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Unpacking the selection environment: Directionality shaped by emerging valuation ecosystems

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Abstract. Arguing against techno-determinism remains one of the cornerstones of innovation studies. Scholars have relentlessly shown how social conditions and strategic choices determine the pace and direction of technological development, supporting the idea that innovation can be steered towards societal goals such as economic competitiveness, employment or sustainability. Most scholarly attention, however, focused on the processes that generate new varieties of products and technologies, while the selection environment determining their direction is left largely unspecified. In this paper, we draw on insights from economic sociology to propose a conceptual framework for unpacking key structures and mechanisms of the selection environment through which societal values act upon technology development during periods of normative contestation. Central to our approach is the concept of valuation devices, understood as the organizational forms and material infrastructures embedded in institutional arrangements through which values are attributed to technologies and products. Beyond identifying these devices as strategic vehicles for actors to steer technology development, we show how they conjointly constitute a valuation ecosystem that shapes the directionality of a field. This framework is applied to the European food packaging sector, where proliferating health and environmental concerns have spurred a range of technological trajectories characterised by diverging strategies and goals. We retrace how actors advance distinct valuation devices to address evolving concerns about food packaging, and how the emerging valuation ecosystem shapes directionality by structuring corridors of legitimate innovation pathways. The paper concludes that deeper conceptual engagement with the selection environment opens promising new research perspectives for innovation studies.

Keywords: Directionality, valuation, selection environment, innovation pathways
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1. Introduction

The ability to understand and eventually shape technological development is a key requirement in any industrial society. While the success conditions for innovation have long been cast in terms of economic competitiveness, its goals have increasingly expanded to include societal well-being and tackling grand challenges (Coenen et al., 2015; Tödtling and and Trippl, 2018). Although recent years have seen various attempts to blend these framings through concepts like green growth, such approaches often fall short of driving transformative change as they insufficiently engage with the fundamentally different ways societal values bear on innovation in the underlying innovation models (Schot and Steinmueller, 2018).

Within innovation studies, the selection environment serves as a fundamental concept for understanding how socio-institutional factors influence the course of innovation. In the linear model of innovation as well as early innovation systems approaches, the selection environment is defined largely by the rules of commercializing new technologies, while broader societal values manifest through external market or regulatory structures. When addressing broader societal concerns like sustainability, however, this externalised view of societal values shows clear limitations (Nesi and Truffer, 2025). The question of how directionality is defined and shaped found growing resonance in this context, emphasizing that for innovations to contribute to broader societal values, these values need to be an endogenous driver of technological development (Weber and Rohracher, 2012). While the construction of societally legitimate innovation pathways is viewed as a key mechanism for embedding societal values in innovation, the processes through which these pathways are formed and contested within the selection environment remain insufficiently understood. This paper is thus concerned with the institutional structures and processes through which societal values shape the innovation activities of technology actors.

As innovation typically unfolds along established technological trajectories, its (re-)orientation towards socially desirable outcomes involves the destabilization and reconfiguration of the institutional structures that underpin incumbent logics of technological development. In evolutionary theorizing, this is closely linked to the criteria for innovation success which govern the selection environment. In broadening the impetus of innovation towards wider societal values, the literature increasingly shifts away from portraying emerging trajectories as racetracks where agency is constrained, selection environments are fixed, and criteria are unequivocal (Garud and Gehman, 2012; Stirling, 2011). Rather, there is growing recognition of the plurality of values, beliefs, and goals involved in (re-)aligning technology development with societal needs, opening up a diversity of possible pathways (Heiberg and Truffer, 2022; Pel et al., 2020). Based on an understanding of directionality as emerging from distributed agency, evolving selection environments, and equivocal criteria, innovation is increasingly seen in light of negotiations over which values it should reflect (Schot and Steinmueller, 2018).

Building on this, the present paper draws on the concept of valuation from economic sociology. Valuation refers to the institutional mechanisms, processes, and structures by which societal values are related to actors, products, and technologies. While societal values have often been treated as static context conditions, a focus on valuation processes foregrounds the actor networks and institutional arrangements that shape how and why innovations are deemed valuable (Kjellberg et al., 2013). Valuation devices such as industry standards and eco-labels emerge as focal points for investigating how actors seek to influence innovation pathways by embedding criteria and values into the selection environment (Doganova and Karnøe, 2015a). We conceptualise the diversity of valuation devices within a field as a valuation ecosystem. As valuation devices are strategically positioned and adapted in relation to existing ones to serve complementary or contradictory aims, their manifold interlinkages and interdependencies form a valuation ecosystem that collectively shapes evolving innovation pathways. Our framework highlights how actors construct and mobilize individual valuation devices to engage with societal concerns, while it is ultimately their synergies and contradictions that collectively shape directionality as an emergent system property.

The food packaging industry provides an instructive case in which these dynamics become apparent. With growing concerns about food packaging as a major source of exposure to hazardous chemicals and plastic waste, the sector faces multiple health and environmental challenges (Groh et al., 2019; Muncke et al., 2020). Food packaging showcases how chemical innovation has historically been geared towards products' functionality, prioritizing technological and economic values. Safety and sustainability concerns were emerging rapidly, but regulatory systems struggled to keep pace with the speed and complexity of chemicals development, lacking the capacity to address these externalities promptly (Persson et al., 2022; Wang et al., 2020). In this institutional void, valuation devices were introduced in diverse steering efforts of actors with varying normative goals and approaches. Consequently, the emerging valuation ecosystem constituted different innovation pathways, leading packaging innovation to follow distinct pathways that reveal both contradictions and complementarities as actors attempted to align with a complex set of societal demands (Asensio et al., 2020; Simoens, 2024).

We investigate directionality within the food packaging sector through a combination of methods. First, we analyse technological trajectories in a large corpus of scientific articles by means of quantitative text analysis. Topic modelling uncovers how research and innovation activity is shaped by proliferating concerns around the functionality, safety, and environmental impacts of packaging materials. Drawing on a series of interviews, we then identify and characterize valuation devices that were introduced by a range of actors in attempts to shape evolving corridors for the development and commercialization of packaging materials, enabling us to map the sectors' emergent valuation ecosystem.

In what follows, Section 2 first discusses how societal values have mainly been perceived as acting through external market and regulatory structures in the literature. It then integrates concepts from innovation studies and economic sociology to conceptualise the valuation ecosystem. Section 3 describes the food packaging case in more detail before outlining our empirical approach. Section 4 proceeds by presenting key results, the implications of which will be discussed in Section 5. Finally, Section 6 reflects on how the valuation ecosystem concept might inspire future research.

2. Conceptualizing the directionality of innovation

Innovation studies have long regarded technological innovation as a general force for good, driving economic growth and competitiveness in a globalizing economy. As concerns about unchecked technological development proliferated, however, this view has increasingly come under scrutiny (Coad et al., 2021; Schot and Steinmueller, 2018; Stilgoe et al., 2013). In addition to economic and technological values, it is argued that the study of innovation should consider broader societal values such as health, environmental protection or equity (Mazzucato, 2018a; Uyarra et al., 2019). Such an expanded normative ambition entails a focus on the content of innovations, emphasizing that they tend to develop along particular trajectories, which may be more or less congruent with the societal values by which they are assessed (Coenen et al., 2015; Rennings, 2000).

Against this background, directionality has become a key concept to study how societal considerations shape the direction of innovation pathways (Bergek et al., 2023; Coenen and Morgan, 2020; Weber and Rohracher, 2012). It is primarily concerned with the conditions and mechanisms by which innovation develops along particular trajectories and how these may be influenced to produce specific socially desirable outcomes (Andersson et al., 2021; Pel et al., 2020; Stirling, 2009). Directionality therefore directs attention to the structure and impact of different forms of selection environments that limit and guide technology actors when generating new technological or product variants (Schot, 1992).

The literature approaches directionality from two complementary perspectives (de Graaff et al., 2025). For one, it is understood in terms of the intentional steering efforts of individual actors, aiming to "give directions" by altering the selection environment. Actors are seen to shape technological trajectories through the top-down definition of missions or regulations, as well as more bottom-up constructions of shared expectations by means of participatory governance (Mazzucato, 2013; Weber and Rohracher, 2012). The second perspective suggests that directionality is formed by the distributed agency of diverse actors within a technological field, often subscribing to diverging values and interests (Garud and Karnøe, 2003; Smith et al., 2005; Yap and Truffer, 2019). Directionality has an emergent character which makes it a systemic property of transformative change (Andersson et al., 2021; Rosenbloom et al., 2019). Taken together, these perspectives suggest that innovation pathways are formed by an interplay of purposive, strategic interventions and emergent system-level dynamics (de Graaff et al., 2025; Pel, 2024). Despite these advancements in understanding the relationship between societal values and directionality, the literature has yet to become more specific about the underlying structures, processes and mechanisms by which directionality is enacted (Heiberg and Truffer, 2022).

2.1. Societal value concerns and the selection environment

Originally, innovation studies emphasized the role of knowledge and capabilities for explaining success or failure of innovations, foregrounding actors and resources contributing to the generation of variety (Edler and Fagerberg, 2017; Schot and Steinmueller, 2018). In response, recurrent calls for a stronger demand-side orientation in innovation policy have criticized this exclusive focus, arguing that it obscures how societal needs are articulated through demand conditions and activities (Edler and Boon, 2018; Edler and Georghiou, 2007; Geels, 2004). Despite such calls, the selection environment has remained largely unspecified or comfortably subsumed under broader visions and expectations. As a consequence, the institutional structures and mechanisms through which value is attributed to new products and technologies often remain sidelined, being relegated to external market or regulatory structures that act as given context conditions for the innovation process (Garud and Gehman, 2012; Jeannerat and Kebir, 2016; Kuokkanen et al., 2018).

Following evolutionary economics, innovation studies originally conceived technology development to result primarily from socio-cognitive processes that lead actors to deem some problems and solutions more feasible and valuable than others. This is epitomized by the seminal concept of technological trajectories (Dosi, 1982), which understands the direction of technological change as the outcome of R&D-driven technological search and learning processes, wherein engineers and technicians employ heuristics to deal with the inherent uncertainty and complexity of technology development (Nelson and Winter, 1977). Building on this evolutionary perspective, socio-technical transition studies set out to understand how institutional structures, such as values, regulations, and expectations, shape technology development (Kemp et al., 1998). The socio-technical regime concept frames the selection environment as embedded within the broader institutional fabric of society, rather than being confined to cognitive processes and decision-making routines of engineers in corporate R&D settings (Rip and Kemp, 1998).

By demonstrating how enduring alignments between actors, technologies, and institutions create path dependencies that reinforce established trajectories and constrain the development and diffusion of environmental innovation (Markard et al., 2012), transitions studies represent a key body of work that offers insights into the systemic and evolutionary character of directionality (Andersson et al., 2021; de Graaff et al., 2025). The influential framework of the multi-level perspective (MLP) (Geels, 2002; Rip and Kemp, 1998) has framed directionality largely via the conflict between an established socio-technical regime and emerging niches with superior normative characteristics. In studies based on the technological innovation system (TIS) framework, directionality has been portrayed in terms of a growing and maturing innovation system forming around a sustainable technology – partly through the function guidance of the search, and partly as a property of system maturation (Bergek et al., 2008; Hekkert et al., 2007). Later, it was linked to a set of dynamic system failures (Weber and Rohracher, 2012; Weckowska et al., 2025) and led to calls for mission-oriented innovation systems (Hekkert et al., 2020). A common thread among these approaches is the view that the selection environment is dominated by path dependencies and a hostile set of incumbent actor interests and institutions that hinder new, potentially disruptive technologies to scale and mature.

What emerged from this at the interface with innovation policy was an actor-based perspective on directionality (Weber and Rohracher, 2012), positing that actors may influence the course of technology development by shaping the selection environment (Schot, 1992). Early expressions of this perspective can be found in the constructive technology assessment framework (Schot and Rip, 1997). Rather than letting technology development unfold in a purely technology- and market-driven manner and treating its societal implications as externalities, this approach stresses endogenous feedback mechanisms between the promotion and control side of technology in order to shape technology already *during* its design and development (van Est, 2017). Its emphasis on the modulation of technological trajectories has informed recent STI policy around responsible research and innovation (Lindner et al., 2016; Stilgoe et al., 2013) as well as mission-oriented innovation policy (Mazzucato, 2018b). Representing primarily a governance approach, the key aim is to design research and innovation processes in such ways that their outcomes align with society's values and needs (Uyarra et al., 2019).

However, both perspectives have been criticized for adopting an overly linear view on innovation in which actors' steering attempts, regime change, and system maturation follow a single, widely endorsed direction that solely needs to be "cultivated" (Pel et al., 2020; Stirling, 2011, 2009). Recent contributions stress how institutional complexity and normative multiplicity within innovation systems and socio-technical systems lend themselves to a diversity of possible development paths (Fuenfschilling and Truffer, 2014; Hacker and Binz, 2021; Heiberg and Truffer, 2022). While scholars have started to disentangle specific structures, processes and mechanisms that influence directionality (Schippl and Truffer, 2020; Yang et al., 2022; Yap et al., 2022; Yap and Truffer, 2019), there is still limited understanding of how actors' shaping attempts interact with the systemic evolution of selection environments to guide technology development into specific directions.

2.2. Institutional arrangements: Valuation devices

Advancing a meso-level perspective on directionality as resulting both from strategic intent and an emergent property of socio-technical systems requires greater attention to the institutional structures that translate and mediate societal concerns into guidance for actors. Against this background, we propose to draw on recent developments in economic sociology, a field concerned with the ways economic activity is interwoven with and shaped by the social, political and cultural dynamics of its broader environment (Granovetter and Swedberg, 1992; Krippner, 2001; Zelizer, 2010). From this perspective, innovation processes are embedded in organizational fields structured by a set of institutions (Windeler and Jungmann, 2023). It follows that these institutions constitute the selection environment, which shape innovations by assigning value to them through processes of valuation. Valuation can be broadly defined as the process of "deeming something of value", making it a rather fundamental social process. It renders technology and product variants distinct and comparable in terms of their perceived value, while also shaping how the underlying values are weighed in this process (Jeannerat and Kebir, 2016; Reale, 2024).

The shaping of technological trajectories through valuation mainly materializes through specific valuation devices (Doganova and Karnøe, 2015a; Muniesa et al., 2007), i.e. organizational forms and material infrastructures through which valuation judgements are reached and communicated, and which are embedded in broader institutional arrangements of valuation. Valuation devices can take various forms, including labels, rankings, ratings, or comparative technology lists. It is through strategically acting on such valuation devices that actors can shape the direction of technology development. A salient example is car safety ratings, bridging traditional performance characteristics of cars, such as handling, acceleration, or build quality, with societal values around health and safety. Based on internationally recognized standards, car safety ratings are performed by a variety of organizations and enact passenger safety as a core quality of vehicles (O'Neill, 2009). Safety ratings not only influence consumer purchasing decisions, contributing to brand identities like those of Swedish car manufacturers, but also shape industry-wide innovation strategies, as demonstrated by the widespread adoption of electronic stability control systems (Lutz et al., 2017; Urde, 2003).

Valuation devices interconnect actors, rules, values and technologies by means of calculative procedures (Kjellberg et al., 2013; Kornberger et al., 2017). In configuring valuation processes across several actors, valuation devices link those issuing valuation judgements (*the valuators*) with those that develop the technology under scrutiny (*the valuees*) and a receptive *audience* which informs their decisions based on the outcomes (Sauder and Lancaster, 2006; Waibel et al., 2021). The criteria, metrics and procedures inscribed into valuation devices enact specific values in the contexts in which these actors operate (Doganova and Karnøe, 2015a; Friedland and Arjaliès, 2021). The rules structuring these interactions are shaped by the institutional logics governing the broader organizational field (Lamont, 2012; Lounsbury, 2002; Stark, 2009).

