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ANALYSIS OF CONTEMPORARY SOLUTIONS FOR MINIMIZING PLASTIC POLLUTION DURING 2020–2025 AND IDENTIFICATION OF FUTURE RESEARCH DIRECTIONS

In recent decades, plastic materials have transformed global production, trade, and consumption systems. Their lightness, durability, and low cost have driven exponential growth, with more than 75% of all plastics produced worldwide remaining unrecycled and either landfilled or entering the environment [1]. The period from 2020 to 2025 has become a critical turning point in recognizing the need to adopt modern solutions to minimize plastic pollution. The role of plastics in economies and ecosystems is being redefined, and a new politico-environmental paradigm is emerging, grounded in international agreements, the circular economy, and science-based decision-making.

The universalization of the environmental threat posed by plastic pollution has led to the institutionalization of a global political response. Resolution 5/14, adopted in 2022 during the fifth session of the United Nations Environment Assembly (UNEA), marked the beginning of negotiations on establishing a comprehensive, legally binding plastic treaty. This decision represents a shift from fragmented regulation to managing the full life cycle of polymers, including raw material extraction, production, consumption, disposal, and transboundary waste trade [2].

Developed countries, particularly the European Union, had already established institutional frameworks for managing plastic flows by that time. The Single-Use Plastics Directive (SUPD), which came into force in 2021, became a cornerstone of the EU’s policy to reduce marine litter. Combined with the broader Circular Economy Action Plan (CEAP) and strategies aimed at promoting reuse and recycling, these measures are designed not only to achieve environmental objectives but also to foster the development of a new industrial paradigm.

Outside the EU, national programs have adapted at varying speeds and depths. Canada implemented a complete ban on six key categories of single-use plastics starting in 2022, while India restricted the production and import of non-recyclable plastic products

beginning in 2021. However, differences in resources, institutional readiness, and consumer behavior make the universal implementation of such measures a challenging task.

Despite the rapid development of plastic policies between 2020 and 2025, the effectiveness of the implemented measures remains limited. The primary reason lies in the profound mismatch between the declarative nature of political initiatives and the real conditions of their implementation. This inconsistency manifests both in legislative gaps and in the shortcomings of managerial and institutional mechanisms. As a result, despite the introduction of directives, strategies, and agreements, most countries have failed to achieve a systemic reduction in the plastic burden on the environment.

Firstly, a significant portion of the existing regulations addresses only the most visible aspects of the problem—primarily single-use plastic items such as bags, straws, cutlery, and packaging. However, this approach targets only a limited segment of overall plastic production. It fails to address the issue of secondary microplastics generated during the wear and tear of synthetic textiles, automobile tires, paint coatings, and other sources that fall outside the scope of current legal frameworks. Regulatory acts generally do not incorporate a comprehensive life-cycle analysis of plastics, which leads to the neglect of the most significant sources of pollution.

Secondly, at the global level, there is no universal legal framework that would oblige states to adhere to common standards for plastic management. The UNEA Resolution 5/14 initiated a negotiation process to establish an international plastic treaty; however, as of 2025, this agreement has not yet entered into force. This situation leads to an asymmetry of efforts: developed countries, which have the resources to implement strict regulations, are gradually adopting measures to transition toward a circular economy, while countries of the Global South remain vulnerable. They often become the final destinations for plastic waste re-exported from countries with stricter restrictions.

The third challenge lies in the weak institutional capacity at the level of executive bodies. Even in countries where laws restricting or banning certain types of plastic have been formally adopted, there is often a lack of adequate mechanisms for monitoring, enforcement, and accountability for violations. Examples from Southeast Asia, Latin America, and Eastern Europe demonstrate that such laws are frequently not supported by comprehensive systems of inspections, penalties, reporting, and standardized data on plastic flows [3]. In practice, this often results in partial or merely formal implementation (Table 1).

