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Navigating regulatory complexities: Challenges and shifting problem framings in turning microplastics into a European policy object

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Research Article

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Abstract

Microplastics are widely discussed as a pervasive environmental issue, yet decisive action and turning them into a governable "policy object" has proven to be slow and challenging. This paper investigates the shifting and heterogeneous problem framings of microplastic pollution and the regulatory complexities that emerge from them. Drawing on research from science and technology studies, we analyze how microplastics remained "hidden in plain sight" for decades, obscured by limited scientific standardization, competing problematizations, debates over scientific evidence, widespread cultural imaginaries and economic interests. The research reveals that the path from scientific knowledge to policy action is not linear but a process of co-production, where public concern, scientific capabilities and political agendas continuously reshape one another. We trace the evolution of the issue – from marine pollution to other media, human health and now nanoplastics – highlighting how each shift opens up new questions posing new (regulatory) challenges. The findings demonstrate that effective environmental governance requires more than data; it demands a critical understanding of the complex innovation pathways that produce such residues. We conclude that durable solutions require extended infrastructures of responsibility and care and the development of adaptive institutional frameworks capable of navigating scientific uncertainty and contested values.

Impact statement

Microplastic pollution is not only a scientific challenge but also a social and political one. This paper examines the evolving interplay between scientific evidence, public concern and European regulatory action. Tracing how microplastics moved from a peripheral observation to a central environmental issue, we show how sociotechnical processes, instruments, standards, economic interests and regulatory institutions co-constitute the problem itself – shaping which interventions become possible and which remain out of reach. By mapping the dynamic relationships among innovation logics, societal framings, scientific research, policymaking and environmental challenges, the study seeks to support better alignment among scientists, regulators and stakeholders in measurement, mitigation and governance. The broader contribution is twofold. First, the article offers a framework for understanding science–policy relations beyond the linear model in which science delivers neutral "facts" (often labeled evidence) and policymakers act upon them. It demonstrates that accumulating more data is insufficient without addressing the social and political forces that determine which evidence is produced, recognized and translated into action that are deemed plausible and feasible. Second, the study provides lessons for governing future innovations within the plastic domain (e.g., replacement materials) and beyond. By foregrounding the innovation residues and their long-term consequences, it argues for more anticipatory and residue-aware innovation pathways, ones that embed responsibility, longitudinal monitoring and adaptive governance from the outset, so that today's solutions do not become tomorrow's persistent problems.

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In September 2024, the fifth MICRO conference gathered on Lanzarote "to celebrate the growing community of researchers and policy-makers concerned about the challenge of Plastic Pollution from macro to nano." It felt like a genuine commons: hallway debates, packed poster sessions, and a shared declaration of purpose – "the challenge of plastic pollution." But what, exactly, was this challenge?

As we moved between talks and posters, a feeling of tension started to settle in. The singular, global problem fractured into a thousand situated objects. Quantifications of microfibers in Italian glaciers stood beside studies on the effects of nanoplastics on aquatic plants and polymer biodegradation in soils. Methods for polymer biodegradation in soils shared a space with airborne particle counts and human biomonitoring. Microplastics were not one object but many – translated through disciplinary vernaculars, sampling protocols, analytical pipelines, and case-based worlds. The problem was framed as planetary; the practices that made it visible remained more local, methodologically diverse, and often incommensurable.

This profusion feels like a strength – an expanding evidence base and repertoire of concerns across soils, air, freshwaters, oceans, and bodies. Yet it exposes a central governance puzzle: how do we connect, link, and scale heterogeneous knowledges so that they travel beyond laboratories and conference halls – toward standards, regulation, and public action? MICRO24 left us with a productive unease: a shared vision paired with fragmented data and practices. The task ahead is translation – turning this impressive, emergent archive of knowledge into coherent, durable political action.