Economic sociology has, in particular, sought to understand how valuation devices reconfigure established market structures, such that the calculative procedures they instigate incorporate broader societal values alongside economic and technological considerations (Doganova and Karnøe, 2015a; MacKenzie, 2009; Reijonen and Tryggestad, 2012). Valuation devices can both reveal and stabilize qualities relating to broader societal concerns, which would otherwise remain externalities eluding the calculative frames of existing markets (Callon, 1998; Doganova and Karnøe, 2015a). They can do so through processes of evaluation as well as valorisation (Helgesson and Muniesa, 2013; Vatin, 2013). Evaluation refers to judging or assessing an option against a set of criteria or values. In this context, the function of valuation devices is to establish *matters of concern* that are socially relevant and should be acted upon (MacKenzie, 2009; Reijonen and Tryggestad, 2012). Complementarily, valorisation refers to the social process that attributes values to products and technologies, positioning them as valuable solutions to societal concerns. Here, valuation devices establish *matters of worth* in which societal values and monetary values coalesce rather than merely coexist (Doganova and Karnøe, 2015b). It is in delineating what counts as relevant problems or valued solutions that valuation devices come to actively guide technological problem-solving. With innovation studies identifying uncertainty as a defining feature of many grand challenges (Wanzenböck et al., 2020), another key aspect of valuation devices relates to how they shape what is treated as established knowledge about problems and how these problems are collectively understood (van Bueren et al., 2003). In contexts where knowledge about the environmental, health and safety risks of technologies is limited and contested, valuation devices may help stabilise *matters of fact* by embodying evidence and establishing parameters that specify problems. While grounded in evidence and observation, they provide a means to shape shared interpretive frames for understanding and addressing these problems. Thus, matters of fact establish what is known, matters of concern what is socially relevant and worth acting upon, and matters of worth what is valuable as a solution.

By constructing and mobilizing valuation devices, actors seek to intervene in the exchange, normalization and representational practices through which selection environments are configured (Kjellberg and Helgesson, 2007). First, valuation devices may influence *the exchange of products or technologies* by defining the conditions under which these are selected (Doganova and Karnøe, 2015a). Second, valuation devices contribute to *normalizing practices*, including the formulation of rules, norms and standards. They represent both sites and instruments in ongoing struggles among actors to impose competing criteria of what is to be recognised as valuable (Lamont, 2012). Third, valuation devices shape *representational practices* concerning the description and measurements of goods

(Azimont and Araujo, 2007; Beunza and Garud, 2007). In signalling product qualities to consumers, they construct market depictions based on specific categories (Aspers, 2009; Boström and Klintman, 2008).

Against this background, valuation offers an entry point for understanding how the selection environment actively shapes technological trajectories. Instead of treating societal values as external boundary conditions, valuation processes direct attention to the institutional structures and agentic processes through which they are conjointly enacted by diverse actors (Carvalho and van Winden, 2018; Haisch and Menzel, 2023; Jeannerat and Crevoisier, 2022). Directionality then results as an emerging system property from both of evolving institutional structures and actor strategies.

2.3. Valuation ecosystems and directionality

As valuation devices reveal and stabilise technology characteristics that are (in-)congruent with certain societal values, their impact on technological trajectories primarily manifests in their influence on selection decisions at different levels, from the individual shop floor innovating engineer to company management and entire innovation systems or economic sectors. Economic sociology has studied the impact of valuation processes and devices in various contexts, suggesting that economic sectors or innovation systems are characterized by a diversity of sites where such devices become influential.

A proliferation of societal concerns in a field is likely associated with a widening range of valuation devices, each trying to internalize certain external demands by inscribing corresponding criteria into the selection environment. While individual devices typically address specific concerns, they collectively pose overlapping, complementing or contradicting demands. Reinecke et al. (2012), for instance, show how the global coffee industry has become subject to a multiplicity of sustainability standards, which converge on core criteria yet remain distinct in specific features due to mutual observation and reciprocal positioning of standard-setters. Companies are rarely exposed to a single device but often navigate the demands of multiple ones at the same time. In these ongoing struggles over directionality, valuation devices are not static structures but must be constantly maintained and adapted to remain relevant and effective (Callon et al., 2002; Ringel, 2021). Valuation devices, then, are not isolated mechanisms but evolve in relation to one another, with their mutual adaptation and entanglement gradually configuring the broader selection environment. NGO labels, for instance, were found to be designed and altered in response to shifts in other labels (Heyes and Martin, 2018).

The selection environment can thus be understood as comprising mutually interdependent valuation devices that exert synergistic or contradictory pressures on innovators. These devices form an evolving ecosystem in which alternative directions of innovation are selectively reinforced or constrained. That is, the valuation ecosystem defines an array of “corridors of acceptable development paths, inside of which the bottom-up forces of innovation […] can operate” (Weber and Rohracher, 2012, p. 1043).

Changes in the structure of valuation ecosystems are linked to the broadening or narrowing of these corridors, thereby shaping the scope for technological variation. Directionality, in this sense, does not result from a single guiding force but emerges from actors' interventions in a heterogenous and often incoherent network of valuation devices. Against this background, we define the assemblage of valuation devices as a valuation ecosystem to highlight that directionality is not steered by any single actor, but rather arises as a systemic property shaped by the interdependencies between devices and the strategic actions of those engaging with them.

In this paper, we aim to empirically identify and map the structure of a valuation ecosystem. Emerging from the functional interlinkages and interdependencies among diverse valuation devices, the structure of valuation ecosystems is defined by the characteristics of their constituent parts. Building on the above discussion, we characterise valuation devices across five dimensions that capture how they constitute valuation processes: (i) the actors they connect, (ii) the actor logics they align with, (iii) the ways they shape the calculative space, (iv) the selection practices they aim to intervene in, and (v) the site of valuation in which they exert influence. These dimensions describe the "scripts" of valuation devices (Akrich, 1992; Doganova, 2019), which together reveal the overall system structure.

3. Methodology: Capturing valuation in food packaging

This paper employs a mixed-methods approach to analyse recent shifts in the innovation dynamics and institutional structures within the food packaging sector in relation to emerging societal concerns. The following section begins with an account of key developments in the sector to establish the empirical context. We describe the topic modelling approach to analyse which concerns have shaped packaging innovation and the interview-based approach to identify and characterize the valuation devices emerging in the sector. This leads us finally to present the approach for mapping the valuation ecosystem.

3.1. The case: Societal concerns shaping food packaging innovation

Food packaging plays a central role in today's globalised food system by preserving and protecting industrially produced and heavily processed food as it moves through international supply chains before reaching consumers on supermarket shelves (Chakori et al., 2021). While traditionally valued and optimized for its functional attributes, food packaging has recently drawn societal concerns for its association with hazardous chemicals exposure and plastic pollution (Groh et al., 2019; Muncke et al., 2020). The sector has consequently witnessed a proliferation of steering attempts and technological trajectories, as actors try to define and align with different goals and strategies, ranging from tighter control of migrating substances and altered packaging designs to reduce chemical exposure, to eliminating plastic waste through bioplastics or recycling (Asensio et al., 2020; Simoens, 2024).

Food packaging therefore presents an instructive case to study how established innovation patterns are challenged by multiple societal concerns and solution approaches. As in many chemical sectors, packaging innovation is strongly shaped by petrochemistry, imposing a framework for technology development based on finding ever new applications for a small number of platform chemicals derived from fossil fuels (Tickner et al., 2021). Within this petrochemical regime, polymer-based materials like multilayer films, and coatings have become key technological foci, driven by a focus on functionality, lightweight, and cost-efficient materials (Sangroniz et al., 2019). These materials have found widespread application across food industry segments**,** where different packaging types have emerged as dominant designs, such as flexible packaging for snacks, PET bottles for beverages, or composite materials for milk containers. Food packaging companies are typically converters of raw and semi-finished materials into finished packages, combining inputs from various suppliers to meet specific functional and design requirements. A producer of snack bags, for instance, laminates plastic films with barrier components like metallized film, prints branding and product information, and then cuts and seals the material into pouches that are finally supplied to food manufacturers for filling. These packaging materials are thus made up of different types of Food Contact Materials (FCMs), including plastics, metals, inks, and adhesives, each of which subject to distinct regulatory requirements.

FCM regulation is particularly focused on limiting chemical exposure through migration limits and lists of authorized substances. Rooted in the need to control the input substances of packaging materials, many of which are plastics, regulation follows primarily a risk-based approach. That is, control is guided by scientific assessments of potential risks, considering both hazard and exposure, rather than by the mere presence of a substance, as in a purely hazard-based approach. FCM regulation hence places greater emphasis than other chemical regulations on limiting chemical exposure by means of migration limits and positive lists as valuation devices. However, it has been found that harmonized EU rules for FCM regulation are still absent for 12 out of 17 FCMs. Moreover, FCM regulation has recently been deemed only "partly effective" in protecting consumers due to a lack of responsiveness to new scientific evidence, and mechanisms of re-evaluation of authorized substance, amongst other things (European Commision, 2022). NGOs and scientists have consequently advocated for a more hazard-based approach to move away from resource-intensive and often uncertain exposure assessments. This approach would prioritize the inherent dangers of substances and is expected to induce the development of safer alternatives by considering toxicity concerns already within material design stages. These arguments have gained further traction as the risk-based approach faces additional challenges when confronted with packaging innovations optimized for environmental characteristics, such as paper, recycled materials, and bioplastics, which introduce further safety concerns due to impurities and degradation products (Lacourt et al., 2024).

3.2. Topic modelling: Capturing values in food packaging research

By capturing the main technological trajectories in food packaging innovation, we seek to test whether and how the field has experienced an increasing variety of societal concerns in the development of novel packaging materials. Topic modelling represents a natural language processing technique designed to reveal general themes in collections of unstructured texts. In the study of environmental innovations and transitions, topic modelling has so far found application in capturing the development (Rakas and Hain, 2019) and structure of technology fields (Kriesch and Losacker, 2024), as well as in tracing the legitimacy and value associations of technologies over time (de Wildt et al., 2022; Dehler-Holland et al., 2022).

The analysis relies on a corpus of 9.670 abstracts of scientific papers in the domain of food packaging. The data was obtained from Scopus, encompassing English articles and reviews published in scientific journals between 1970 through 2023, limited to those (co-)authored by at least one author affiliated with a European organization (see Appendix A). Although scientific publications generally stem from universities and research institutes at the early stages of R&D, they can be considered suitable proxy measures for innovation activity. Given its focus on concrete packaging materials, science-based risk assessment, and regulatory science, the food packaging field is closer to application than basic research areas, making scientific papers suitable for identifying prevalent problems, solutions and the proliferation of societal concerns.

The paper leverages a transformer-based topic model to analyse shifts in innovation within food packaging, with a particular focus on the societal concerns addressed. More specifically, we examine the development of topics over time in the abstracts of publications on food packaging using BERTopic (Grootendorst, 2022) (refer to Appendix A for more details). Compared to keyword-based approaches frequently employed in bibliometric analyses, topic modelling better captures the latent expression of values and societal concerns, which tend to be revealed through a flexible and undefined vocabulary (de Wildt et al., 2022). Transformer-based topic models further offer better contextual understanding over approaches based on Latent Dirichlet Allocation, as they utilize embeddings rather than a bag-of-word approach (Bianchi et al., 2021). This grants them an advantage in revealing expressions of societal concerns in relation to technological or scientific issues (Smith et al., 2023).

Topics identified by the topic modelling algorithm in the corpus of scientific abstracts are represented by distinct lists of keywords derived from c-TF-IDF, KeyBERT, and maximal marginal relevance. These representations of topics allow for the interpretation of their semantic content. The interpretive analysis specifically focused on keywords that highlight particular problems and solutions related to both technological and societal issues. Based on identification and interpretation of these keywords combined with background case knowledge, topics were linked to specific societal concerns.

3.3. Mapping valuation ecosystems

The second part of the empirical analysis examines key elements and mechanisms of the selection environment, focusing on their evolution over time in relation to societal concerns. The analysis draws on 14 semi-structured interviews with 15 stakeholders in the European food packaging sector, and three scoping interviews. The guiding question focused on how, in the absence of strict regulation, emerging concerns altered specific institutional structures in the field, which render certain characteristics of novel packaging materials more relevant and valuable than others. Interviewees were selected from organisations articulating selection pressures such as retailers or authorities, as well as those responding to them, including packaging companies or testing laboratories (see Appendix A).

Informed by the interview findings, we captured how valuation devices have been mobilized to shape packaging innovation in five steps. The first step concerned the identification of valuation devices. Interviewees typically referred to specific devices when describing how societal actors articulate certain concerns, how companies strategically respond when confronted with such pressures, or how actors collaborate to develop shared understandings and standards. Considering the institutional void in the field, these statements primarily highlighted non-regulatory devices intended to address societal concerns that remain overlooked by formal regulation. A label, substances list, company guideline, or any other such institutional arrangement was coded as a valuation device if it was intentionally established by actors to articulate or respond to concerns about food packaging, and enable the assessment of packaging materials. Based on these conditions, the empirical observation of valuation devices mainly focused on their influence on selection processes, rather than the underlying calculative and testing practices. As an example of our front-end focus, consumer organization tests were considered primarily through their rating outputs, instead of the back-end testing procedures from which they derive. Although these two elements are conceptually intertwined, this differentiation is crucial to empirically observe distinct devices.

In a second step, supplementary desk research was conducted to locate associated documents of valuation devices, such as underlying requirements of labels or packaging strategies of companies. Given the often substantial number of functionally similar devices operating across different countries, industry segments, or with varying emphases, we aggregated individual devices into broader classes. Testing guidelines drafted by multiple trade associations of companies manufacturing different FCMs, for instance, were grouped into the type "Industry guidelines for migration testing". This aggregation was guided by both a theoretical understanding of typical characteristics and functions of valuation devices discussed in the literature as well as empirical insights into their observable forms and roles in the specific case of food packaging. Lastly, the first instance of use of each valuation devices was coded based on when actors initially mobilized it in their steering efforts.

In a third step, we then systematically assessed the identified types of valuation devices against the abductively derived dimensions outlined in Section 2, drawing on both interview and desk research data. First, we considered the actors involved, categorizing valuators and audiences as societal, corporate, or governmental. Second, we examined the institutional logics in which the criteria of devices are anchored. Third, we considered how valuation devices intervene in the calculative space of actors by conveying matters of fact, concern or worth. Fourth, we differentiated the practices affected by devices, which shape exchange, normalization, and representational activities by setting temporary conditions for selection, establishing norms and standards, or categorizing markets in particular ways. Finally, we assessed the site of valuation, distinguishing whether valuation devices assess innovations within companies, along the supply chain, through third party or retailer testing, or in end-user markets. This step resulted in a matrix mapping the valuation devices against all descriptive dimensions, with each device coded as 1 if it embodied a specific element and 0 otherwise. Table 1 provides a brief explanation of each dimension along with the main guiding questions for the assessment.

In a fourth step, we then mapped the structure of the valuation ecosystem based on the information from the matrix, and guided by the principles of semantic network analysis (Heiberg et al., 2022; Truffer et al., 2025). The way valuation devices connect to shared or divergent elements as they constitute valuation processes offers a basis to infer their proximity within the overall system. When devices perform similar functions, such as emphasizing chemical safety to consumers, or embody related criteria, like the share of recycled content, they can be seen to occupy closely related positions within the valuation ecosystem and operate within the same domain. To assess the proximity between devices, we then applied the Jaccard similarity measures on the profiles of binary features, capturing the relative overlap between any two profiles. The resulting similarities were visualized using multidimensional scaling to map the valuation ecosystem.

