>
- Bulgaria EPR. (2025). *Bulgaria EPR guide*. <http://vatcompliance.co/guides/epr/bulgaria-epr-guide/>
- Burlakovs, J., Jani, Y., Kriipsalu, M., Grinfelde, I., Pilecka, J., & Hogland, W. (2020). Implementation of new concepts in waste management in tourist metropolitan areas. *IOP Conference Series: Earth and Environmental Science*, 471(1), Article 012017. <https://doi.org/10.1088/1755-1315/471/1/012017>
- Buzeti, Z., & Tian, D. (2025). *Digital Product Passports (DPPs) required by EU legislation across sectors: ESPR, toys, detergents, batteries, and more*. Circularise. <https://www.circularise.com/blogs/dpps-required-by-eu-legislation-across-sectors>
- Chernets, O. V., Korzyk, V. M., Marynsky, G. S., Petrov, S. V., & Zhovtyansky, V. A. (2008). Electric arc steam plasma conversion of medicine waste and carbon containing materials. In *GD 2008 - 17th International Conference on Gas Discharges and Their Applications* (Vol. 1, pp. 465–468).
- Christova-Balkanska, I. (2024). *Challenges for Bulgarian industry and the National Recovery and Resilience Plan (NRRP) implementation*. https://www.globeco.ro/wp-content/uploads/vol/split/vol_11_no_2/geo_2023_vol11_no2_art_004.pdf
- David, S., Popa, C., Lipowsky, G., & Petrescu, P. (2025). *The competitiveness of the European chemical industry*. Cefic. <https://cefic.org/app/uploads/2025/05/Cefic-Advancy-study-The-Competitiveness-of-the-European-Chemical-Industry.pdf>
- De Serio, F., & Mossa, M. (2016). Environmental monitoring in the Mar Grande basin (Ionian Sea, Southern Italy). *Environmental Science and Pollution Research*, 23(13), 12662–12674. <https://doi.org/10.1007/s11356-015-4814-y>
- del P. Pablo-Romero, M., Sánchez-Braza, A., & Torreblanca, C. (2024). Implementing the circular economy in the European Union and Spain: Links to the low-carbon transition. *Energies*, 17(21), Article 5255. <https://doi.org/10.3390/en17215255>
- Deng, Y., Wu, W., Zhang, X., Li, S., Song, X., & Wang, J. (2024). Overview of China's waste electrical and electronic equipment recycling in the last two decades. *Sustainability*, 16(23), Article 10683. <https://doi.org/10.3390/su162310683>
- Dimitrov, I. (2023). Challenges for the Bulgarian companies in the implementation of sustainability practices. *European Journal of Marketing and Economics*, 6(1), 1–14. <https://doi.org/10.2478/ejme-2023-0001>
- Dinzhos, R., Fialko, N., Prokopov, V., Sherenkovskiy, Y., Meranova, N., Koseva, N., Korzhik, V., Parkhomenko, O., & Zhuravskaya, N. (2020). Identifying the influence of the polymer matrix type on the structure formation of microcomposites when they are filled with copper particles. *Eastern-European Journal of Enterprise Technologies*, 5(6-107), 49–57. <https://doi.org/10.15587/1729-4061.2020.214810>
- DIWASS Implementing Regulation. (2025). *DIWASS implementing regulation*. European Commission. https://environment.ec.europa.eu/document/download/11633156-5fea-4067-8170-212c852a0830_

- en?filename=C_2025_3932_1_EN_ACT_part1_v5.pdf
- Eelager, M. P., Dalbanjan, N. P., Madihalli, S., Madar, M., Agadi, N. P., Korganokar, K., & Kiran, B. (2025). Pathways to a sustainable future: Exploring the synergy between sustainability and circular economy. *Sustainable Futures*, 10, Article 101208. <https://doi.org/10.1016/j.sftr.2025.101208>
- European Chemical Regions Network. (2025). *Advancing plastic recycling in Europe ECRN position paper*. https://ecrn.net/wp-content/uploads/2025/07/Advancing-plastic-recycling-in-Europe_ECRN-2.pdf
- European Commission. (2025). *The efficient functioning of waste markets in the European Union – Legislative and policy options*. https://ec.europa.eu/environment/pdf/waste/studies/waste_market_study.pdf