Conclusions from the table:

• The EU demonstrates the highest level of regulatory maturity and an integrated approach to addressing the issue of plastic waste, with a focus on the life cycle, digitalization, and regional support.

Table 1 – Comparative Table: Regulatory Barriers and Gaps in Plastic Waste Management

Parameter	EU	US	Ukraine
Single-use Plastics Strategy	Full ban on major SUPs since 2021 (Directive (EU) 2019/904)	Absent at the federal level; only in certain states.	Planned adaptation of the SUP Directive within the framework of the EU Association Agreement.
National Circular Economy Strategy	EU-wide, updated within the framework of the Green Deal (CEAP 2020)	No comprehensive strategy.	The first concepts are not institutionalized at the government level.
Microplastics Regulation	The European Chemicals Agency (ECHA) is preparing additional restrictions	Limited to voluntary standards (e.g., cosmetics).	No regulatory definition of microplastics.
Extended Producer Responsibility (EPR) System	Mandatory for packaging, electronics, tires, and other sectors	Voluntary, partially regulated by the EPA.	Introduced in 2023 for packaging, but with a low level of implementation.
Bioplastics Labeling	Unified European standards EN 13432 have been introduced	No mandatory requirements.	No unified criteria.
Control of Plastic Waste Export/Import	Export ban to non-OECD countries (in accordance with the Basel Convention)	Partial control with many loopholes.	Export-import is almost unregulated.
Coverage of Rural Areas by Policy Measures	A high level of coverage and financing is provided through EU funds.	Uneven: regulation mainly in urban areas.	Lack of coverage in rural areas and small towns.
Plastic Flow Accounting Platforms	A unified digital portal (EU Waste Tracking) is under development	Decentralized, mostly for industrial waste.	No national platforms.
Science-Policy Integration	A high effectiveness supported by funding from Horizon Europe and the Joint Research Centre (JRC)	Weak integration of science into policy.	Fragmented; research does not directly influence policy.

• The United States operates in a fragmented manner, with inconsistencies at the federal level, but has high development potential due to its strong scientific base and private sector.

• Ukraine is at the stage of legislative transformation under the influence of European integration commitments, but currently lacks a systematic implementation of key instruments.

An additional aspect of regulatory inconsistency lies in the technical and methodological fragmentation regarding labeling, standardization, and classification of plastics. The absence of harmonized definitions for “biodegradable” or “compostable” plastics complicates both their proper application and their monitoring. Companies frequently employ marketing terms without sufficient scientific evidence, which leads to “greenwashing” and undermines consumer trust in environmental initiatives.

The problem is further exacerbated by the insufficient consideration of economic incentives and behavioral mechanisms. In many countries, plastic remains economically advantageous for both producers and consumers since real environmental costs are not incorporated into the market price. Tax measures or subsidies for alternative materials are either absent or remain in their early stages of development. As a result, the adoption of sustainable alternatives is progressing extremely slowly.

Finally, there is a noticeable gap between academic knowledge and policy practice. While research in microplastic toxicology, circular economy, life cycle assessment (LCA), and behavioral economics demonstrates the complex and multidimensional nature of the issue, most regulatory initiatives are limited to narrowly focused measures. Scientific evidence is often not fully integrated into the decision-making process, and policymaking rarely involves comprehensive risk assessments, evaluations of environmental and economic scenarios, or predictive modeling.

Thus, at the current stage, the fight against plastic pollution remains largely declarative, particularly in countries with limited resources and weak governance infrastructure. Transitioning to an effective system of sustainable plastic management requires not merely revising certain legislative provisions but implementing a profound institutional reform. This reform must be grounded in science, transparency, and international coordination while also taking into account cultural, economic, and technological differences between countries and regions.

There is a significant lack of scientific support for decision-making. Life cycle assessment (LCA) strategies, when compared with alternative materials such as PLA, PHA, or cellulose composites, provide ambiguous results. Meta-analyses indicate that bioplastics can outperform conventional plastics in terms of greenhouse gas emissions and freshwater

consumption, particularly at the stages of raw material cultivation and composting under unsuitable conditions.