(vignette from field notes)

Introduction

It is safe to say that, certainly in Europe, we live in innovation societies: environments saturated with the imperative to foster, accelerate and incubate novelty in the name of economic growth and, by extension, assumed societal benefits and promising futures (Felt, 2015; Pfotenhauer et al., 2019). These innovation trajectories are not immaterial; they are underpinned by extractive political economies, most notably fossil fuel infrastructures, and shaped by competitiveness logics and industry influence. Plastics once stood as the emblem of such an innovation. Derived from petrochemical feedstocks, they were marketed as resource-saving, hygienic, bright and democratizing – materials that, cheaply accessible to everyone, would modernize everyday life across various sectors, including packaging, medicine, construction and electronics (Meikle, 1995; Davis, 2022; Strasser, 2000; Dennis, 2024). Over time, they became so deeply woven into daily routines that life without them became hard to imagine (Roberts, 2010).

The case of microplastics makes a simple point clear: innovations do not arrive alone; they bring residues with them. Extending Boudia et al.'s (2022) work on chemical residues, we conceptualize the material, infrastructural, epistemic and regulatory traces generated by dominant innovation regimes as innovation residues – traces that endure beyond celebrated achievements and continue to shape social–ecological futures long after production, use, or disposal of the respective innovation (Felt, 2021, 2025). In the plastics domain, these residues include microplastics and chemical additives that not only accumulate in soils, waters, air, bodies and supply chains but also entrench modes of knowing and governing that constrain ways of thinking (Geyer et al., 2017; Thompson et al., 2024). Plastic residues are generated across the entire life cycle – from extraction and manufacturing to logistics, consumption and disposal – yet often remain unnoticed or unproblematic. This is not simple absence but structured inattention (Zerubavel, 2015). Residues slip through measurement limits, regulatory categories and testing protocols, and become normalized in everyday routines (Gabrys et al., 2013). They are shaped by "regimes of (im) perceptibility" (Murphy, 2006): historically specific configurations of instruments, standards, disciplinary practices and thresholds that render some phenomena actionable while leaving others below concern.

What is not measured is often not socially seen. Following Zerubavel (2015), microplastics remained "hidden in plain sight" for decades – not because unknown but because prevailing sociocultural conventions of attention, scientific priorities and regulatory framings did not mark them as salient. Pollution, harm and evidence were structured in ways that made diffuse fragmentation difficult to register as urgent. Microplastics have thus only gradually become recognized as a pervasive environmental concern, and their transformation into a governable "policy object" has been contested. Indeed, although first identified in the 1970s (Carpenter and Smith, 1972), the European Commission initiated its first regulatory measure only in 2023, banning "intentionally added microplastics" under REACH (European Commission, 2023b). Drawing on science and technology studies (STS), this paper analyses how shifting regimes of perceptibility – through evolving measurement techniques, standardization efforts, evidentiary debates, public concern and political agendas – gradually reconfigured microplastics from background residue to regulatory target. The movement from scientific knowledge to policy action, however, is neither linear nor automatic but co-produced through changing ways of seeing, knowing, caring and governing.

Tracing the issue's evolution – from marine pollution to other environmental media, human health and more recently nanoplastics – we show how each shift opens new questions while generating fresh regulatory dilemmas. Effective environmental governance, our findings suggest, requires more than accumulating data; it demands engagement with the innovation pathways and political–economic structures that generate plastic residues. Durable responses will not emerge from isolated downstream interventions but from extended infrastructures of responsibility and care, alongside adaptive institutional frameworks capable of navigating uncertainty and contested values.

Our guiding questions are pragmatic and aim at policy relevance: How did microplastics become a scientific, public or institutional concern? How could they remain a marginal issue for so long, despite early evidence? How do facts and concerns evolve together in making microplastics actionable? By which devices – methods, labels, standards and imaginaries – are plastic residues made visible or rendered invisible? And how do these processes enable or constrain effective regulation and stewardship? Together, these questions allow us to reflect on what we can learn from microplastic's history.

Material and method

The paper is grounded in STS, a field concerned with how science, technology and society are entangled and how these relations are governed (Felt and Irwin, 2024), including questions of responsibility (Felt, 2025). Methodologically, we adopt a comparative assemblage ethnography approach (Felt, 2021), working qualitatively and interpretively – through interviews, ethnographic fieldwork and document analysis – empirically tracing shifting articulations and problem framings of microplastics across scientific, public and policy arenas. We do not treat microplastics as a fixed entity awaiting discovery but as continuously constituted, partially stabilized and reassembled through practices across heterogeneous sites, actors,

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disciplines and institutions (DeLanda, 2016; Wahlberg, 2022; Ghoddousi and Page, 2020).