In a fifth step, we then analysed the topography of the valuation ecosystem in terms of its temporal development and structural configuration. A narrative was developed that traces the valuation ecosystem's evolution. It brings together key arguments and decisions by actors to construct a coherent description of how shifts in societal concerns have driven the introduction and modification of valuation devices. Furthermore, this temporal account informed our analysis of the current structural make-up of the valuation ecosystem. Focussing on groups of valuation devices that exhibit similar characteristics and functions, the structural analysis set out to identify closely located and interlinked devices, which together prescribe certain behavioural expectations and criteria, or mediate between them. This allows the valuation ecosystem to be delineated into several domains and coupling areas which reveal localized arenas and contexts for negotiation and contestation.

Table 1: Dimensions to characterize valuation devices operating in the food packaging sector

Dimension	Description	Subdimensions	Explanation	Guiding questions
Valuators	The actors linked by valuation devices. Valuators shape valuation devices and articulate judgements. Audiences are affected by these judgements in their decision making.	Societal valuator	Actors like NGOs, consumer organizations	Which actors have set up the valuation device and formulate valuation judgements: - societal valuators, - corporate valuators, - regulatory valuators, or - self valuation in companies?
		Corporate valuator	Individual companies and industry consortia	
		Regulatory valuator	National and European regulatory agencies	
		Self-valuation	Companies set up devices to assess their own products	
Site of valuation	The part of a sector on which a valuation device centres and where it assesses new products and technologies. Focuses more on the site of assessment than on where actor decisions are influenced.	On the market	Valuation of final products that have already entered the market	Where in the sector is the valuation device operating as they assess new products and technologies? - on the end-user market - pre-market entry - along the supply chain, or - within organizations?
		Along the supply chain	Valuation of intermediary goods exchanged through B2B relations	
		External gatekeeping	Valuation of final products before put on the market by other actors	
		Internal gatekeeping	Valuation of products in R&D or for final control before being sold	
Practices	The practices constructing the selection environment in which valuation devices seek to intervene.	Normalizing practices	Devices advance frameworks defining and testing safety, recyclability, functionality etc .	Is the underlying aim of a valuation device to: - establish some norms, standards or criteria, - equip buyers with tools to assess and compare products offered - depict the market or products in a certain way?
		Exchange practices	Devices mediate relationship of buyers & sellers through shared basis for assessment	
		Representational practices	Devices signal product characteristics and establish categorizations of markets	
Matters	The way valuation devices shape the calculative space of actors in a field when being confronted with the uncertainty of societal challenges. This involves knowledge and negotiation of the problems and solutions in a field.	Matter of fact	Devices establish knowledge on presence, migration, & hazard of substances	Does a valuation device primarily influence: - the perception of what is real and supported by evidence - what is relevant and requires attention, revealing mis/alignments with values? - what is valuable and addresses a concern, enacting and assigning values?
		Mater of concern	Devices establish associations of substances & material features with problems	
		Matter of worth	Devices establish associations of substances & material features with solutions	
Logic	Sets of values, beliefs, and rules governing a field. Give valuation devices certain rationalities by determining legitimate criteria and actor roles.	Risk management logic	Focuses on the (acceptable) level of exposure to certain hazardous substances	Do the criteria and metrics of valuation devices primarily capture: - the exposure of consumers to substances, - the inherent hazard properties of materials - the share and properties of bioplastics & recycled materials - the functional properties and economic viability of materials?
		Hazard prevention logic	Focuses on the inherent hazard of substances and their presence in materials	
		Plastic reduction logic	Focuses on reducing plastic waste by increasing the use of alternatives like bioplastics and recycled materials	
		Functional materials logic	Focuses on established performance criteria relating to functionality and costs	

4. Results

The analysis consists of three interrelated steps. It begins with a descriptive account of how R&I in food packaging has taken up emerging environmental and health concerns in the last decades. We then reconstruct through which valuation devices the field has dealt with evolving concerns and finally map out its valuation ecosystem and describe its structure and temporal development.

4.1. Mapping the proliferation of societal concerns over time

The topic model captures the main areas of research and innovation in food packaging. A total of 22 topics were extracted from the corpus, attributing 8.773 articles to their most probable topic and excluding 897 articles due to low assignment confidence. Table 2 presents the profiles of each topic, including manually assigned labels, representative keywords and article counts. These topics were further grouped into six categories, reflecting their shared orientations towards societal concerns.

Among all topics, *Packaging effects on microbial growth* emerged as the most prominent, comprising 1.442 articles. It captures R&I activity to limit microbial spoilage, particularly by means of atmosphere control. Sharing this concern with packaging's core technical function, four additional topics were identified that centred on material barrier properties. The topics *Packaging barrier properties: Multi-layer materials* and *Plasma surface modification* feature methods to enhance blockage of gases, moisture and other external factors, while *Aroma scalping* and *Wine aging* examine barrier performance in relation to specific chemical and sensory characteristics of packaged foods. These topics collectively represent a thematic cluster aligned with the societal objective of ensuring "Preservation and protection of food". The topic *Active and intelligent packaging* complements this group by addressing novel technologies designed to monitor, communicate, or actively extend food quality. It becomes evident from Figure 1 that these functional characteristics of packaging, which are captured with the blue line, traditionally accounted for a large share of R&I in the sector.

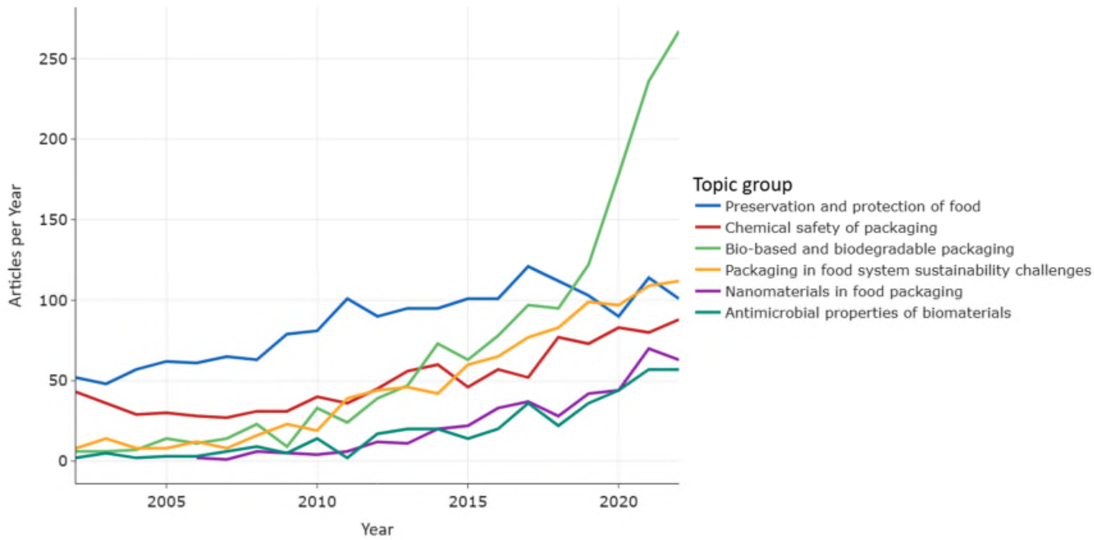

Figure 1: Number of articles per concern-related topic group over time

A second major concern addressed across multiple topics relates to the "Chemical safety of packaging", represented by the red line. The topic *Chemical migration from packaging* covers research on the diffusion of potentially harmful substances from packaging into food. It particularly focuses on bisphenol A and phthalates, two endocrine disrupting chemicals often used in can linings and polyvinyl chloride food packaging, respectively. In contrast, the topic *Migration of heavy metals* concerns contamination stemming from metal-based packaging. Although this group of topics has been present since the early 2000s, research activity remained stagnant until around 2010, when attention began to increase. A contributing factor has been the topic *Safety evaluation of recycled PET*, which relates to the migration of contaminants from recycled polyethylene terephthalate increasingly used in bottles. It thus reflects health concerns sparked by growing efforts to reduce plastic waste.

Topics addressing environmental concerns have gained prominence in the last decade, as the trend of the light green and orange lines indicates. A key focus has been alternatives to conventional plastics, particularly "Bio-based and biodegradable materials" (light green). Significant research activity has emerged around *Bioplastics based on starch*; *polylactic acid (PLA)*; and *chitosan*. In addition, *cellulose* has attracted attention as a functional enhancer to improve the performance of these materials. *Bio-based polyesters* have also gained traction for more demanding applications. The urgency of developing such alternatives is underscored by the growing body of research on the environmental impacts of plastic pollution, most notably in the topic *Marine litter and microplastics*. Similar concerns surface in the topic *Packaging in food system sustainability challenges*, which also captures the issue of emission-intensive plastic production. Due to its broader scope, however, this topic represents its own category (orange), focusing on general systemic issues instead of specific material characteristics.

Moreover, the topics *Bio-based antimicrobial packaging with carvacrol* and *nisin* focus on two particular bio-based antimicrobial agents (dark green). This pair of topics is distinct to the previous group on bio-based alternatives to synthetic substances in that it emphasizes their ability to actively inhibit microbial growth by reacting with food rather than material characteristics like barrier properties. The rise in articles on "Antimicrobial properties of biomaterials" suggests that these materials are increasingly being considered for functions related to active shelf-life extension.

A last group of topics is concerned with efforts to improve the functional properties of packaging materials by incorporating "Nanomaterials in food packaging", the growing attention to which is indicated by the purple line's trend. It comprises two topics on the use of specific *Nanocomposites* and *Production techniques* to reduce antimicrobial growth through packaging. In addition to the general potential of nanotechnologies, there are also two topics about the *Migration and toxicological risks of nanomaterials* as well as their more general *Innovation and safety landscape*. This combination of topics suggests negotiations over the boundaries within which nanotechnology can be applied.

Overall, we observe that among the six identified groups of topics, preservation and protection of food has long been the main area of R&I. Health concerns have been consistently present, though a notable rise in publications on chemical safety has occurred since 2010. Topics related to environmental concerns, however, have seen the steepest growth in the last decade, with efforts to develop functional bio-based materials accounting for the largest share of R&I today. Nanomaterials represent a new technological field that cuts across multiple areas of concern and focus.

Table 2: Description of topics including topic names, c-TF-IDF representations, article counts, and attributed topic group

Topic name	c-TF-IDF representation	Count	Topic group
Packaging effects on microbial growth	storage, samples, meat, map, days, stored, atmosphere, shelf, co2, growth, life, quality, vacuum, packaging, modified, microbial, spoilage, packaged, sensory, bacteria	1.442	Preservation and protection of food
Active and intelligent packaging	sensor, food, sensors, packaging, intelligent, oxygen, quality, indicator, color, indicators, ph, monitoring, detection, temperature, based, smart, systems, freshness, active, packages	294	
Packaging barrier properties: Multi-layer materials	seal, pressure, packaging, process, steel, food, corrosion, material, high, properties, materials, laser, water, polymer, aluminum, model, temperature, welding, heat	164	
Packaging barrier properties: Aroma scalping	aroma, permeability, water, sorption, polymer, evoh, ethylene, polyethylene, gas, temperature, packaging, compounds, barrier, properties, film, ldpe, permeation, food, tocopherol, oxygen	141	
Packaging barrier properties: Wine aging	cork, wine, wines, tca, stoppers, compounds, aging, volatile, so2, corks, oak, oxygen, barrels, bottle, months, wood, bottles, different, closure, analysis	80	
Packaging barrier properties: Plasma surface modification	plasma, barrier, surface, films, oxygen, layers, permeation, coating, coatings, properties, deposited, deposition, film, pet, layer, coated, siox, packaging, substrate, bopp	77	
Chemical migration from packaging	migration, food, bpa, contact, used, substances, exposure, kg, materials, compounds, ms, samples, method, bisphenol, packaging, mass, mg, phthalate, simulants, using	1.133	Chemical safety of packaging
Safety evaluation of recycled PET	pet, recycled, recycling, polymer, food, bottles, migration, plastic, diffusion, packaging, polyethylene, process, material, virgin, used, terephthalate, plastics, pyrolysis, using, contaminant	272	
Migration of heavy metals	al, mg, cadmium, aluminium, tin, lead, chromium, kg, metals, levels, cr, µg, pb, concentrations, food, concentration, atomic, intake, samples, mercury	64	
Bioplastics based on starch	films, based, packaging, starch, properties, protein, materials, food, edible, film, biodegradable, mechanical, water, waste, used, plastics, gelatin, bio, applications, environmental	518	Bio-based and biodegradable materials
Bioplastics based on PLA	pla, properties, films, barrier, poly, mechanical, wt, packaging, thermal, acid, food, materials, phb, applications, based, polymer, blends, phbv, film, biodegradable	481	
Bioplastics based on chitosan	chitosan, films, properties, film, antimicrobial, activity, cs, active, water, packaging, based, mechanical, food, antioxidant, lae, addition, showed, applications, materials	339	
Bioplastics based on cellulose	cellulose, properties, barrier, films, water, nanocellulose, paper, mechanical, materials, based, coating, applications, cnf, coated, food, cnc, pva, oxygen, xylan	254	
Marine litter and microplastics	litter, plastic, marine, items, microplastics, debris, plastics, sites, environment, containers, food, beach, pollution, coastal, abundance, sediment, mps, species, accumulation	111	
Bioplastics based on bio-based polyesters	pef, pet, poly, copolymers, molecular, polyesters, properties, furanoate, synthesized, polyester, thermal, polycondensation, pbs, bio, barrier, based, ethylene, high, applications, mol	55	
Packaging in food system sustainability challenges	food, packaging, consumers, environmental, waste, products, study, product, impact, results, consumption, consumer, energy, foods, information, production, data, health, research, use	1.159	Packaging in food system sustainability challenges
Bio-based antimicrobial packaging with carvacrol	antioxidant, active, films, carvacrol, activity, packaging, extract, food, antimicrobial, essential, release, properties, eos, film, pla, thymol, compounds, cinnamon, oil	259	Antimicrobial properties of biomaterials
Bio-based antimicrobial packaging with nissin	antimicrobial, packaging, food, active, films, nisin, materials, properties, biofilm, film, natural, activity, agents, shelf, growth, products, monocytogenes, life, meat	203	
Antimicrobial effects of nanocomposites	zno, nanoparticles, nps, antimicrobial, films, properties, antibacterial, oxide, packaging, food, activity, nanocomposite, silver, nanocomposites, agnps, zinc, chitosan, materials, metal, based	177	Nanomaterials in food packaging
Nanotechnologies to generate antimicrobial effects	electrospun, electrospinning, nanofibers, fibers, zein, food, active, pcl, properties, antimicrobial, packaging, multilayer, release, antioxidant, applications, morphology, encapsulation, loaded, materials, barrier	119	
Migration and toxicological risks of nanomaterials	silver, nanoparticles, agnps, migration, ag, food, nanosilver, nps, nanomaterials, icp, exposure, nm, toxicity, potential, oral, 10, particles, human, cell, effects	90	
Innovation and safety landscape of nanomaterials	nanotechnology, food, nanomaterials, nanoparticles, safety, applications, nano, packaging, review, new, industry, potential, products, use, nps, sector, agriculture, materials, science, application	86	

4.2. From valuation devices to valuation ecosystem

Just as societal concerns in the field have evolved, so too have the institutional structures addressing them. In particular, chemical safety experienced shifts in how it was understood and managed. We identified 42 types of valuation devices that food packaging companies engage with. Tables B.2 and B.3 in Appendix B provide a full list of valuation devices and their profiles. NGOs, often in collaboration with scientists, developed ratings and labels to inform consumers. Food companies and retailers introduced substances lists, testing procedures and procurement specifications to define and assess packaging characteristics in response to evolving market demands. A number of de-facto standards emerged in this context, representing key reference points for both NGOs and upstream companies articulating additional demands, and packaging companies navigating them. These include restricted substances lists, national regulations, and company strategies. Packaging firms collaborated via industry consortia to develop guidelines that define shared testing and design approaches.