- European Environment Agency. (2023). *Investigating Europe's secondary raw material markets*. <https://www.eea.europa.eu/en/analysis/publications/investigating-europes-secondary-raw-material>
- European Parliament and Council Directive 2008/98/EC of 19 November 2008 on waste and repealing certain Directives. (2008). *Official Journal of the European Union*, L 312, 3–30. <https://eur-lex.europa.eu/eli/dir/2008/98/oj/eng>
- European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste. (1994). *Official Journal of the European Communities*, L 365, 10–23. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31994L0062>
- European Parliament and Council Regulation (EU) 2024/1157 of 11 April 2024 on shipments of waste. (2024). *Official Journal of the European Union*, L 2024/1157. <https://eur-lex.europa.eu/eli/reg/2024/1157/oj/eng>
- European Parliament and Council Regulation (EU) 2024/1781 of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products. (2024). *Official Journal of the European Union*, L 2024/1781. <https://eur-lex.europa.eu/eli/reg/2024/1781/oj/eng>
- Eurostat. (2025). *Exports of recyclable raw materials decreased in 2024*. <https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20250424-2>
- Expert Market Research. (2025). *Europe high density polyethylene (HDPE) market size and share analysis report: Forecast trends and outlook (2025–2034)*. <https://www.expertmarketresearch.com/reports/europe-high-density-polyethylene-hdpe-market>
- Hou, Y., Xi, S., Li, H., Fan, Y., Li, F., Wen, Q., & Hao, J. (2025). The development of circular economy in China's coal industry: Facing challenges of inefficiency in the waste recycling process. *Sustainability*, 17(18), Article 8147. <https://doi.org/10.3390/su17188147>
- Hsu, W.-T., Domenech, T., & McDowall, W. (2020). How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity. *Cleaner Environmental Systems*, 2, Article 100004. <https://doi.org/10.1016/j.cesys.2020.100004>
- Independent Commodity Intelligence Services. (2025). *HDPE & PP market in Europe*. Plastics Recyclers Europe. <https://www.plasticsrecyclers.eu/wp-content/uploads/2025/04/HDPE-Report-Executive-Summaryv2.pdf>
- International Organization for Standardization. (2015). *Quality management systems — Requirements* (ISO Standard No. 9001:2015). <https://www.iso.org/standard/62085.html>
- Joint Research Centre. (2025). *European Commission Joint Research Centre overview*. https://commission.europa.eu/about/departments-and-executive-agencies/joint-research-centre_en

- Kehayova, A., & Anastasova, D. (2024). *Plastics and packaging laws in Bulgaria*. CMS Expert Guides. <https://cms.law/en/int/expert-guides/plastics-and-packaging-laws/bulgaria>
- Krasnikova, N. O., Krupsky, O. P., Kobylak, D. M., Shepel, M. E., Stasyuk, Y. M., & Kositsyna, O. S. (2025). Impact of the Chinese ban on countries-exporters of plastic waste. *Journal of Chemistry and Technologies*, 33(3), 746–758. <https://doi.org/10.15421/jchemtech.v33i3.335504>
- Lallana, M., Torrubia, J., & Valero, A. (2024). Metals for energy & digital transition in Spain: Demand, recycling and sufficiency alternatives. *Resources, Conservation and Recycling*, 205, Article 107597. <https://doi.org/10.1016/j.resconrec.2024.107597>
- Li, B., Liu, D., Zhang, L., Wu, Y., Ding, X., & Zeng, X. (2024). Challenges of e-waste dismantling in China. *Toxics*, 12(12), Article 867. <https://doi.org/10.3390/toxics12120867>