This approach implies methodological partiality. Like all research, we foreground certain dynamics while sidelining others, follow microplastics into selected sites, and draw boundaries around particular actors. Rather than offering a singular explanation, we emphasize the processual and contingent character of microplastics. The issue cannot be reduced to a linear, clearly compartimentalized narrative of scientific discovery, cultural (in)attentiveness, economic interests, or regulatory efforts. Instead, it requires attention to how scientific, political and social processes come together and are co-produced in distinct ways (Jasanoff, 2005).

The analysis is based on 2 years of fieldwork (2023–2025) within a larger project on innovation residues. It comprises ethnographic observations (online and in person) at 10 conferences, webinars and workshops (e.g., UNESCO Limnoplast conference 2023; MICRO24; Plastics Europe Microplastics Workshop 2025). This provided valuable insights into the diversity of actors, disciplines and interests that gather around microplastics (e.g., Koch, 2023). Analysis of key scientific publications, combined with interviews (they were recorded and transcribed with participants' informed consent) with researchers in oceanography, geology, toxicology and medicine (20 interviews) enabled us to trace the stabilization of microplastics research as a field, following shifting classifications, research questions and understandings of harm as the issue moved from a marginal concern within marine science to a rapidly expanding interdisciplinary domain. Finally, we examined European regulatory developments through document analysis (Asdal, 2015) of expert reports, communications, green papers and policy texts, complemented by interviews with policymakers, to analyze how emerging scientific knowledge is translated into regulatory contexts and what work is required to transform microplastics into a policy object (Mathies, 2025). Sampling followed a grounded theory approach and theoretical sampling (Charmaz, 2006), meaning that data collection and analysis proceeded iteratively rather than according to a predefined sample. Emerging questions guided further interviews and document selection until theoretical saturation was reached.

Bringing these materials together allows us to examine how value, responsibility and stewardship are negotiated across sites: which harms are rendered measurable, which thresholds – such as detection thresholds (what is made visible and counted) and toxicological exposure thresholds (what is deemed harmful to bodies and ecosystems) – matter, and whose expertise is recognized. Our aim is both empirical and conceptual: to develop framings that support residue-aware innovation pathways in which responsibility is addressed early and throughout innovation processes rather than retrofitted later.

In what follows, we map the shifting relations among innovation logics, societal framings, scientific research, policymaking and environmental challenges in the microplastics arena. We proceed in four steps: first, examining how microplastics remained largely unnoticed; second, tracing the co-evolution of facts, concerns and care; third, analyzing changing problem framings; and finally, showing what it takes to render microplastics governable.

Results and discussion

Hidden in plain sight: Failing to fully acknowledge the problem of plastics' microscopic residues

It was in 1972 when Italo Calvino published his iconic book "Invisible cities" (Calvino, 1974 [1972]). He reflects therein our lives with waste in urban regions, pointing us to the ways in which we deal with consumption and waste as well as to what he describes as "talent for making new materials excel." Yet as materials improve, so does "the rubbish": it "resists time, the elements, fermentations, and combustions." In the end, we create "a fortress of indestructible leftovers." Calvino's image crystallizes a modern cultural script: progress as daily purge, throwing away the innovations of yesterday, ingenuity that hardens even rubbish, and a past that persists as residue. It offers a fitting prolog to the story of microplastics. For decades, we reconfigured the material world while preserving it in its most durable form – tiny, heterogeneous plastic particles of various chemical compositions, shapes, sizes and origins diffused through soils, waters, air and bodies. Added to cosmetics, shedding from clothing and car tires, or degrading from plastics litter: micro- and nanoplastics are, in retrospective unsurprisingly, the ubiquitous residues of a world enabled by plastics. In what follows, we trace how these residues could remain "hidden in plain sight" (Zerubavel, 2015): not absent, but overlooked because our instruments, categories, epistemic priorities, economic interests, cultural scripts and routines were primed to look past them, even as residues thickened every day.