The distribution of valuation devices across the describing dimensions is shown in Table 3. A key distinction lies in the actors by whom they are mobilized. Companies account for the largest number of valuation devices, deploying them for both field-level and internal functions. NGOs play a significant role as well, while regulators' involvement is limited to a few devices. Relatedly, valuation devices also vary by where they operate. The majority is embedded within companies or across supply chains, while others focus on assessing packaging materials before or after they have reached the market.

Moreover, these devices reflect different underlying logics within the field, each prioritizing specific values and material characteristics. Four main logics were identified. The functional materials logic emphasizes performance, cost, and marketing aspects of packaging, but is only of secondary concern in steering efforts because it is already well-established. Health concerns have long been addressed through a risk management logic, which ties chemical safety to tolerable exposure limits. The growing focus on hazard properties and phase-out strategies in the field is reflected in the high share of devices aligned with the hazard prevention logic. More recently, environmental concerns led to the formation of a plastic reduction logic, which focuses on the use of recycled and bio-based materials.

Beyond their criteria, valuation devices differ in how their judgements are embedded within selection environments, shaping to varying degrees matters of concern, fact and worth. Most devices assess materials and flag problematic findings, while about a third engage in problem-setting, and qualify products as valuable solutions. Within a hazard-based logic, for instance, restricted substances lists identify harmful chemicals and portray their use as problematic, whereas eco-labels qualify materials without these as safe. Lastly, valuation devices vary in the practices they influence. About two-thirds intervene in normalizing and exchange practices, while one-third shape representational practices.

Table 3: Distribution of characteristics across valuation devices. Percentages indicate the share of devices found to embody a certain subdimension out of the whole set of valuation devices

Category	Dimension	Count	Percentage
Valuator	Societal valuator	15	35.7%
	Business valuator	22	52.4%
	Regulatory valuator	11	26.2%
	Self-valuation	8	19%
Site of Valuation	On market	8	19%
	Along supply chain	17	40.5%
	Gate before market	13	31%
	Internal	19	45.2%
Practices	Normalizing practices	25	59.5%
	Exchange practices	25	59.5%
	Representational practices	14	33.3%
Matters	Matters of fact	14	33.3%
	Matters of concern	34	81%
	Matters of worth	12	28.6%
Logics	Risk management	21	50%
	Hazard prevention	28	66.7%
	Circular economy	12	28.6%
	Functional materials	8	19%

In sum, the food packaging sector hosts a broad spectrum of valuation devices. While each device fulfils a discrete function within a delimited space, their properties, functioning and interactions create synergies, overlaps and contradictions. It is from these complex interactions among devices – not as isolated entities but as constituent parts in a wider whole – that the valuation ecosystem emerges.

4.3. Emerging topography of the valuation ecosystem

Figure 2 depicts a semantic network map of the valuation ecosystem in the European food packaging sector. Each node represents a distinct type of valuation device, with the colour indicating the period when it was first mobilized in steering attempts of actors. Valuation devices with similar functions tend to occupy proximate and interconnected positions. It becomes evident that the valuation ecosystem comprises three distinct domains, each emerging as a cluster of valuation devices that has been shaped by cumulative steering efforts of legislators, companies, or civil society actors, respectively.

The differentiation into domains of *regulatory oversight*, *societal assessment*, and *corporate compliance* (*grey shaded ellipses*) reflects different institutional logics in responding to evolving societal concerns. Each domain is thus shaped by a distinct way of framing and addressing chemical safety, promoting distinct criteria and behavioural expectations regarding its assessment and enactment. The domains are linked by valuation devices situated between them. Collectively forming three distinct institutional coupling areas (*clusters represented by colour shaded polygons*), these devices engage in aligning or translating between different rules and normative prescriptions.

When considering the three temporal phases, we observe that the valuation ecosystem was initially set in motion by a few regulatory and corporate devices (blue nodes), which now form two corners of the valuation ecosystem. European FCM regulation's initial focus on the migration of input substances, particularly those used in plastics, still manifests today through regulatory valuation devices based on migration limits *(RegChem_MigLimit)* and positive lists *(RegChem_PosList)*. The regulation for plastic FCMs (Regulation (EU) No 10/2011)[1], for instance, comprises lists of monomers and additives that may be used in their production. Responses by food and packaging companies strongly relied on valuation devices embedded within internal compliance structures. These devices, represented as *FoodComp_Test* and *PackComp_Test* in the top-left quadrant, evaluate products using standardized migration testing. Many of these tests are carried out by third-party laboratories commissioned by companies, which are then responsible for interpreting the results. In this early phase, health concerns were thus largely treated as external constraints, articulated through *Regulatory Oversight* and monitored within the *Corporate Compliance* domain, which together set broad boundaries for material development.

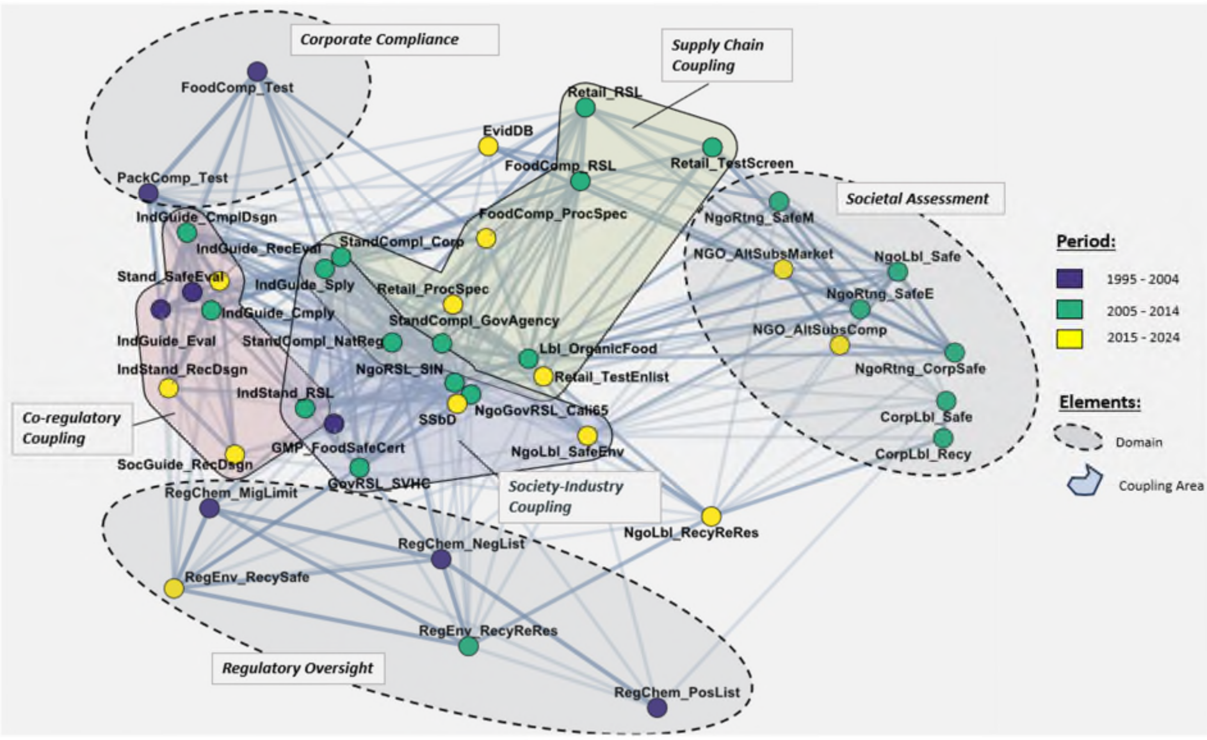

Figure 2: Topography of the valuation ecosystem. Each type of valuation device is represented as a node, with their colours indicating the period when they have first mobilized. Domains are indicated by grey-shaded ellipses and coupling areas as coloured polygons.

[1] Although regulation (EU) No 10/2011 was only adopted in 2011, it was based on the earlier Directive 2002/72/EC which build on similar devices.

That said, by the end of this initial phase, companies began to adopt more proactive approaches to material assessment. A distinct set of valuation devices emerged at the interface of regulation and corporate compliance, forming an area of *Co-regulatory Coupling*. This shift was driven by increasing regulatory and scientific attention to the migration of non-intentionally added substances (NIAS) like oligomers, and degradation and reaction products, as well as by a series of high-profile incidents of food contamination, many of which involved FCMs without harmonized regulation (Grob, 2017). Amid growing safety concerns, companies found themselves confronted with increasing pressure to demonstrate the safety of their materials yet faced uncertainty due to a lack of regulatory guidance on appropriate testing methods for non-intentionally added substances and the absence of harmonized EU rules for FCMs like printing inks or board and paper (Muncke et al., 2020). Regulation obliged companies to ensure product safety but left the means of doing so largely unspecified (Nerín et al., 2022). Packaging companies therefore began coordinating through intermediary organizations and technical committees to develop shared guidelines (*IndGuide_Eval*, *IndGuide_Cmply*), and standards (*Stand_SafeEval*), focussing on establishing and legitimizing common approaches to assess and design different packaging materials. Regarding the composition and assessment of packaging materials, a packaging company representative noted:

> "With no EU regulations, there are no clear guidelines on how this should be done. That's why NGOs and others often criticize the industry. […] Many industry associations have thus created their own guidelines, which members follow. I think it works well. We don't really need stricter laws" [CorpPack1]

These guidelines and standards established the definition of safe exposure levels and testing procedures as a shared domain of regulators and industry (Kato and Conte-Junior, 2021).

The second period from 2005 to 2014 (green nodes) shows growing involvement of civil society actors. A cluster of green nodes on the figure's right reflects the intensifying steering efforts by NGOs in coalitions with academic scientists, whose valuation devices largely define the *Societal Assessment* domain. Against the backdrop of mounting evidence regarding the scale and toxicity of migrating chemicals, slow and ineffective regulatory responses led civil society actors to perceive a widening regulatory void in which consumers were being exposed to substances of concern at levels exceeding socially acceptable thresholds. Explaining their growing involvement in steering efforts, an interviewee from a consumer organization remarked:

> "There's a general understanding that we have the legislation, it takes care of the most important and serious problems, but it takes so long. So, we have this gap where we know something, but still don't have the regulation. And there is a need for information to consumers so that they can act on it." [NgoCons2]

Of particular concern for NGOs is the continued use of certain hazardous substances in packaging materials by companies, which remain inadequately regulated in food packaging. A coalition of NGOs and scientists therefore introduced a broad array of labels (*NgoLbl_Safe*) and rating systems (*NgoRtng_SafeM* and *NgoRtng_SafeE*). Consumer organizations, for instance, increasingly assess food products in commerce for the presence or migration of certain substances of concern, and compare them against official recommendations. These valuation devices often rely on testing procedures that are independent of companies and aim to inscribe science-based criteria to the selection environment, which deliberately exceed the respective regulatory requirements.

The emerging *Societal Assessment* domain engages in two key processes: it evaluates whether products in the marketplace align with societal concern through ratings, and it shapes market dynamics by valorising certain products with labels. To signal pro-active compliance with rising societal expectations, companies have also begun to claim the absence of certain substances through self-declared Type II labels such as "BPA-free" or "without PFAS" (*CorpLbl_Safe*). Furthermore, alternative marketplaces (*NGO_AltSubsMarket*) and substitution assessment tools (*NGO_AltSubsComp*) were introduced by NGOs and research groups, which position different types of chemicals, barrier coatings, printing inks, adhesives etc. as safer alternatives to conventionally used intermediary inputs for packaging. A salient example is ChemSec Marketplace, which lists alternative offerings that do without substances of concern such as phthalates, PFAS, or bisphenol A. Overall, these valuation devices embedded chemical safety as a key quality in both consumer markets and industrial supply chains, assessing whether products increase or reduce exposure to hazardous chemicals.

In seeking to minimize reputational risks and enhance market positioning, corporate compliance has become increasingly shaped by societal assessment, manifesting in two coupling areas. First, the *Society-Industry Coupling area* illustrates how the demands of scientists and NGOs, reaching beyond regulatory mandates, have recently come to define shared standards of chemical safety within the field. Several centrally positioned nodes reflect this trend, highlighting the role of alternative restricted substances lists (RSLs) at the core of this development. Denoted as *NgoRSL_SIN*, *NgoGovRSL_Cali65*, and *GovRSL_SVHC*, these lists identify chemicals associated with adverse health effects that are not yet formally regulated in FCMs. Lists such as the SIN List, the REACH Candidate List of substances of very high concern, or the California Proposition 65 List of Chemicals are cases in point. Alluding to the quasi-standard nature of such lists, an employee from a packaging company explained:

> "Customer from Nordic countries often take the SIN as a reference and demand compliance with it. But I don't really agree with all of what is on there" (CorpPack1)

A second coupling between societal demands and corporate compliance emerges from the strategic efforts of food companies and retailers to govern their production networks, as represented by the *Supply Chain Coupling* polygon. Confronted with heightened reputational risks, they have sought to internalize and disseminate societal demands within the supply chain through procurement specifications like packaging guidelines and style guides (*Retail_ProcSpec* and *FoodComp_ProcSpec*). Highlighting the role of valuation devices advanced by retailers, an interviewee from a packaging company stated:

> "Retail is a big driving force (…). By now, hardly any retailer hasn't published a style guide, signalling to suppliers: this is how packaging should look, how it should be constructed, and what components to use or avoid. This affects us as the next link in the chain. (…) We must meet those demands." (CorpPack4)

Additionally, migration and screening tests have become common means to establish and assess the properties of materials supplied to them (*Retail_TestScreen* and *Retail_TestEnlist*). These practices are often based on internal restricted substances lists (*FoodComp_RSL* and *Retail_RSL*), which are drawing on industry-wide lists. Some retailers have assumed intermediary roles, framing themselves as consumer advocates bridging the gap between societal concerns and corporate compliance mechanisms. For instance, the Danish retailer Coop introduced the "Dirty Dozen" in 2016, a list of twelve (groups of) chemicals of concern the company aimed to remove from its private labels. In sum, such lead firms can be seen to introduce chemical safety criteria into supply chain interactions, setting reference points that define expectations and markets for packaging suppliers.

In the context of this second coupling, a range of de-facto standards has taken shape, which institutionalize safety criteria by legitimizing additional requirements of reputationally exposed firms and coordinating company practices in the sector. These standards are typically anchored in regulations and policy recommendations within specific countries, or in progressive corporate packaging strategies (*StandCompl_Corp*). The nodes referred to as *StandCompl_GovAgency* and *StandCompl_NatReg*, for instance, refer to the German BfR Recommendation 36 for board and paper, and the Swiss Printing Inks Ordinance respectively, which have become key standards for companies producing these FCMs without harmonized regulation. The relevance of such standards is underscored in the following quote:

> "There is the BfR 36 - a guideline from Germany that is widely used in Europe, especially Central Europe. Though technically a guideline, it's practically treated as a law. (…) Since few things are truly regulated at the EU level, most of Europe relies on BfR 36 for compliance [in board and paper]." (CorpPack2)

Similarly, Nestle's packaging guide, which is represented by *StandCompl_Corp*, has become a key guidepost for companies within the sector. Set up by the company in response to major incidents in the 2000s, the guide's progressive criteria today exert a structuring effect by providing a common benchmark for suppliers and upstream actors in the field.