The toxicology of microplastics and nanoplastics remains the least studied area. Experimental data show bioaccumulation of particles in the lung, liver, and lymphatic tissues; however, the mechanisms affecting genetic expression and endocrine regulation remain unknown. Some studies suggest a possible association between inhalation of microplastics and chronic inflammatory diseases, yet causative links have not been confirmed.

An equally important area remains the behavioral and cultural barriers to transitioning toward a plastic-free economy. Consumers in most countries show limited responsiveness to initiatives aimed at reducing single-use packaging, even when they are aware of the environmental risks. This necessitates the implementation of new models of social governance — from green nudging to the introduction of deposit-return systems.

A key challenge for the next stage is transforming the fragmented regulatory environment into a synchronized multi-level mechanism. This includes developing a global agreement with a unified reporting standard, as well as supporting countries with low institutional readiness through “plastic transition justice” mechanisms. Particular attention should be given to the informal sector, which accounts for up to 60% of recycling in Global South countries but remains excluded from formal policymaking processes.

Simultaneously, a transition from product bans to systemic economic transformation is necessary. This can be achieved through the creation of “green ecosystems” for recycling, subsidies for innovative materials, and the digitalization of plastic flows, utilizing artificial intelligence (AI), the Internet of Things (IoT), and blockchain technologies for tracking, assessing, and optimizing the life cycle.

The period from 2020 to 2025 represents a critical stage in shaping a new environmental and managerial paradigm to combat plastic pollution. The adoption of several precedent-setting policy decisions at the global level, including the launch of negotiations on a legally binding international agreement, demonstrates growing global awareness of the issue. At the same time, there are significant discrepancies in the effectiveness of policy measures at the regional and national levels, highlighting the need for deeper coordination and the universalization of approaches to plastic life cycle management.

Despite the significant expansion of legal frameworks and the introduction of circular economy principles, a persistent gap remains between declared objectives and actual environmental outcomes. This gap is driven by a complex set of factors, with key issues including institutional constraints, fragmented inter-agency coordination, insufficient

integration of scientific data into policymaking processes, and sociocultural barriers that slow down changes in consumption patterns. A critical problem lies in the fact that national strategies are predominantly focused on regulating a limited range of plastic products, while issues such as microplastics, illegal waste trade, bioplastic management, and innovative alternative materials remain largely outside a comprehensive political agenda.

Furthermore, many countries lack effective mechanisms for monitoring and evaluating the impact of implemented environmental policies, resulting in limited transparency and low accountability of responsible authorities. An additional contributor to this gap is the insufficient level of business incentives to transition toward environmentally sustainable production models, including systems of reuse, packaging reduction, and the adoption of biodegradable materials. Sociocultural factors, such as low public awareness of environmental issues, weak motivation to sort waste, and limited access to recycling infrastructure, further exacerbate the problem.

As a result, even in the presence of large-scale regulatory initiatives, the actual environmental impact remains limited. To bridge this gap, it is essential to implement integrated approaches that combine scientific research, innovative technologies, economic incentives, and educational programs for society. Only the systemic alignment of environmental, economic, and social policies can ensure the effective implementation of circular economy principles and the achievement of established environmental pollution reduction goals.

A key condition for success is the ability to build long-term political will aimed not at temporary bans but at institutional and cultural transformations. In particular, this involves the need to transform the entire production–consumption logic toward systemic sustainability — from packaging and material design to shaping a culture of waste management. Effective strategies cannot be imposed externally; they must be developed with consideration of the national context while remaining aligned with international commitments and scientific standards.

Thus, the fight against plastic pollution becomes an indicator of the maturity of environmental governance and the capacity of states and companies to build future development scenarios based on the principles of sustainability.

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