In the same year that oceanographers Carpenter and Smith (1972, 1241) reported "small plastic particles" on the surface of the western Sargasso Sea, warning that "the increasing production of plastics, combined with present waste disposal practices, will probably lead to greater concentrations on the sea surface." Culturally and scientifically, the coordinates were set: durable materials, combined with a linear "throw-away" society, yield durable residues. How, given these early signals, did microplastics successfully remain marginal and continue to accumulate? The answer lies in socially produced invisibility: things observable yet collectively ignored because attention is trained by shared frames and taboos. Through what Zerubavel (2015) calls optical socialization, we construct "islands of relevance," fencing off other facts as irrelevant. The unseen is not secret but deemed unimportant – until categories or measures shift.

Intertwined dynamics – recounted in interviews, conference narratives and scholarly accounts – help explain why early signals did not spur action. First was measurement. Early observations were episodic, methods unstandardized and particles microscopic – hard to detect and quantify (Ryan, 2015; Schmid et al., 2021). The result was evidentiary fragility: findings were notable but not cumulative, and thus easy to discount. Decades later, calls for harmonized definitions, reference materials, sampling, analytics and interlaboratory comparisons show how much metrological work remains (Hartmann et al., 2019).

Framing was equally decisive. Plastic pollution was cast mainly as litter – a matter of consumer behavior, civic tidiness and downstream waste management. This individualized responsibility and narrowed policy imagination focused on clean-ups and recycling, even as production volumes increased (Liboiron, 2014; MacBride, 2019). Importantly, it obscured that residues are generated during production, use and recycling and proliferate even when litter is addressed.

Meanwhile, regulatory time, so the time needed to trigger regulatory concerns and related decisions, did not align with industrial production and distribution times. Polymer families, additives and (single-use) plastic products proliferated faster than standards, toxicology and exposure studies; mixture effects and chronic, low-dose pathways take years to evidence. Without agreed hazard thresholds for myriad particles and additives, precaution was deferred or deemed premature (Vogel, 2009, 2012).

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Political economy reinforced the drift. Plastics underwrote jobs, logistics, export balances, consumer price stability and national competitiveness (Hawkins, 2018). "Recycling" and circularity narratives reassured publics yet often left primary resin production untouched – what Mah (2021, 2022) calls a political economy of permanent plastics (see also Geyer et al., 2017; Villarrubia-Gómez et al., 2023). And infrastructures of forgetting moved residues out of sight: exports, distant landfills and incineration that transforms solids into invisible atmospheric stocks. Such systems distribute waste and desensitize publics to harm, a pattern long noted in infrastructure studies as black-boxing and displacement (Star and Ruhleder, 1996).

Affordance and habit entrenched dependence. Plastics' virtues – lightness, sterility and flexibility – made daily life smoother across medicine, packaging and logistics (Davis, 2019). Convenience hardened into a moral economy: when benefits are widespread, structural change feels like self-harm, raising switching costs and reinforcing lock-in. Together, these forces produced a form of managed non-knowledge: enough awareness to register concern, never enough to disrupt the trajectory (Proctor and Schiebinger, 2008). Categories like "marine litter," detection thresholds, life-cycle spreadsheets and recycling symbols stabilized a sense of control – even as microplastics accumulated across environments and bodies, from ocean gyres to soils and airsheds, from fisheries to placentas.

These dynamics intersected with funding politics that marginalized microplastics research. Interviewees repeatedly noted that early inquiries were considered "irrelevant" because "other environmental issues were more prominent." Edward Carpenter (2022, 107) similarly recalls: "it was clear to me in 1972 […] that I could not build a career on plastic pollution, so I turned my attention to other topics."

Returning to 1972 is thus diagnostic rather than nostalgic. Calvino (1974 [1972]) names the cultural script – renewal through disposability that preserves itself as residue; Carpenter and Smith (1972) provide the empirical footnote – small fragments already present, likely to grow; policy and industry supply buffering narratives – individual responsibility and end-of-pipe fixes. Two lessons follow. First, early warnings fail less because signals are weak than because infrastructures, interests and imaginaries are strong. Second, a different plastics future requires attending to the full innovation trajectory: reframing responsibility to include design, resources, materials and production, and redesigning innovation so residues become constraints – not afterthoughts – that shape what is possible from the outset (Felt, 2025).