- Li, Y., Li, X., & Ahmad, F. (2024). Foreign waste ban and green development of Chinese manufacturing industry: Comprehensive evidence based on provincial data. *Heliyon*, 10(19), Article e38589. <https://doi.org/10.1016/j.heliyon.2024.e38589>
- Mikhno, I., Ihnatenko, N., Cherniaiev, O., Vynogradnya, V., Atstaja, D., & Koval, V. (2023). Construction waste recycling in the circular economy model. *IOP Conference Series: Earth and Environmental Science*, 1126(1), Article 012003. <https://doi.org/10.1088/1755-1315/1126/1/012003>
- Mossa, M. (2006). Field measurements and monitoring of wastewater discharge in sea water. *Estuarine, Coastal and Shelf Science*, 68(3-4), 509–514. <https://doi.org/10.1016/j.ecss.2006.03.002>
- Nguyen, T., Van Nguyen, T., Zhou, L., Duong, Q. H., & Ieromonachou, P. (2025). Assessing the impact of EU policies on recycling supply chain: A system dynamics perspective on advancing packaging recycling capacity. *Annals of Operations Research*, 355, 2017–2069. <https://doi.org/10.1007/s10479-024-06438-y>
- Oriordan, F., Ubani, C., Dos Santos, D., & Fiedosiuk, A. (2025). *European recycled polymer prices rise, spreads to virgin widen*. S&P Global Commodity Insights. <https://www.spglobal.com/energy/en/news-research/latest-news/chemicals/050125-european-recycled-polymer-prices-rise-spreads-to-virgin-widen>
- Pak, Y. N., Pak, D. Y., Ponomaryova, M. V., Baizbayev, M. B., & Zhelayeva, N. V. (2018). Radioactivity of coal and its combustion wastes. *Coke and Chemistry*, 61(5), 188–192. <https://doi.org/10.3103/S1068364X1805006X>
- Pak, Y. N., Vdovkin, A. V., & Borodachyov, A. D. (2001). The effect of heterogeneity in gamma-ray albedo analysis of mineral raw materials. *Applied Radiation and Isotopes*, 54(3), 509–517. [https://doi.org/10.1016/S0969-8043\(99\)00264-X](https://doi.org/10.1016/S0969-8043(99)00264-X)
- Paliova, I. (2024). Challenges of Bulgaria's fiscal policy towards green transition in the European Union 2. *Economic Studies*, 33(2), 27–49. https://www.iki.bas.bg/Journals/EconomicStudies/2024/2024-2/2024-02_bodytext.pdf
- Pantcheva, R. (2023). Circular economy awareness in Bulgaria. *Yearbook of the Faculty of Economics and Business Administration, Sofia University*, 22(1), 109–124. <https://www.febsa.uni-sofia.bg/sko/yrbook/Yearbook22-07.pdf>
- Paton, B. E., Chernets, A. V., Marinsky, G. S., Korzhik, V. N., & Petrov, V. S. (2005a). Prospects of using plasma technologies for disposal and recycling of medical and other hazardous waste: Part 2. *Problemy Spetsial'noj Electrometallurgii*, 4, 46–54.
- Paton, B. E., Chernets, A. V., Marinsky, G. S., Korzhik, V. N., & Petrov, V. S. (2005b). Prospects of using plasma technologies

- for disposal and recycling of medical and other hazardous waste: Part 1. *Problemy Spetsial'noj Electrometallurgii*, 3, 49–57.
- Pierrri, E., Egle, L., Milios, L., & Saveyn, H. (2024). *EU-wide end-of-waste criteria for plastic waste*. Publications Office of the European Union. <https://publications.jrc.ec.europa.eu/repository/handle/JRC139303>
- Plastic Portal. (2025a). *Polymer prices – Polymer prices under pressure*. <https://www.plasticportal.eu/news/polymer-prices-polymer-prices-under-pressure>
- Plastic Portal. (2025b). *Prices of commodity plastics*. <https://www.plasticportal.eu/price-reports/2020/8?filterWeek=2020-53>
- Pozzetto, E., & Leoni, L. (2025). Communication of circular economy in the public sector in Bulgaria: A study of space, agenda, language, and tools. *Circular Economy and Sustainability*, 5(6), 5727–5748. <https://doi.org/10.1007/s43615-025-00694-1>
- Radkevich, M., & Shipilova, K. (2019). The processes of accumulation and transport of automobile waste in the city of Tashkent. *Waste Forum*, 3, 211–218.