In the last period from 2015 onwards (yellow nodes), we observe a further expansion of the valuation ecosystem, which is largely driven by concerns about the environmental impacts of packaging. This trend is also reflected in the growth of biomaterials publications, as captured by the topic model presented above. As the valuation ecosystem formed around chemical safety, new valuation devices began to emerge at the fringes of its different domains. These included NGO-operated labels focused on recycling and bio-materials (*NgoLbl_RecyReRes*), and corporate efforts to develop standards to assess and design such materials (*IndGuide_RecEval* and *IndStand_RecDsgn*). Additionally, recent regulations have set strong requirements regarding the recyclability and shares of recycled materials that will come into effect in the coming years (*RegnEnv_RecyReRes*). As recycling introduces additional risks of chemical migration due to contaminants, degradation, and inconsistent feedstock, recent valuation devices promoting circularity may come into conflict with those focused on safety.

However, valuation devices integrating environmental and health concerns have also emerged recently. In addition to restricted substances lists, it has been particularly by-design approaches (*SSbD*), that were introduced to ensure the absence of hazardous substances in both virgin and recycled materials. Moreover, recent regulations, such as the Packaging and Packaging Waste Regulation captured by node *RegEnv_RecySafe* and eco-labels (*NgoLbl_SafeEnv*), have a more integrative character. Until now, the introduction of new valuation devices has primarily contributed to a proliferation of possible innovation pathways within the field. Nevertheless, recent discussions around hazard-based approaches and more integrative devices suggest a shift towards consolidation within the ecosystem through which the number of devices may be reduced and their boundaries sharpened.

5. Discussion

The study reconstructed how actors have mobilized a wide range of valuation devices to address a widening institutional void left by insufficient regulatory responses to growing evidence of the health and environmental risks of food packaging. Shaped by a plurality of intentional steering attempts, the resulting selection environment is often one of overlapping, conflicting and complementary demands, which do not chart a singular racetrack towards a common goal but instantiate a diversity of possible directions for packaging innovations. In line with the transformative innovation model described by Schot & Steinmueller (2018), the valuation ecosystem constitutes a key site where divergent societal values are enacted, contested, and negotiated around both new and incumbent technologies and products. Directionality emerges as a systemic property of the valuation ecosystem, resulting from the continuous strategic positioning and partial alignment of valuation devices across regulatory, corporate, and societal domains. These interactions structure corridors of legitimate innovation pathways that extend beyond the prescriptions and intentions of individual actors.

Our results suggest that the valuation ecosystem charts shifting corridors for the development and commercialization of packaging materials, as valuation devices are introduced in response to evolving concerns. These build on and transform existing configurations to constrain some pathways while opening others. Criticism of FCM regulation often points to what may be seen as a failure to define and enforce sufficiently restrictive corridors for packaging innovations that keep consumer exposure to hazardous chemicals within socially acceptable bounds. From this perspective, valuation devices formed a core element of NGOs' attempts to narrow these corridors by restricting substances, tightening migration limits, and enforcing compliance. To demonstrate adherence to these boundaries, companies consequently relied on valuation devices that specify and assess material characteristics throughout product development and the supply chain. Emerging standards and guidelines reflect how companies both negotiated alignment with these boundaries and attempted to reshape innovation pathways themselves. More recently, valuation devices addressing environmental concerns formed innovation pathways around plastic alternatives. Initially, these devices prioritized environmental aspects over chemical safety, resulting in partially conflicting pathways. More recent efforts to integrate environmental and safety criteria, however, have begun to define more coherent innovation pathways.

Resonating with Smith et al. (2005), our results suggest that actors intentionally position valuation devices within the ecosystem to articulate selection pressures or build adaptive capacities in response. Devices, such as NGO ratings or retailer specifications, translate societal concerns into explicit demands companies must address. Others, including industry guidelines, alternative marketplaces and labels, contribute to building resources by shaping markets for alternative materials, legitimizing testing and design approaches, and developing pooled tools such as shared assessment methods. In this sense, valuation devices represent strategic interventions in the configuration of valuation ecosystems through which actors seek to alter existing corridors or improve their capacity to operate within them.

It is through actors' conscious engagement with existing configurations of valuation devices, that these become increasingly interconnected and begin to function as components of a larger ecosystem. Mirroring observations in other sectors (Reinecke et al., 2012; Turcotte et al., 2014), the structure of the valuation ecosystem is shaped by processes of convergence and differentiation, as actors inscribe aligning or contrasting criteria in valuation devices while negotiating which pathways should be enabled or restricted. The systemic character emerges from functional interlinkages within particular subsets of devices that share common criteria or reference one another, allowing them to fulfil complementary functions. These interlinkages not only increase devices' collective capacity to shape specific pathways, but also create interdependencies that make their evolution increasingly path dependent. Over time, the valuation ecosystem then reflects the cumulative effects of prior choices and interventions. Actors' steering attempts target configurations of valuation devices that themselves are outcomes of past steering attempts and alignment. In sum, the valuation ecosystem's development is a systemic and evolutionary process, where the range of possible directions is dependent on past alignments and exclusions.

6. Conclusion

The integration of societal concerns in technology development represents a central tenet of innovation studies. Directionality emerged as a key concept in this regard, emphasizing both the systemic processes that lead innovations to follow particular trajectories, and actors' intentional steering efforts to align them with societal goals. While prior research has shed light on the drivers and barriers of such reconfigurations, it has paid less attention to the mechanisms through which societal values act upon technology development. This omission becomes particularly salient in contexts where technological trajectories are subject to multiple normative demands, which are increasingly recognized as a core characteristic of innovation processes directed at broader societal goals (Schot and Steinmueller, 2018).

This paper addresses this gap by focusing on valuation devices as key means for actors' steering attempts, suggesting that the introduction of new devices in relation to evolving concerns and existing institutional setups can give rise to valuation ecosystems. Our empirical analysis of the European food packaging sector reveals how diverse and layered attempts of actors to address societal health and environmental concerns have formed a valuation ecosystem. Directionality within the sector constitutes an emergent system property, as evolving configurations of valuation devices collectively define shifting corridors for packaging innovation. Our framework contributes to the analysis of directionality by highlighting valuation devices as crucial mechanisms through which societal values are embedded and negotiated within technology development. Closer investigation into the interlinkages between valuation devices can offer insights into the mechanisms through which they constrain existing corridors or enable new ones. This calls for deeper analysis of the functional linkages among subsets of devices that not only allow them to jointly shape innovation pathways, but also create systemic interdependencies that drive co-evolution and produce system-level properties.

Focussing on institutional structures and mechanisms, the valuation ecosystem concept complements the predominant emphasis on socio-cognitive dynamics around visions and expectations in guiding technology development towards societally desirable directions. It furthermore provides an additional lens for assessing transformative system failures (Weber and Rohracher, 2012). Rather than stemming solely from the absence of coordinating visions and imaginaries, directionality failure can also emerge from underdeveloped valuation ecosystems, leading to the inability to establish legitimate innovation pathways. Along similar lines, demand articulation failures and reflexivity failures may be linked to deficiencies in more specific functions within the valuation ecosystem. While demand articulation stems from a lack of mechanisms communicating market signals to anticipate and learn about consumer needs, the sources for reflexivity failures may be found in a lack of devices that monitor and adapt to changes as the transformation unfolds. Lastly, examining how different valuation devices relate to one another may hint at policy coordination failures. By stabilizing inconsistent and conflicting valuations, misaligned valuation devices generate contradictory impulses and signals that may hinder coordinated innovation and system-building efforts.

As part of an emerging effort to outline key structures and mechanisms of the selection environment, this paper also carries several limitations that may suggest areas for future research. First, our analysis did not fully attend to the interlinkages between valuation devices, involving both synergies and frictions among them. In particular, this may obscure key moments and sites of dissonance, where valuation can open new pathways for innovation and institutional change (Hussels et al., 2024). Closer attention is also needed to how the functional interlinkages between devices are actively constructed and maintained, which form those interdependencies that underpin their systemic dynamics. Second, the framework currently gives limited consideration to the varying capacities of actors to shape parts of the valuation ecosystem and thereby assert their goals and priorities within it. Yet examples abound demonstrating how powerful incumbents influence standard-setting, classification schemes or regulations to slow down transitions (Smink et al., 2015). Future research might therefore zoom in on specific groups of valuation devices and the ways actors, endowed with different kinds of resources, modify both their characteristics and interrelations. Third, this may also highlight the power of valuation devices to shape valuation ecosystems. Valuation devices differ in terms of their degree of institutionalization, i.e. the extent to which they are accepted by a broad range of actors and referenced by other devices. An important direction for future research lies in analysing how the relative weight and level of valuation devices determines their position within the valuation ecosystem. Linking these dynamics to specific actors offers insights into the politics of directionality, which is tied to questions of who possesses the power to influence valuation processes (Parks, 2022).

A final aspect that deserves further attention concerns the spatial dimension of valuation. In line with emerging interest in the ways institutional dynamics shape the geography of innovation, the valuation concept lends itself to study how configurations of spatially anchored capabilities, institutions and actors may structure opportunity spaces for development paths (Carvalho and Vale, 2018). The development of new assessment methods for hazardous chemicals, for instance, has reportedly followed different trajectories in the United States, Europe or China (Hartung, 2010). This suggests that these macro-regions provide distinct valuation contexts comprising different concerns, knowledge bases and institutional structures. Similarly, the introduction of novel valuation devices within regions or countries is likely to depend on their existing institutional make-up. Recent research has shown such path dependencies in institutional dynamics in the context of national climate policies (Mealy et al., 2025). In conclusion, specifying the selection environment through a valuation perspective provides ample opportunities to further our understanding of the directionality and geography of innovation.

Appendix A

Introduction

The appendix presents additional information on the methods (Appendix A) and results (Appendix B). Section A.1 elaborates on the collection and cleaning of publication data for the topic modelling exercise. Section A.2 lays out the steps that are combined by BERTopic, going from sentence embeddings to the clustering of documents and finally the representations of the resulting topics. Section A.3 focuses on the interview campaign and the rationales behind interviewee selection and drafting the interview guideline. Appendix B allows for a closer examination of our results. Section B.1 presents the identified topics in the corpus of publications, while Section B.2 zooms in on the involvement of different organizations across topics. Finally, Section B.3 shows the profiles of valuation devices, alongside descriptions, examples and explanations regarding their characterization.

A.1 Search string for corpus of scientific abstracts

The topic modelling is based on a corpus of scientific abstracts about food packaging. The data was obtained from Scopus via a search query based on the following keywords in either the title, abstract or provided keyword of the articles: ("food packag*" OR "beverage packag*" OR "packaging of food*" OR "packaging of beverag*" OR “packaging for food*” OR "packaging for beverag*" OR ("packaging material*" AND food) OR ("packaging material*" AND beverages) OR "food container*" OR "beverage container*"). The corpus was limited to English articles and reviews published in scientific journals between 1970 and 2023. In terms of geographical scope, the corpus only encompasses scientific papers that were (co-)authored by at least one author affiliated to a European organization.

After data cleaning and initial data analyses, we decided to exclude abstracts with the following keywords in the title: "label", "labelling", "health", "healthier", "diet", "dietary", "nutrition", "nutritional", "obesity", "allergy", "allergenic", "allergic", "allergen", "allergens", "labeling". This was necessary to improve the quality of the topic modelling results. The keywords point towards the topics health/dietary labelling and allergy labelling, which are only indirectly linked to food packaging materials.

A.2 Key steps in transformer-based topic modelling

Quantitatively analysing text through topic modelling requires several steps to transform the original text data. Figure A.1 provides an overview of the processing pipeline. In a first step, the text contained in the abstracts was transformed into embeddings. Text embeddings are numerical representation of the text where words or sentences are represented in the form of dense vectors. Capturing the semantic meaning of and relationship between text sequences, text embeddings measure the relatedness of text strings. As the generated text embeddings are represented in a highly dimensional space, the second empirical step employed UMAP for dimensionality reduction. UMAP is a popular alternative to t-SNE, as it is faster, allows better for scaling, and preserves the global structure of the data. Based on this information on the relatedness of the text contained in the abstracts, the abstracts were clustered into groups of relatively similar texts according to their embeddings. To do that, we relied on HDBSCAN, a non-parametric and density-based clustering method.

Hyperparameter tuning of BERTopic involved in particular the control of the minimum cluster size in HDBSCAN. Furthermore, outliers were controlled during clustering, as well as the dimensionality of embeddings and number of neighbouring sample points for dimensionality reduction with UMAP. Assessment of model performance relied on the silhouette score and manual inspection of topics. Ranging from -1 to 1, the silhouette score provides an indication for clustering quality and can be used to assess how well documents are grouped into topics. The final topic model specification reached a silhouette score of 0.51.

Abstracts that have been attributed to the same cluster represent one topic. Based on the text contained in each cluster's abstracts, different topic representations were generated. Our main topic representation are keywords generated by c-TF-IDF, a class-based TF-IDF that joins all documents per class. By setting the number of times a word occurs in a document (term frequency, TF) in relation to its commonness across the whole set of documents (inverse document frequency, IDF), TF-IDF provides a measure for a word's relevance within a document. The TF-IDF topic representation accordingly captures the most relevant words for each topic. This topic representation was complemented by two more keyword representation of the topics: maximum marginal relevance (MMR) and KeyBERT. While MMR captures the breath of keywords within a class of documents through reducing the redundancy among keywords, KeyBERT uses the embeddings of the BERT language model together with cosine similarity in order to identify the text strings in a document that share the highest similarity with the document itself.

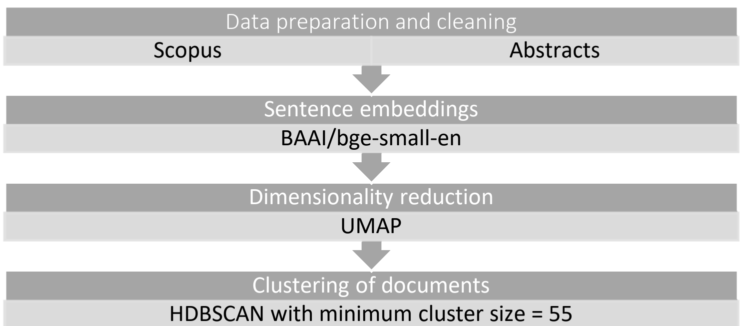

Figure A.1: Key steps in BERTopic

A.3 Interview campaign

The second part of the empirical analysis set out to examine key elements and mechanisms of the selection environment, focusing on their evolution over time in relation to emerging societal concerns. The analysis draws on a series of interviews with 18 stakeholders in the European food packaging sector. Based on three scoping interviews, 14 semi-structured interviews with 15 interviewees were conducted. Interviewee selection focused on actors' involved in articulating selection pressures such as retailers or authorities as well as on those that have to respond to them like packaging companies or testing laboratories. Table A.1 provides a list of interviewees.

An interview guideline was prepared, which starts with general questions on how packaging requirements have evolved over time, followed by a discussion of the channels through which companies are exposed to different demands. The interviews concluded with a section on how companies and other stakeholder are confronted with or try to address these concerns, focusing on the establishment of new valuation devices. The interview guideline was revised as the campaign progressed and brought up new aspects relevant to our research questions that have not been included before. Recordings were transcribed verbatim using NoScribe (Dröge, 2024) and manually revised for accuracy. Qualitative coding was structed around 1st- and 2nd-order analysis, moving from rather direct representations of interviewees' understanding of the problems at hand to a more aggregated and synthesized set of categories which tie in with theoretical considerations (Gioia et al., 2013). A tentative conceptual framework was developed at the beginning, which co-evolved with the interviews.