Between facts, concerns and care: The co-production of science, publics and politics

At MICRO24, as in many other settings of engagement, discussion repeatedly moved through a familiar sequence – facts and data, rising concerns and calls for intervention or regulation. This is often cast as a pipeline: what we know (matters of fact) leads to questions of who is impacted and who should thus be concerned (matters of concern), which in turn justifies how we should engage with the world around us (matters of care). STS scholarship shows, however, that this order is rarely linear. Concerns routinely precede and reshape the production of facts: public anxiety, activist scrutiny, or regulatory attention reconfigure what will count as evidence by prompting new measurements, revised thresholds and different sampling strategies (Jasanoff, 2004; Latour, 2004; Marres, 2007; Münster and Felt, under review). In microplastics specifically, several authors have noted that policy debate has often outpaced consolidated toxicological certainty, raising legitimate questions by scientists and policymakers about how to act under uncertainty and incomplete knowledge (e.g., Burton, 2017; Koelmans et al., 2019; Backhaus and Wagner, 2020). In other words, concern calls for care and co-produces the kinds of facts on which decisions later rest (Jasanoff, 1990; Funtowicz and Ravetz, 1993; Jasanoff, 2004; Puig de la Bellacasa, 2011; Puig de la Bellacasa, 2017).

This dynamic surfaces practical questions: when, where and for whom does an issue become a matter of concern, and what investments in care – standards, monitoring, regulation – follow? Speaking to scientists and policymakers, we encountered recurrent disputes over which microplastics/sources of microplastics warrant regulation, which metrics are credible, and what levels of evidence should trigger action. These frictions reflect clashing value judgments and disciplinary commitments, as well as the politics of measurement: what one method detects, another may miss; what is feasible for one sector may be prohibitive for another (Pine and Liboiron, 2015; Murphy, 2006). The resultant boundary work – between science and policy, toxicology and ecology, precaution and proof – is performed by people and institutions that translate across worlds (Gieryn, 1983; Guston, 2001). Meanwhile, the infrastructures of evidence – reference materials, interlaboratory trials, categories and thresholds – do quiet but decisive work in stabilizing what will be seen and acted upon (Bowker and Star, 1999; Lampland and Star, 2009).

Recognizing the co-production of facts, concerns and care is not a recipe for paralysis; it is a way to clarify decision-making. It foregrounds the normative and infrastructural labor required to move from evidence to action. It helps explain why regulatory pathways around microplastics are (and should be) necessarily iterative, contested and adaptive. In practice, this suggests combining post-normal science approaches (explicit uncertainty appraisal, extended peer communities) with precautionary yet proportionate measures, iterative standard-setting and participatory monitoring – so that knowledge and governance can be jointly steered as evidence accumulates (Funtowicz and Ravetz, 1993; Stirling, 2010).

Shifting problematizations of microplastics and issue framings

Microplastics research deals with a moving target: as methods, sites and concerns evolve, the object itself is remade, with direct consequences for monitoring and regulation. Analyzing the history of microplastics research through scientific publications, we observed three shifts that we find especially instructive.

First, attention has moved beyond marine sinks toward tracing plastics across freshwater, air and soils. As Wagner and Lambert (2018) noted, early work treated rivers and lakes largely as conduits to the sea – "similar to a sewer" – with less than 4% of publications focusing on freshwaters at the time. Reframing waters, airsheds and soils as sources and sinks rather than mere pathways immediately redirects and prioritizes what needs to be measured (fluxes, residence times, transformation processes) and where standards should be introduced. It also multiplies scales and interfaces – stormwater overflows, wastewater effluent, agricultural amendments and urban dust – forcing coordination across environmental compartments (Vithanage and Prasad, 2023).