- Radkevich, M., Shipilova, K., Pochuzhevskiy, O., & Gapirov, A. (2022). Assessment of oxygen concentration reduction near the highway - importance for health and quality of life. *International Journal for Quality Research*, 16(3), 863–876. <https://doi.org/10.24874/IJQR16.03-14>
- Ren, R. (2025). *Polypropylene price per kg in 2025: Trends, forecasts, and market analysis*. Sales Plastics. <https://salesplastics.com/polypropylene-price-per-kg/>
- Resnick, E. (2024). Sustaining containability. *Cultural Anthropology*, 39(2), 217–245. <https://doi.org/10.14506/ca39.2.03>
- RLOG. (2024). *What are Producer Responsibility Organizations (PROs)?* <https://rev-log.com/resource/what-are-producer-responsibility-organisations/>
- Rodrigues, M., Franco, M., Filipova, H., Silva, R. J., Kazandzhieva, V., Nacheva, R., Koleva, V., Lyubenov, L., Oliveira, C., Borges, A. P., Braga, J., Ivanova, P., & Antonova, K. (2024). Profile of urban sustainability in Bulgaria. *Environment, Development and Sustainability*. <https://doi.org/10.1007/s10668-024-05657-4>
- Russell, D. (2025). *Plastristribution's polymer price know-how: February 2025*. PlastikMedia. <https://www.plastikmedia.co.uk/february-2025-price-know-how/>
- Shahid, M. A., Hossain, M. T., Habib, M. A., Islam, S., Sharna, K., Hossain, I., & Limon, M. G. M. (2024). Prospects and challenges of recycling and reusing post-consumer garments: A review. *Cleaner Engineering and Technology*, 19, Article 100744. <https://doi.org/10.1016/j.clet.2024.100744>
- Singh, N., & Walker, T. R. (2024). Plastic recycling: A panacea or environmental pollution problem. *npj Materials Sustainability*, 2(1), Article 17. <https://doi.org/10.1038/s44296-024-00024-w>
- Skakov, M., Bayandinova, M., Kozhakhmetov, Y., & Tuyakbaev, B. (2025). Microstructure and corrosion resistance of composite based on ultra-high molecular weight polyethylene in acidic media. *Coatings*, 15(1), Article 89. <https://doi.org/10.3390/coatings15010089>
- Skorokhod, A. Z., Sviridova, I. S., & Korzhik, V. N. (1994). Structural and mechanical properties of polyethylene terephthalate coatings as affected by mechanical pretreatment of powder in the course of preparation. *Mekhanika Kompozitnykh Materialov*, 30(4), 455–463.
- Sobrino-García, I. (2024). European waste management regulations in Spanish local administrations: Compliance assessment and integration frontiers. *Sustainable Development*, 33(2), 2553–2565. <https://doi.org/10.1002/sd.3258>

- Song, N., McLellan, I., Liu, W., Wang, Z., & Hursthouse, A. (2021). The waste ban in China: What happened next? Assessing the impact of new policies on the waste management sector in China. *Environmental Geochemistry and Health*, 45(4), 1117–1131. <https://doi.org/10.1007/s10653-021-01101-y>
- Tastemir, N., Bulatov, N., & Menendez-Pidal De Navascues, I. (2025). A system for the removal of solid household waste from a multi-storey building. *Proceedings of the Institution of Civil Engineers - Transport*. <https://doi.org/10.1680/jtran.24.00120>
- The Insight Partners. (2025). *High-density polyethylene packaging market report: Trends, forecast and competitive analysis to 2031*. <https://www.theinsightpartners.com/reports/high-density-polyethylene-hdpe-packaging-market>
- Todorova, E., Yunussova, G., Formazyuk, X., Kostadinova-Slaveva, A., Kazkenova, G., & Jetpysbai, G. (2025). Advancing plastic waste management for a circular economy: Comparative insights from Plovdiv (Bulgaria) and Kostanay (Kazakhstan). *Processes*, 13(3), Article 888. <https://doi.org/10.3390/pr13030888>
- Todorović, I. (2025). *Bulgaria's plastic waste recycling rate is much lower than in official statistics, the report reveals*. Balkan Green Energy News. <https://balkangreenenergynews.com/bulgarias-plastic-waste-recycling-rate-much-lower-than-in-official-statistics-report-reveals/>
- Tudball, M. (2025). *INSIGHT: Europe's R-LDPE market facing unpredictable future*. ICIS. <https://www.icis.com/explore/resources/news/2025/03/28/11088211/insight-europe-s-r-ldpe-market-facing-unpredictable-future/>
- Waste Management Act. (2012). Ministry of Environment and Water of Bulgaria. https://www.moew.government.bg/static/media/ups/tiny/%D0%A3%D0%9E%D0%9E%D0%BF/%D0%97%D0%B0%D0%BA%D0%BE%D0%BD%D0%9E%D0%94%D0%90%D0%A2%D0%95%D0%9B%D0%A1%D0%A2%D0%92%D0%9E/WASTE%20MANAGEMENT%20ACT_13.pdf
- Zero Waste Europe. (2025). *Parallel realities: Managing plastic packaging waste in Bulgaria beyond official statistics*. <https://zerowasteurope.eu/library/parallel-realities-managing-plastic-packaging-waste-in-bulgaria-beyond-official-statistics/>
- Zhikeyev, A., Khankelov, T., Irisbekova, M., Sabirova, D., & Muxamedova, N. (2024). Selection of an optimal set of machines for sorting and crushing municipal solid waste. *BIO Web of Conferences*, 130, Article 03015. <https://doi.org/10.1051/bioconf/202413003015>