Table A.1 : List of interviewees

Interviewee	Code	Organization	Role, Department / Type	Country, Market	Interview type
1	CorpRetl1	Company, retail	Sustainability department	DE, Europe	Semi-structured
2	CorpTest1	Company, compliance consulting	/	CH, Europe	Semi-structured
3	NgoChem1	NGO, chemicals	Regulatory affairs	UK, Europe	Semi-structured
4	CorpRet2	Company, retail	Quality management	DK, DK	Semi-structured
5	NgoChem2	NGO, chemicals	"Managing VDs"	SE, Europe	Semi-structured
6	NgoCons1	NGO, consumers	Chemicals, regulation	BE, Europe	Semi-structured
7	NgoCons2	NGO, consumers	Chemicals, testing	DK, DK	Semi-structured
8	CorpPack1	Company, packaging	Regulatory compliance	AT, Europe	Semi-structured
9	CorpRet3	Company, retail	Sustainability department	CH, Europe	Semi-structured
10	CorpPack2	Company, packaging	Regulatory compliance	AT, Europe	Semi-structured
11	CorpPack3	Company, packaging	Sustainability department	DE, DE	Semi-structured
12	Reg1	Regulatory, former government authority	Advisor	FI, Europe	Semi-structured
13	CorpRet4	Company, retail	Sustainability department	CH, CH	Semi-structured
14	CorpPack4	Company, packaging	Marketing and Sales	DE, Europe	Semi-structured
15	CorpPack5	Company, packaging	Regulatory compliance	DE, Europe	Semi-structured
16	Scope1	Research institute	Toxicology department	CH	Scoping
17	Scope2	NGO, chemicals	Food packaging	CH	Scoping
18	Scope3	University	Chemistry	CH	Scoping

Appendix B

B.1 Topic representations

Table B.1 presents the topics identified in the corpus of scientific abstracts. In addition to the manually assigned topic name, it presents the topic representations and the number of articles assigned to each topic. The topics are ordered by the concerns they relate to, which is represented in the last column.

Table B.1: Overview of topics

Topic name	Ctf- idf representation	KeyBERT representation	MMR representation	Count	Concern
Packaging Effects on Microbial Growth	[storage, samples, meat, map, days, stored, atmosphere, shelf, co2, growth, life, quality, vacuum, packaging, modified, microbial, spoilage, packaged, sensory, bacteria]	['packaging', 'meat', 'pork', 'beef', 'listeria', 'strains', 'isolates', 'fillets', 'bacteria', 'bacterial']	['storage', 'meat', 'co2', 'vacuum', 'packaging', 'spoilage', 'bacteria', 'fresh', 'conditions', 'cfu']	1.442	Preservation and protection of food
Active and Intelligent Packaging	['sensor', 'food', 'sensors', 'packaging', 'intelligent', 'oxygen', 'quality', 'indicator', 'color', 'indicators', 'ph', 'monitoring', 'detection', 'temperature', 'based', 'smart', 'systems', 'freshness', 'active', 'packages']	['packaging', 'sensors', 'anthocyanin', 'anthocyanins', 'co2', 'polymer', 'sensing', 'sensor', 'materials', 'h2o2']	['sensor', 'sensors', 'packaging', 'indicators', 'ph', 'smart', 'freshness', 'colorimetric', 'products', 'sensing']	294	
Packaging Barrier Properties: Multi-layer Materials	['seal', 'pressure', 'packaging', 'process', 'steel', 'food', 'corrosion', 'material', 'used', 'high', 'properties', 'materials', 'laser', 'water', 'polymer', 'aluminum', 'model', 'temperature', 'welding', 'heat']	['polypropylene', 'polyethylene', 'polymer', 'packaging', 'sealing', 'adhesion', 'lacquer', 'seal', 'materials', 'coatings']	['seal', 'packaging', 'steel', 'materials', 'aluminum', 'welding', 'heat', 'results', 'coated', 'tinplate']	164	
Packaging Barrier Properties: Aroma Scalping	['aroma', 'permeability', 'water', 'sorption', 'polymer', 'evoh', 'ethylene', 'polyethylene', 'gas', 'temperature', 'packaging', 'compounds', 'barrier', 'properties', 'film', 'ldpe', 'permeation', 'food', 'tocopherol', 'oxygen']	['polymers', 'copolymers', 'polyethylene', 'polymer', 'polypropylene', 'ethylene', 'packaging', 'permeability', 'sorption', 'polymeric']	['aroma', 'permeability', 'sorption', 'ethylene', 'polyethylene', 'packaging', 'ldpe', 'limonene', 'polymers', 'materials']	141	
Packaging Barrier Properties: Wine Aging	['cork', 'wine', 'wines', 'tca', 'stoppers', 'compounds', 'aging', 'volatile', 'so2', 'corks', 'oak', 'oxygen', 'barrels', 'bottle', 'months', 'wood', 'bottles', 'different', 'closure', 'analysis']	['corks', 'wine', 'phenolic', 'aldehydes', 'wines', 'bottling', 'compounds', 'pulps', 'chromatography', 'bottles']	['wine', 'compounds', 'aging', 'corks', 'barrels', 'wood', 'bottles', 'stopper', 'bleaching', 'otr']	80	
Packaging Barrier Properties: Plasma Surface Modification	['plasma', 'barrier', 'surface', 'films', 'oxygen', 'layers', 'permeation', 'coating', 'coatings', 'properties', 'deposited', 'deposition', 'film', 'pet', 'layer', 'coated', 'siox', 'packaging', 'substrate', 'bopp']	['polymers', 'polypropylene', 'polyethylene', 'coatings', 'polymer', 'coating', 'coated', 'laminates', 'nanoparticles', 'permeability']	['plasma', 'barrier', 'coating', 'coatings', 'coated', 'adhesion', 'oxide', 'substrates', 'materials', 'aluminum']	77	
Chemical Migration from Packaging	['migration', 'food', 'bpa', 'contact', 'used', 'substances', 'exposure', 'kg', 'materials', 'compounds', 'ms', 'samples', 'method', 'bisphenol', 'packaging', 'mass', 'mg', 'phthalate', 'simulants', 'using']	['bisphenol', 'bpa', 'foodstuffs', 'packaging', 'plastics', 'phthalate', 'chromatography', 'phthalates', 'chemicals', 'styrene']	['bpa', 'substances', 'materials', 'compounds', 'samples', 'bisphenol', 'packaging', 'phthalate', 'simulants', 'chromatography']	1.133	Chemical safety of packaging
Safety Evaluation of Recycled PET	['pet', 'recycled', 'recycling', 'polymer', 'food', 'bottles', 'migration', 'plastic', 'diffusion', 'packaging', 'polyethylene', 'process', 'material', 'virgin', 'used', 'terephthalate', 'plastics', 'pyrolysis', 'using', 'contaminant']	['terephthalate', 'plastics', 'polymers', 'polyethylene', 'polypropylene', 'polymer', 'packaging', 'plastic', 'acetaldehyde', 'recycling']	['recycled', 'diffusion', 'packaging', 'polyethylene', 'terephthalate', 'plastics', 'pyrolysis', 'materials', 'polymers', 'contaminants']	272	
Migration of Heavy Metals	['al', 'mg', 'cadmium', 'aluminium', 'tin', 'lead', 'chromium', 'kg', 'metals', 'levels', 'cr', 'µg', 'pb', 'concentrations', 'food', 'concentration', 'atomic', 'intake', 'samples', 'mercury']	['cadmium', 'aluminium', 'arsenic', 'aluminum', 'concentrations', 'tea', 'metals', 'lead', 'acid', 'juices']	['mg', 'cadmium', 'aluminium', 'lead', 'chromium', 'metals', 'levels', 'concentrations', 'mercury', 'foods']	64	
Bioplastics based on Starch	['films', 'based', 'packaging', 'starch', 'properties', 'protein', 'materials', 'food', 'edible', 'film', 'biodegradable', 'mechanical', 'water', 'waste', 'used', 'plastics', 'gelatin', 'bio', 'applications', 'environmental']	['bioplastics', 'biopolymers', 'bioplastic', 'polymers', 'biopolymer', 'biodegradable', 'plastics', 'pectin', 'packaging', 'composites']	['packaging', 'materials', 'film', 'biodegradable', 'plastics', 'gelatin', 'bioplastics', 'biopolymers', 'proteins', 'coatings']	518	Bio-based and biodegradable materials
Bioplastics based on PLA	['pla', 'properties', 'films', 'barrier', 'poly', 'mechanical', 'wt', 'packaging', 'thermal', 'acid', 'food', 'materials', 'phb', 'applications', 'based', 'polymer', 'blends', 'phbv', 'film', 'biodegradable']	['biocomposites', 'polymers', 'nanocomposite', 'nanocomposites', 'biodegradable', 'polymer', 'pla', 'composites', 'polylactic', 'poly']	['pla', 'packaging', 'materials', 'phb', 'polymer', 'blends', 'biodegradable', 'antimicrobial', 'nanocomposites', 'composites']	481	
Bioplastics based on Chitosan	['chitosan', 'films', 'properties', 'film', 'antimicrobial', 'activity', 'cs', 'active', 'water', 'packaging', 'based', 'mechanical', 'food', 'antioxidant', 'lae', 'addition', 'showed', 'applications', 'used', 'materials']	['chitosan', 'biodegradable', 'antibacterial', 'biopolymer', 'antimicrobial', 'antioxidant', 'chitin', 'packaging', 'gelatin', 'glycerol']	['chitosan', 'film', 'antimicrobial', 'packaging', 'antioxidant', 'materials', 'natural', 'results', 'zein', 'chitin']	339	

Bioplastics based on Cellulose	['cellulose', 'properties', 'barrier', 'films', 'water', 'nanocellulose', 'paper', 'mechanical', 'packaging', 'materials', 'based', 'coating', 'applications', 'cnf', 'coated', 'food', 'cnc', 'pva', 'oxygen', 'xylan']	['nanocellulose', 'cellulose', 'nanocomposite', 'nanocomposites', 'biodegradable', 'nanofibers', 'chitosan', 'polymer', 'hemicellulose', 'composites']	['cellulose', 'nanocellulose', 'paper', 'packaging', 'materials', 'applications', 'cnc', 'coatings', 'composite', 'starch']	254	
Marine Litter and Microplastics	['litter', 'plastic', 'marine', 'items', 'microplastics', 'debris', 'plastics', 'sites', 'environment', 'containers', 'food', 'beach', 'pollution', 'coastal', 'abundance', 'sediment', 'mps', 'use', 'species', 'accumulation']	['macroplastics', 'plastics', 'sediments', 'sediment', 'litter', 'anthropogenic', 'environmental', 'pollution', 'benthic', 'polymers']	['microplastics', 'debris', 'plastics', 'environment', 'containers', 'pollution', 'sediment', 'mps', 'aquatic', 'rats']	111	
Bioplastics based on Bio-based Polyesters	['pef', 'pet', 'poly', 'copolymers', 'molecular', 'polyesters', 'properties', 'furanoate', 'synthesized', 'polyester', 'thermal', 'polycondensation', 'pbs', 'bio', 'barrier', 'based', 'ethylene', 'high', 'applications', 'mol']	['polymers', 'polyesters', 'copolymers', 'polycondensation', 'polyester', 'copolymerization', 'copolymer', 'polymer', 'copolyesters', 'nanocomposites']	['pef', 'copolymers', 'polyesters', 'furanoate', 'polyester', 'polycondensation', 'ethylene', 'copolyesters', 'butylene', 'polymers']	55	
Packaging in Food System Sustainability Challenges	['food', 'packaging', 'consumers', 'environmental', 'waste', 'products', 'study', 'product', 'impact', 'results', 'consumption', 'consumer', 'energy', 'foods', 'information', 'production', 'data', 'health', 'research', 'use']	['sustainability', 'packaging', 'environmental', 'sustainable', 'impacts', 'consumption', 'impact', 'research', 'industry', 'emissions']	['packaging', 'consumers', 'environmental', 'results', 'consumption', 'health', 'research', 'impacts', 'content', 'participants']	1.159	Packaging in Food System Sustainability Challenges
Bio-based antimicrobial packaging with Carvacrol	['antioxidant', 'active', 'films', 'carvacrol', 'activity', 'packaging', 'extract', 'food', 'antimicrobial', 'essential', 'release', 'properties', 'eos', 'film', 'pla', 'thymol', 'compounds', 'cinnamon', 'oil', 'showed']	['biodegradable', 'bioactive', 'packaging', 'antioxidants', 'antioxidant', 'phenolic', 'polymer', 'antifungal', 'antibacterial', 'antimicrobial']	['antioxidant', 'active', 'films', 'carvacrol', 'packaging', 'antimicrobial', 'thymol', 'oils', 'extracts', 'materials']	259	Antimicrobial properties of biomaterials
Bio-based antimicrobial packaging with Nissin	['antimicrobial', 'packaging', 'food', 'active', 'films', 'nisin', 'materials', 'properties', 'biofilm', 'film', 'natural', 'activity', 'agents', 'shelf', 'growth', 'products', 'monocytogenes', 'life', 'meat', 'used']	['antimicrobial', 'antimicrobials', 'packaging', 'biodegradable', 'bioactive', 'preservatives', 'antioxidant', 'polymers', 'biofilm', 'listeria']	['antimicrobial', 'packaging', 'nisin', 'biofilm', 'products', 'monocytogenes', 'meat', 'bacteria', 'biofilms', 'compounds']	203	
Antimicrobial effects of Nanocomposites	['zno', 'nanoparticles', 'nps', 'antimicrobial', 'films', 'properties', 'antibacterial', 'oxide', 'packaging', 'food', 'activity', 'nanocomposite', 'silver', 'nanocomposites', 'agnps', 'zinc', 'chitosan', 'materials', 'metal', 'based']	['chitosan', 'nano-composites', 'nano-composite', 'nanoparticles', 'bionanocomposites', 'biodegradable', 'zno', 'antibacterial', 'antimicrobial', 'tio2']	['zno', 'nanoparticles', 'antibacterial', 'nanocomposite', 'nanocomposites', 'agnps', 'zinc', 'chitosan', 'materials', 'tio2']	177	Nanomaterials in food packaging
Antimicrobial Effects of Nanomaterials	['electrospun', 'electrospinning', 'nanofibers', 'fibers', 'zein', 'food', 'active', 'pcl', 'properties', 'antimicrobial', 'packaging', 'multilayer', 'release', 'antioxidant', 'applications', 'morphology', 'encapsulation', 'loaded', 'materials', 'barrier']	['electrospinning', 'curcumin', 'bioactive', 'nanostructured', 'nano-fibers', 'nanofiber', 'polymer', 'packaging', 'nanoparticles', 'antibacterial']	['electrospun', 'electrospinning', 'nanofibers', 'fibers', 'antimicrobial', 'packaging', 'multilayer', 'encapsulation', 'materials', 'nanofiber']	119	
Migration and Toxicological Risks of Nanomaterials	['silver', 'nanoparticles', 'agnps', 'migration', 'ag', 'food', 'nanosilver', 'nps', 'nanomaterials', 'icp', 'exposure', 'nm', 'toxicity', 'potential', 'oral', '10', 'particles', 'human', 'cell', 'effects']	['nanoparticles', 'nanoparticle', 'nanomaterials', 'nanosilver', 'agnps', 'nano', 'agnp', 'tio2', 'packaging', 'containers']	['silver', 'nanoparticles', 'agnps', 'nanosilver', 'nanomaterials', 'toxicity', 'rats', 'tio2', 'gastrointestinal', 'nanoparticle']	90	
Innovation and Safety Landscape of Nanomaterials	['nanotechnology', 'food', 'nanomaterials', 'nanoparticles', 'safety', 'applications', 'nano', 'packaging', 'review', 'new', 'industry', 'potential', 'products', 'use', 'nps', 'sector', 'agriculture', 'materials', 'science', 'application']	['nanotechnology', 'nanoparticles', 'nanomaterial', 'nanomaterials', 'nanotechnologies', 'nanosensors', 'nano', 'biosensors', 'nanofibers', 'research']	['nanotechnology', 'nanomaterials', 'nanoparticles', 'nano', 'packaging', 'industry', 'agriculture', 'nanomaterial', 'risks', 'research']	86	

B.2 Topic modelling: Engagement of organizations across topics

Additionally, we aimed to better understand what type of organizations engage with particular topics based on the affiliations of authors. The activity of organizations across the topics serves as an indicator for the internalization of societal concerns within the field. By measuring the engagement of different actor categories, positioned at varying distances from the core innovation process, we can gauge the proximity of these concerns to the effective innovation process. By and large, the vast majority of authors have been affiliated to universities (66.3%) or other research organizations (17.5%). 4.8% of authors have been affiliated to companies, and 3.2% to a ministry, agency or laboratory. Advocacy organizations account for a share of under 1% of authors. However, there is a stark contrast in the involvement of organizations across topics.