Second, a late turn to human health has shifted the problem from "where do particles go?" to "what might they do in or to human bodies?." For a long time, concern clustered around ecological impacts, chemical leeching and occupational fibers; only in the last decade has biomedical uptake accelerated, with studies

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mapping presence and pathways in tissues (e.g., lungs, placenta, blood) while mechanisms and outcomes – dose–response, toxicodynamics and life-course effects – remain comparatively underdetermined (Koelmans et al., 2019; Vethaak and Legler, 2021; WHO, 2022). As everyday human exposure becomes thinkable, the issue space expanded from marine pollution to a multi-media, human-facing problem whose legitimacy rests on how evidence is interpreted, and thresholds are set. Large, multidisciplinary and multi-stakeholder research clusters such as the EU-funded CUSP (https://cusp-research.eu/) signal an epistemic reorientation in micro- and nanoplastics research. By enrolling biomedical disciplines that had previously been only marginally involved, these initiatives shift attention from environmental distribution toward embodied exposure. Research increasingly focuses on detecting and analyzing particles in human tissues and fluids – including blood, placentas and umbilical cord blood – in order to investigate potential implications for early-life development, allergic diseases, asthma and immune function. This re-scaling of inquiry – from oceans and ecosystems to human bodies – coincides with and helps consolidate, growing public concern about health risks, thereby reconfiguring micro- and nanoplastics as an issue of intimate, biological vulnerability as much as environmental pollution.

Third – and perhaps most consequential – is the move from micro- to nanoplastics, which compels us to reckon with a novel set of questions about their behavior, movement, risks and degradation over time (Science for Environment Policy, 2023). Emerging research on nanoplastics quickly reveals the limits of current knowledge, raising unresolved questions of classification (where to draw size/chemistry boundaries), measurement (how to detect, quantify and compare nanoparticles across matrices without artifacts), behavior (ability for translocation across biological barriers) and risk assessment (challenging to study while simultaneously potentially more harmful) (Hartmann et al., 2019; SAPEA, 2019; Gigault et al., 2021; Rani-Borges and Ando, 2024). Here, metrology and governance are tightly coupled: without robust detection and reference materials, policy struggles to stabilize "nanoplastics" as a regulatory object (Abdolahpur Monikh et al., 2022).

These shifts reveal a powerful temporality built into the problem. Even with early interventions to reduce releases, cumulative stocks and ongoing fragmentation mean environmental loads may continue to rise for years; interventions today can register only after lags in dispersion, degradation, detection and reporting. Scientific framings also evolve. New insights into pathways and harmfulness may outpace solutions tailored to yesterday's microplastics. For policymakers, the lesson could be pragmatic: adopt adaptive, lag-sensitive strategies that combine precautionary action with iterative standards, cross-media monitoring and metrics capable of distinguishing short-term noise from long-term trends (Funtowicz and Ravetz, 1993; Stirling, 2010). In short, as the scientific object expands – from seas to catchments and airs, from presence to health, from micro to nano – so too must the regulatory imagination, aligning methods, mandates and responsibilities with a problem that is being continually made and remade.

Turning microplastics into a European policy object

How does a messy, emerging phenomenon like microplastics become governable in Europe? This requires the formation of a European policy object, that is, a mix of material entities and bureaucratic constructs (e.g., chemicals, foods, drinking water, financial products) assembled and stabilized through categories, standards, tests and legal procedures. In Brice Laurent's terms, these "European objects" are brought into being at "sites of problematization," where they become matters of concern and targets for intervention (Laurent, 2022).

A first move was naming – coining the term microplastics (Thompson et al., 2004) – and classifying. Labeling a heterogeneous set of particles as "microplastics" drew boundaries, created a focal point for debate, gradually managed to attract funding, mobilized public concern, and provided a handle for measurement and comparison (Bowker and Star, 1999; Lampland and Star, 2009; Münster and Felt, under review). The label remained flexible enough for ecologists, toxicologists, metrologists, publics and regulators to be used differently, yet robust enough to coordinate across communities. However, as participant observation at conferences revealed, this flexibility also generated frictions: distinct epistemic communities employed different instruments and classifications, producing a fragmented object (Hartmann et al., 2019; Rochman et al., 2019).

Once drawn into European administrative and market logics, microplastics had to be reconstituted to become regulatable. Scientific distinctions between primary and secondary microplastics were taken up and transformed in policy processes. EU debates asked: What exactly should be regulated – intentionally added particles (e.g., microbeads), process-derived emissions (e.g., tire wear, fiber shedding), or particles at specific sites (e.g., drinking water, wastewater, compost)? Each framing implies particular instruments: bans and restrictions, performance standards, extended producer responsibility, eco-design rules, labeling, monitoring, procurement, or soft-law guidance. Each mobilizes specific expertise – toxicology for hazard thresholds, metrology for reference materials, economics for impact assessment, and legal reasoning for definitions and exemptions (Hilgartner, 2000).[1] In the EU, these choices are also filtered through the Treaty on the Functioning of the European Union (TFEU) principles (precaution, prevention and the polluter pays principle) and the Better Regulation Toolbox (European Commission, 2023a), which prioritizes measurable impacts and proportionality (Stirling, 2010).

Problem framings and instruments travel together in problem–solution packages: those who define the object of concern shape the universe of remedies. A framing that centers "intentionally added microplastics" invites classification politics, exemptions and transition periods; centering diffuse "unintentional" emissions points toward performance limits, design change and infrastructural overhaul. EU microplastics policy reflects this. The 2023 REACH restriction on intentionally added microplastics foregrounded definitional precision, socioeconomic analysis and feasibility of implementation, delivering phased obligations and long lead times where alternatives were not yet viable (Mathies, 2025). By contrast, larger streams of "unintentionally" released particles from tires, paints and textiles sit at the intersection of standardization, product policy, transport and industrial strategy – areas where measurement methods and substitution pathways remain under development (Hartmann et al., 2019; Koelmans et al., 2019; SAPEA, 2019; Wagner, 2022).

Europeanization adds its own tempo. Comitology and delegated acts allow the Commission to act within mandates (e.g., REACH),

[1]It will be relevant to follow European litigation emerging from regulatory framings to see how courts negotiate when micro- or nanoplastics become a legal problem and what evidence is used. In the US, most microplastic cases proceed under consumer protection, labeling, or greenwashing claims rather than traditional environmental pollution law.

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but only after ECHA dossiers, RAC/SEAC opinions, consultations and impact assessments; Directives (e.g., on single-use plastics, wastewater) require transposition across 27 legal systems across member states. Along the way, categories harden into standards, methods into norms and thresholds into legal limits. What appears technical is also constitutional: instruments chosen narrate Europe's effort to reconcile tensions – striving to be an innovation champion while wanting to remain precautionary leader, social-justice guardian and market integrator (Reins and Ala-Lahti, 2025).

Throughout, economic competitiveness remains the tacit horizon. EU impact assessments and socioeconomic analyses weigh environmental and health benefits against costs to firms and consumers; "no undue burden" narratives co-shape definitions and timetables. This helps explain why celebrated measures can still leave large flows untouched. REACH has focused on intentionally added particles; diffuse emissions from road wear, coatings and laundering are only beginning to be addressed through performance metrics, design requirements and infrastructure adjustments. Where alternatives are lacking, regulations build in grace periods and review clauses; where methods are immature, they mandate monitoring and method development rather than immediate limits (SAPEA, 2019; WHO, 2019).

Seen this way, turning microplastics into a policy object is not a single decision but a network of translations: from dispersed observations to label, from label to concerns, from concerns to policy, from policy to enforcement. Each translation both opens and closes options (Stirling, 2010). Governing well therefore means keeping the object revisable – aligning categories, measurement and intervention as science evolves – while building residue-aware policies that move upstream, reward reduction, substitution and redesign and render diffuse emissions tractable through standardized methods, cross-media monitoring and iterative targets. The politics of classification and measurement are inseparable from the politics of Europe's economic and environmental future; the microplastics object enacted today defines tomorrow's solution space.

Conclusions

Microplastics could become a wider lesson for innovation societies: novel technologies arrive with residues, and whether those residues can become visible and governable depends on how science, publics and policy manage to co-produce a coherent "policy object" which in turn allows action. This lesson demands three interlinked reflexive moves.