Figure B.1 shows the shares of articles that have been published across the topic groups for each organization class. Universities and research organizations have the most balanced portfolio across the different topics, being active in most domains. This may be attributed to both organizations' general strength in research and their broader problem focus. Moreover, universities and research organizations are relatively active in *Bio-based and biodegradable packaging*, which find rather limited coverage by companies. Government-related organizations, in contrast, have the least balanced portfolio, publishing the majority of papers on *Chemical safety of packaging*. As this class encompasses ministries, laboratories, as well as environmental and health agencies, this is a clear reflection of their focus on toxicology and public health.

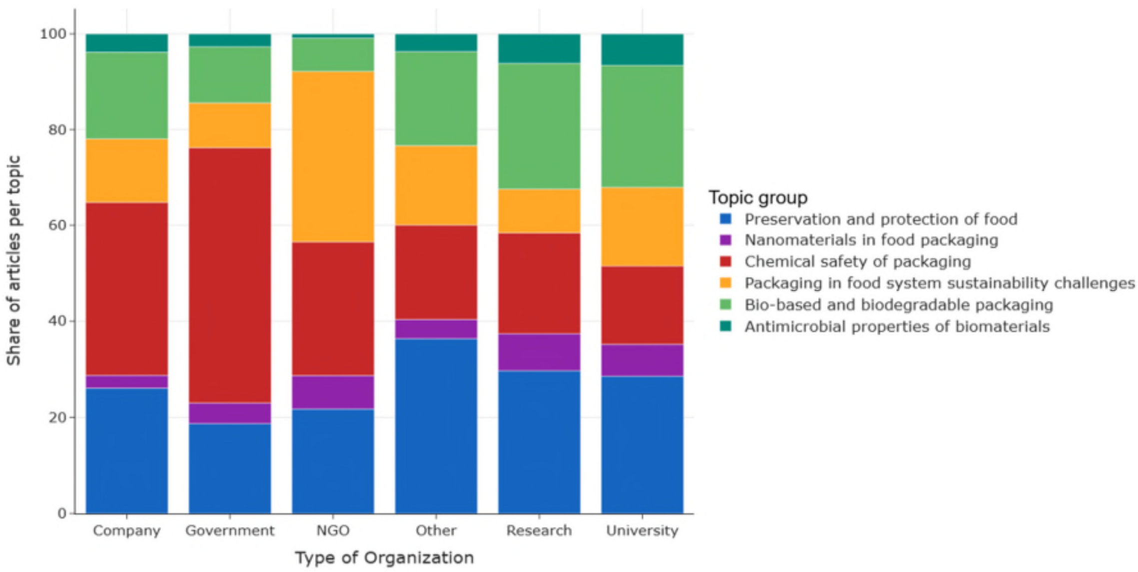

Figure B.1: Shares of articles on each topics for each class of organizations

Figure B.2 shows that Government-related organizations have been responsible for a relatively high share of articles on this topic until 2008, with a brief resurgence between 2012 and 2015. Companies hold the second highest share of publications on chemical safety. They increasingly started to engage with the topic only after 2008, indicating a growing corporate awareness. It is, however, universities and research organizations, which claim an ever higher share of articles on the topic due to their growing focus on packaging overall, accounting for about 60% and 20% of articles in the most recent years respectively.

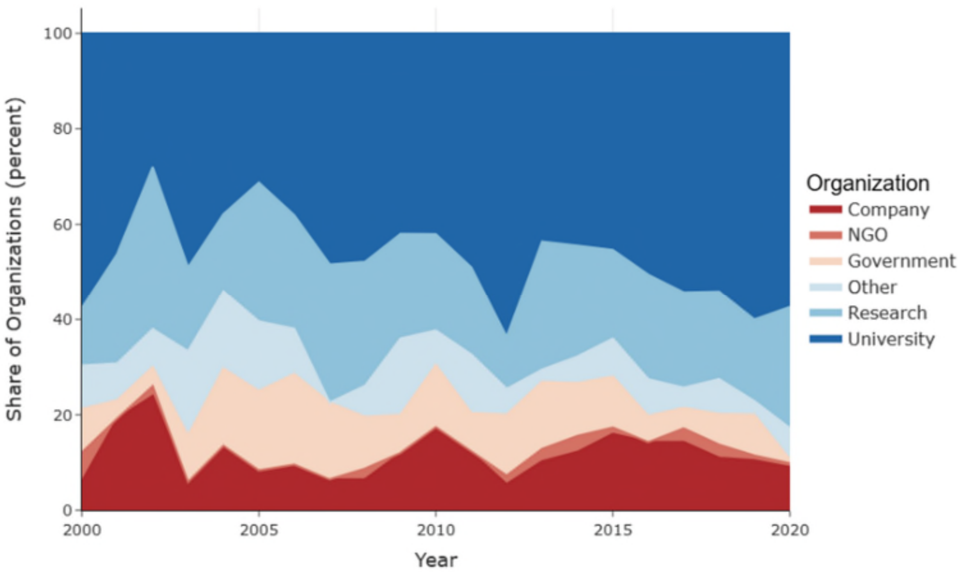

Figure B.2: Shares of organizations contributing to the topic "Chemical safety of packaging" in the period 2005 to 2020

B.3 Characterization of valuation devices

Identifying and characterizing valuation devices in food packaging constitutes a key steps in analysing the valuation ecosystem of this field. Table B.2 presents the types of valuation devices identified, accompanied by short descriptions and illustrative examples. Where available, examples are supported by links to relevant documents and websites. Given the confidential nature of some valuation devices, particularly those advanced by companies, the respective supporting materials often does not disclose the specific criteria or metrics on which they are based. In certain cases, examples from American initiatives are included to illustrate valuation devices, even though the primary focus of the analysis remains in the European Union. More broadly, it should be noted that examples of specific companies or organizations do not necessarily reflect the employers of our interviewees.

Table B.3 presents the profiles of valuation devices, which result from their characterization along the describing dimensions discussed in the theory section. These devices are primarily described in terms of their front end, i.e. the effect their judgements they have on innovation or market processes, rather than how this judgement was reached. If a valuation device was found to embody a specific dimension, it was coded with 1 and 0 otherwise. This results in a similarity matrix, which was visualized to reveal the structure of the valuation ecosystem.

Table B.2: Overview of classes of valuation devices identified

Name	Abbreviation	Description	Examples
NGO ratings based on extraction tests	NgoRtng_SafeE	NGOs conduct extraction tests of packaging materials within specific product categories on the market. Test results are published in magazines, online, or are taken up by the general media. These ratings often take the form of lists where different alternatives are compared to each other. NGOs also confront companies directly with testing results. Extraction tests can be seen to follow a more hazard-based approach as they primarily assess whether a particular substance is found in a material.	FIDRA UK: 'Forever' chemicals in 'single use' food packaging Danish Consumer Council: BPA and BADGE in coconut milk cans Friends of the Earth Germany: PFAS Verpackungscheck; Consumer Reports US: Dangerous PFAS Chemicals Are in Your Food Packaging IPEN: Forever chemicals in single-use food packaging and tableware from 17 countries Foodwatch: MOSH contamination in food
NGO ratings based on migration tests	NgoRtng_SafeM	NGOs conduct migration tests of packaging materials within specific product categories on the market. Test results are published in magazines, online, or are taken up by the general media. These ratings often take the form of lists where different alternatives are compared to each other. NGOs also confront companies directly with testing results. Migration tests primarily follow a risk-based approach because they are focused on the quantity of substances migrating into food, the risk assessment of which then involves additional information on their hazards.	Stiftung Warentest: BPA in canned foods European Consumer Organization BEUC: Silicon baking moulds Danish Consumer Council: Danish testing of printed paper packaging
Consumer safety labels licensed from NGOs	NgoLbl_Safe	Companies can license labels of NGOs based on the tests conducted by the latter. These tests generally target products that are already on the market. This option is primarily attractive in cases with positive testing results.	Ökotest Germany: Alnatura Margarine For context, this margarine was one of the few tested products in the sample that were not contaminated by MOSH/MOAH at levels that are considered to pose a threat to human health (see here).
General safety labels that indicate the absence of certain substances	CorpLbl_Safe	General labels that indicate the chemical safety of packaging materials. Typically Type II labels, which are not tested by third-party certifying body but self-declared based on ISO standard. Often refer to the absence of one specific chemical of concern like PFAS-free or BPA-free, for example.	Coop Denmark: PFAS-free Popcorn bags Nalgene US: Water bottles BPA/BPS-free Migros Switzerland: Food container BPA-free
General eco-labels indicating the share of recycled content and recyclability of materials	CorpLbl_Recy	General labels that indicate environmental characteristics, such as the share of recyclates and recyclability of packaging materials. Typically Type II, which are not tested by third-party certifying body, but self-declaration based on ISO standard.	Volvic rPET Bottles Mondelez Cadbury Chocolate Wrapper
General eco-labels which relate to both environmental protection and chemical safety	NgoLbl_SafeEnv	Broad eco-labels that address a range of environmental aspects and also relate to the use and migration of substances of concern. These are typically Type I labels, whose criteria are defined and independently verified by third-party organizations such as NGOs or government agencies.	Nordic Swan Ecolabel for packaging for liquid foods Craddle-to-Craddle product standard for packaging Blue Angel for food packaging like coffee to go cups
General eco-labels focused on circular economy and renewable resources	NgoLbl_RecyReRes	Type I labels focused on environmental aspects of packaging such as recycling and renewable resources. Labels can refer to a percentage of recycled materials, for instance, or the general "recyclability" of them. Other may relate to the degree to which they are bio-based, biodegradable, recycled/recyclable, based on responsibly sourced natural resources etc. The vast majority are based on pre-defined criteria companies have to adhere to.	Forest Stewardship Council (FSC) for packaging Tetra Pak FSC certification ISCC Plus for packaging PEFC Sustainably Managed Forests for sustainable packaging TÜV Austria Compostable Packaging
Organic food labels	Lbl_OrganicFood	General eco- or organic labels, which primarily focus on food but also include requirements on packaging materials that are used.	German Bioland Organic Label with requirements for packaging BioSuisse Knospe Packaging Guideline
Official food safety GMP standards for food packaging	GMP_FoodSafeCert	Food manufacturers and retailers expect suppliers to be certified to a recognized packaging safety standard maintained by a specific organization. These certifications often relate to the production and distribution of the manufacturers. Hazard Analysis Critical Control Point (HACCP), a recognized approach for food safety, is often a core element in these standards. They are mainly used for suppliers to signal to companies up the value chain that they comply with the necessary food safety standards	FSSC 2200 for Food Packaging BRCGS Packaging Materials IFS Food packaging guidelines

Standards for risk assessment	Stand_SafeEval	Standards for conducting risk assessment drafted by task forces of scientists and industry representatives from companies producing various FCMs and occupying different positions along the supply chain. These actors come together and summarize current scientific knowledge and state of the art of the safety evaluation of materials. These are not limited to a single FCM but have a broader applicability.	ILSI task force for Food Contact Materials ILSI guideline for NIAS assessment
Industry guidelines for migration testing	IndGuide_Eval	Guidelines for companies regarding methods for safety assessments. Developed by companies collaborating via industry associations. Recommends testing methods for assessing the migration of substances from materials into food. Such guidelines set standards and communicate the practices of companies to be safe.	European Printing Ink Association (EuPIA): EuPIA Guidance on Migration Test Methods for the evaluation of substances in printing inks and varnishes for food contact materials Association of the European Adhesive & Sealant Industry (FEICA): Migration testing of adhesives intended for food contact materials
Industry guidelines for general compliance	IndGuide_Cmply	Broader compliance guidelines that go beyond evaluation methods. Developed by companies collaborating via industry associations. These guidelines typically encompass positive lists and migration limits used in certain FCM types.	European Council of the Paint, Printing Ink, and Artist's Colors Industry (CEPE) Code of Practice for Coated Articles where the Food Contact Layer is a Coating Confederation of European Paper Industries (CEPI): Food Contact Guidelines for the Compliance of Paper & Board Materials and Articles European Printing Ink Association (EuPIA): Exclusion Policy for Printing Inks and Related Products
Industry guidelines for chemical management along the supply chain	IndGuide_Sply	Guidelines on gathering information for raw or intermediate inputs from suppliers. Developed by companies collaborating via industry associations. Aim to help food packaging companies to decide whether a raw materials or intermediary input is suitable for given applications.	European Printing Ink Association (EuPIA): Customer Guidance Note for using ink Statements of Composition when considering compliance of food packaging Association of the European Adhesive & Sealant Industry (FEICA): Guidance for a food contact status declaration for adhesives
Industry guidelines focused on design approaches for compliance	IndGuide_CmplDsgn	Recommendations for companies on how to design their products to be safe already from the beginning (i.e. the design stage). These guidelines seek help companies to design packaging materials for compliance. Developed by companies collaborating via industry associations.	Flexible Packaging Europe and CITPA: Code for Good Manufacturing Practices for Flexible and Fibre-Based Packaging for Food
Industry guidelines and standards for the design of recycled materials	IndStand_RecDsgn	Guidelines for companies to develop their products in such a way that they are widely recyclable. Developed by industry consortia. Often functions as a standard to allow recycling to take place across industry. Set out criteria to use during the design process.	4evergreen industry consortium: Circularity by Design Guidelines for Fibre-Based Packaging CEFLEX: Designing for a Circular Economy Guidelines
Recycling evaluation protocols	IndGuide_RecEval	Guidelines drafted by industry consortia that help companies to assess the recyclability of individual packaging or materials.	4evergreen: Fibre-Based Packaging Recyclability Evaluation Protocol European PET Bottle Platform (EPBP): Test Protocol
Recycling guidelines maintained by NGOs	SocGuide_RecDsgn	Standards for recyclable design that are maintained by an NGO. These standards a generally a bit broader and not solely focused on food packaging.	Waste and Resources Action Programme (WRAP) Design Guidance for Recyclability of Household Rigid Plastic Packaging Ellen MacArthur Foundation: Introduction to circular design
Restricted substances list drafted by retailers	Retail_RSL	Retailers draft their own lists of restricted substances. They primarily represent a requirement which suppliers should adhere to and an internal guidance. Some are more elaborate like Coop DK's Dirty Dozen other are limited to a few substances. They are a specific element in their procurement specification.	Coop Denmark: List of Dirty Dozen Fidra Report: Set of retailers in the United Kingdom adopting group-based chemical approaches Costco US: List of targeted substances
Restricted substances list drafted by food companies	FoodComp_RSL	Food companies have their own lists of restricted substances. They provide internal guidance and specify requirements for packaging suppliers.	Nestle Rules of Sustainable Packaging: The Negative List for Food Packaging Restaurant Brands International: Phase-out of PFAS by 2025