First, *be attentive to how the object is defined*. Classification, standards and metrics do constitutive work: names and measures are not neutral descriptors but infrastructures that shape what can be known, compared and acted upon (Bowker and Star, 1999). Governing microplastics therefore begins not only with regulation but also with ontological stabilization – settling what counts as "microplastic," at which size thresholds, with which detection limits, and whether and how nano-fractions are included. Shared taxonomies, reference materials, interlaboratory trials, quality criteria and standardized methods do more than improve measurement; they enact the object in particular ways and such enactments are never merely technical (Mol, 1999). They distribute visibility and invisibility, responsibility and accountability. Phenomena become politically "real" only when they are rendered consistently detectable and comparable – but what is rendered detectable depends on prior classificatory decisions. Which particles count, which exposure pathways matter, which harms are measurable, and which remain below thresholds of concern are all effects of these infrastructures. This calls for attentiveness to exclusions: which actors and disciplines participate in enacting microplastics as particular kinds of objects; which definitions and categories become dominant; which alternatives are marginalized; and what regulatory futures are foreclosed as a result. At the same time, it requires keeping definitions open to revision as methods, evidence and political stakes evolve, recognizing that stabilizing an object is always provisional and consequential.

Second, attend to *how the problem is framed and who is involved in that framing*. In STS terms, problems and solutions are often co-produced and travel together as "problem–solution packages." If residues are addressed only after innovations have been widely deployed, remedies tend to become afterthoughts, defaulting to waste management, behavioral change, or environmental clean-up. Problematizing residues as design constraints, by contrast, shifts intervention upstream – toward material choices, shedding tests and performance standards for high-emitting applications (such as textiles, tires and paints), as well as toward forms of producer responsibility indexed to measured releases. Framing residues as inherent to particular innovation pathways may, in turn, open space for debates about essential use. In other words, it matters which solutions are attached to which problem definitions – and, consequently, which particles remain unaddressed, which habits persist, and which polluting processes remain undisturbed. For example, while regulating intentionally added microplastics is important, such measures address only a fraction of the overall scale of the issue (Liboiron and Lepawsky, 2022). For policymaking in the field of microplastics, this means situating regulatory interventions within the broader political economy in which the problem is embedded, as well as recognizing the asynchronicities between innovation cycles and regulatory rhythms. These dynamics shape what is politically and economically feasible at any given moment. In the EU context, regulatory measures are strongly filtered through competitiveness considerations, often resulting in hesitant or incremental action. At the same time, accumulated environmental stocks and ongoing fragmentation processes generate temporal lags: even after interventions begin, microplastic concentrations may continue to rise.

Third, *govern adaptively*. Policymaking on microplastics must confront both the political economy that sustains plastics production and the misalignment between fast innovation cycles and slower regulatory rhythms. These structural conditions delimit what is politically and economically feasible. In the EU, regulatory measures are strongly filtered through competitiveness considerations, often resulting in cautious or incremental action. At the same time, accumulated environmental stocks and ongoing fragmentation generate temporal lags: microplastic concentrations may continue to rise even after interventions begin. Adaptive governance therefore requires acknowledging that matters of concern often precede consolidated matters of fact (Latour, 2004; Marres, 2007). Rather than waiting for epistemic closure, policymaking should proceed under conditions of uncertainty. A post-normal science approach offers guidance, emphasizing explicit uncertainty appraisal, inclusion of extended peer communities, and precautionary, iterative instruments equipped with review and adjustment mechanisms (Funtowicz and Ravetz, 1993). Given that plastics constitute a slow-moving stock-and-fragmentation problem, governance must also rely on lag-sensitive indicators, capable of distinguishing short-term fluctuations from long-term trends and allowing standards to tighten as evidence and alternatives evolve (Stirling, 2010). Adaptation alone is insufficient. It must be paired with a politics of care for the worlds already shaped

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by plastics (Puig de la Bellacasa, 2017). With micro- and nanoplastics embedded in environments and bodies, policy cannot depend solely on upstream redesign or substitution. It must also sustain long-term maintenance and mitigation – continuous monitoring, targeted capture at critical nodes, and stewardship of legacy stocks.

This calls for a need to *reframe responsibility* – from focusing on consumer morality to building modalities and infrastructures of care (Felt, 2021; Felt, 2025) for innovation residues, that is, develop standards, monitoring systems, procurement rules and market design that make responsible practice the default. The long period in which microplastics could remain unseen warns against repeating pathways of invisibility as new materials enter markets. Data are indispensable, but the key question is which knowledge can count for which interventions: numbers without redesign and governance will not deliver durable change. A residue-aware regime – upstream by design, iterative in implementation and explicit about political–economic and temporal constraints – offers a credible path for aligning the vision of a successful European innovation society with environmental stewardship.

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