Collective restricted substances lists drafted by multiple companies	IndStand_RSL	Beyond having their own internal lists of substances, companies also work together to draft shared lists of restricted substances. These efforts may involve food companies, packaging companies and/or chemical suppliers.	Food Safety Alliance for Packaging: Food Packaging Product Stewardship Considerations
Retailer procurement specifications	Retail_ProcSpec	Retailers set specific requirements for packaging materials through procurement specification. These typically take the form of so-called Style Guides, which lay out various characteristics of packaging materials retailers deem desirable. They represent a key means to interact with suppliers, particularly for retailer's private labels. A strong focus is on recycling but style guides generally comprise requirements regarding the absence of specific substances as well.	Coop Denmark: Trade Agreements Lidl Austria: Pfiat di Plastik Lidl GB Packaging Format & Material Preferences (download link) ALDI South: ALDI's International Recyclability Guideline Rewe Germany: Guideline on more eco-friendly packaging Note: Retailer's style guides tend to be confidential. The links therefore navigate to more general websites discussing their packaging strategies
Food company procurement specification	FoodComp_ProcSpec	Similar to Retailers, food companies have adopted procurement specification regarding what kind of packaging they want. Typically involve criteria through which the recyclability of packaging materials should be improved, and lists of substances which should not be contained in packaging materials.	Nestle International: The Rules of Sustainable Packaging Nestle International: Summary/Abstract of Nestle Standards on Materials in Contact with Food Emmi Switzerland: General Requirements for Packaging Materials delivered to Emmi Schweiz AG PepsiCo: ESG Topics A-Z Packaging
Screening rests of Retailers	Retail_TestScreen	Retailers screen their assortment for certain substances of concern. Compared to the procurement specification, this measure targets products already on retailer's shelves. It is thus primarily an ex-post measure. Findings of certain substances can lead to delisting of products.	Coop Denmark: Delisting of microwave popcorn because packaging contained PFAS Costco US: Smart Screening Program Carrefour France: Compliance of Suppliers
Enlisting tests of Retailers	Retail_TestEnlist	Retailers conduct enlisting tests to ensure the supplied products comply with their requirements. Enlisting tests act as gatekeeping mechanisms, being the last checkpoint for retailers to assess the safety of the products they sell before putting them on their shelves.	Costco US: Chemicals Policy Carrefour France: Supplier Quality Management Hofer Austria
Migration testing of food companies	FoodComp_Test	Food companies conduct internal testing to ensure compliance with internal and external requirements. This is a long standing practice. While some companies have their own testing labs, the majority of tests is done by third-party testing labs	Nestle International: Internal Testing Labs SQTS: Third party testing Intertek: Packaging Testing Services
Migration testing of packaging companies	PackComp_Test	Packaging companies conduct internal testing to ensure compliance with internal and external requirements. While some companies have their own testing labs, the majority of tests is done by third-party testing labs.	Constantia Flexibles: Peeking behind the curtain Tetra Pak: Unpacking the legacy and future of food safety FEICA: Migration testing of adhesives SQTS: Third party testing Intertek: Packaging Testing Services
Individual substances lists maintained by NGOs	NgoRSL_SIN	The SIN list is representative of restricted substances list advocated for by NGOs. It is widely recognized and intended to act like a more comprehensive SVHC REACH list. Maintained by the NGO ChemSec and based on the SVHC criteria (1) CMR; (2) PBT; and (3) SoEC. The SIN list often acts as a reference point for companies that aim develop safer products. These lists are generally more stringent than regulation and used by companies to check whether any chemicals of concern are present their products.	International Chemical Secretariat (ChemSec): SIN List Food Packaging Forum: FCCprio List Environmental Defense Fund (EDF): Key chemicals of concern in food packaging and food handling equipment Chemical Footprint Project: Chemicals of High Concern See here for a more general overview of lists
Restricted substances lists from local governments in collaboration with consumers	NgoGovRSL_Cali65	The California Proposition 65 is a list of restricted substances that is representative of lists which are seen as progressive and best-practice by societal actors. California Proposition 65 is a chemical regulation in California that acts as a rather strict reference point for companies. For businesses selling into California, the Prop 65 regulation requires warnings to be provided to citizens prior to exposure to any chemical found on the list. In Europe, it can be understood as a tool for companies to ensure compliance, both internally and with regard to suppliers.	United States: California Proposition 65 (see here for additional information) See here for a more general overview of lists

Regulatory and governmental lists of restricted substances	GovRSL_SVHC	Governmental and regulatory restricted substances list. The REACH SVHC list is a European chemical regulations that is stricter in many aspects than the food packaging legislation. Seen as best-practice by societal actors and used as a reference point for FCM companies. REACH is the general chemicals regulation in the EU, which does not apply to FCMs in terms of public health. The SVHC candidate list of REACH is the first step in the restriction of certain chemicals. But also leveraged by companies to state that they do not want certain substances in their products.	EU REACH: Candidate List SVHC Sweden KEMI: PRIO Phase-Out See here for a more general overview of lists
Chemical assessment tools	NGO_AltSubsComp	These devices assess the substances within a product and propose safer alternatives to substances of concern. The safer and/or more sustainable alternatives are often matched to the ones currently in use by their function within the overall material.	German Umweltbundesamt: ChemSelect ZeroPM Research Project ChemSec: SINimilarity tool
Marketplaces for safer and more sustainable alternatives	NGO_AltSubsMarket	Alternative marketplaces listing products with socially desirable properties. Connect suppliers of alternatives with companies looking for them. Linking between established substances and materials with alternatives is typically based on their function.	ChemSec: Marketplace Chem Forward: Safer Programme
Ratings maintained by NGOs focused on their chemical management	NgoRtng_CorpSafe	Ranking of companies based on their chemical management practices. Chemical producers and retailers, for instance, are evaluated on criteria such as the presence of hazardous chemicals in their product portfolio, efforts to identify safety alternatives, and their management systems and transparency.	ChemSec: ChemScore Rating Toxic Free Future: Mind the Store Report Card
Compliance standards based on non-binding recommendations of national government agencies	StandCompl_GovAgency	In the absence of harmonized EU regulation, companies operating in the legislative realm of a particular FCM type tend to resort to the strictest national recommendation. These have gained the role of industry standards by now. The BfR36 is a recomendation of the BfR in Germany for paper and board FCMs.	German Federal Institute for Risk Assessment Recommendations: BfR 36 for Board and Paper FCMs German Federal Council: German Printing Inks Ordinance For an overview of BfR recommendations on FCMs see here
Compliance standards based on national regulations	StandCompl_NatReg	In the absence of harmonized EU regulation, companies operating in the legislative realm of a particular FCM type tend to resort to the strictest national regulation. The Swiss Ordinance for printing inks has long been the key reference standard for printing inks.	Swiss Federal Food Safety and Veterinary Office: Swiss Printing Inks Ordinance
Compliance standards based on company strategies	StandCompl_Corp	Some company strategies – and especially that of Nestlé - have become industry benchmarks, with smaller companies aligning themselves with these standards.	Nestlé: Nestlé's Packaging Sustainability Strategy
Regulations combining environmental aspects with chemical restrictions	RegEnv_RecySafe	Regulation combining environmental and chemical aspects. In Europe, the recently adopted Packaging Packaging Waste Regulation had a great impact. PPWR extends the SUPD and focuses on the life cycle of materials, promoting reusability, design requirements and waste management. Specific measures: reduction of packaging (5% by 2030, 10% by 2035 and 15% by 2040); Ban on single-use containers by 2030 in the hotel/restaurant/catering sector (bottles, body lotions, etc.) and in the food sector (fruit, vegetables, sauces, sugar, etc.); Minimum proportion of recycled material in plastic packaging (e.g. PET bottles 30% in 2030, 50% in 2040); All packaging must be recyclable from 2030; Introduction of a deposit and return system (DRS) by 2029 for plastic beverage containers (<3 liters); Harmonization of environmental labelling at European level; Harmonization of the EPR Directive (Extended Producer Responsibility).	EU Regulation: Packaging and Packaging Waste Regulation (PPWR)
Regulations focused on renewable and recyclable resources as inputs	RegEnv_RecyReRes	Regulations setting requirements for the input materials, relating to the share of recycled content and the way it has been sourced. The regulation of deforestation-free products, for example, requires companies to conduct extensive diligence on the value chain to ensure the goods do not result from deforestation, forest degradation or breaches of local environmental and social laws. It essentially requires companies to evaluate their supplier themselves, but based on standards set by regulation. Related to the responsible forest management certification FSC and PEFC	European Union: Single-Use Plastics Directive (SUPD) European Union: Regulation on Deforestation-free Products

Regulations based on positive lists	RegChem_PosList	Some FCM-specific regulations and directives within the broader European regulatory framework build on positive list. The most comprehensive positive lists is in Regulation (EU) 10/2011 for plastic FCMs. It comprises a union lists including monomers and other starting substances, additives (excluding colorants), and polymer production aids. Regulation (EC) No 450/2009 on active and intelligent materials intends to establish a Union list of substances permitted for their manufacture, but this list has not yet been published. The directive on cellulose FCMs contains a positive list of substances that can be used in the manufacturing of packaging materials based on cellulose.	European Union: FCM regulation on plastic materials and articles (EC 10/2011) European Union: FCM regulation on active and intelligent materials and articles (EC 450/2009) European Union: FCM commission directive 2007/42/EC United States FDA: Compliance list for board and paper FCMs
Regulations based on negative lists	RegChem_NegList	FCM regulation comprises bans of certain substances. For instance, BPA is banned in several FCM applications. The same is true for epoxy resin derivatives BADGE, BFDGE, NOGE for FCMs. General chemical regulation, however, also affects food packaging companies, such as the Stockholm Treaty on POPs.	European Union: Ban of BPA in Food Contact Materials European Union: Regulation of epoxy derivatives like BADGE Stockholm Convention: Lists of POPs
Regulations based on migration limits	RegChem_MigLimit	Most FCM regulations are based on migration limits for certain substances. Prominent examples include: Regulation of ceramics FCMs & Regulation No 2018/213 on BPA. The FCM regulation for ceramics sets migration limits for cadmium and lead, for instance. BPA is also linked to a SML (Regulation 2018/213) Plastics: Overall migration limit of 10mg/dm2. The FCM regulation for ceramics sets migration limits for cadmium and lead, for instance. BPA was also linked to a SML (Regulation 2018/213). Certain phthalates are also subject to migration limits.	European Union: FCM regulation on BPA (old) European Union: FCM regulation on plastic materials and articles (EC 10/2011) European Union: Migration limits for ceramic and glass FCMs
Data bases on substances found to be migrating and potentially a risk to human and environmental health	EvidDB	Different lists of chemicals contained in or migrating from food packaging. Typically relate these substances to hazard properties or regulatory status, amongst others. These lists serve primarily the function of establishing the state of the problem and reducing the associated uncertainty.	Food Packaging Forum: Food Contact Chemicals Database (FCCdb) Food Packaging Forum: Database on Migrating and Extractable Food Contact Chemicals (FCCmigex) Ospar Lists of Concern
By design approaches	SSbD	"By design" is a broader trend within the chemical sector, emphasizing that chemical safety aspects should be incorporated into the development of new chemicals already from the outset. SSdB specifically is a framework developed and advocated for by the European Commission within its Chemicals Strategy for Sustainability	European Union: Safe and sustainable by design (SSbD framework) Sherwin-Williams: Safety-by-design initiative

Table B.3: Profiles of valuation devices across descriptive dimensions

	Valuator				Site of valuation				Practices			Matters			Logics			
	Societal Valuator	Business Valuator	Regulat. Valuator	Self-Valuation	Market	Supply Chain	External Gate	Internal Gate	Normal Practices	Exchange Practices	Represent Practices	Matter of Fact	Matter of Concern	Matter of Worth	Risk Management	Hazard Prevention	Plastic Reduction	Functional Materials
NgoRtng_SafeE	1	0	0	0	1	0	0	0	0	1	1	0	1	0	0	1	0	0
NgoRtng_SafeM	1	0	0	0	1	0	0	0	0	1	1	0	1	0	1	0	0	0
NgoLbl_Safe	1	0	0	0	1	0	0	0	0	1	1	0	0	1	1	1	0	0
CorpLbl_Safe	0	0	0	1	0	0	1	0	0	1	1	0	0	1	0	1	0	0
CorpLbl_Recy	0	0	0	1	0	0	1	0	0	1	1	0	0	1	0	0	1	0
NgoLbl_SafeEnv	1	0	0	0	0	0	1	0	1	1	1	0	1	1	1	1	1	0
NgoLbl_RecyReRes	1	0	0	0	0	0	1	0	1	1	1	0	1	1	0	0	1	0
Lbl_OrganicFood	1	1	0	0	1	1	0	0	1	1	1	0	1	1	1	1	1	0
GMP_FoodSafeCert	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0	0	0
Stand_SafeEval	1	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0
IndGuide_Eval	0	1	0	0	0	0	0	1	1	0	0	1	1	0	1	0	0	0
IndGuide_Cmply	0	1	0	0	0	0	0	1	1	0	0	1	1	0	1	1	0	0
IndGuide_Sply	0	1	0	0	0	1	0	0	1	1	0	1	1	0	1	1	0	0
IndGuide_CmplDsgn	0	1	0	0	0	0	0	1	1	0	0	1	1	0	1	1	0	1
IndStand_RecDsgn	0	1	0	0	0	0	0	1	1	0	0	1	1	0	0	0	1	1
IndGuide_RecEval	0	1	0	1	0	0	0	1	1	0	0	1	1	0	0	0	1	1
SocGuide_RecDsgn	1	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	1	1
Retail_RSL	0	1	0	0	1	1	0	1	0	1	1	0	1	0	0	1	0	0
FoodComp_RSL	0	1	0	0	0	1	0	1	0	1	1	0	1	0	0	1	0	0
IndStand_RSL	0	1	0	0	0	1	0	1	1	1	0	0	1	0	0	1	0	0
Retail_ProcSpec	0	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	1	1
FoodComp_ProcSpec	0	1	0	1	0	1	0	0	0	1	0	0	1	0	1	1	1	1
Retail_TestScreen	0	1	0	1	1	0	0	0	0	1	1	0	1	0	0	1	0	0
Retail_TestEnlist	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0
FoodComp_Test	0	1	0	1	0	1	0	0	0	0	0	1	1	0	1	0	0	0
PackComp_Test	0	1	0	1	0	1	0	1	0	0	0	1	1	0	1	0	0	0
NgoRSL_SIN	1	0	0	0	0	1	0	1	1	1	0	0	1	0	0	1	0	0
NgoGovRSL_Cali65	1	0	1	0	0	1	0	1	1	1	0	0	1	0	0	1	0	0
GovRSL_SVHC	0	0	1	0	0	1	0	1	1	1	0	0	1	0	0	1	0	0
NGO_AltSubsComp	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0
NGO_AltSubsMarket	1	0	0	0	0	1	0	1	0	1	1	0	0	1	0	1	0	1
NgoRtng_CorpSafe	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0	1	0	0
StandCompl_GovAgency	1	1	1	0	0	1	1	0	1	1	0	1	1	0	1	1	0	0
StandCompl_NatReg	0	1	1	0	0	1	1	0	1	1	0	1	1	0	1	1	0	0

StandCompl_Corp	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0
RegEnv_RecySafe	0	0	1	0	0	0	1	1	1	0	0	0	1	0	1	0	1	0
RegEnv_RecyReRes	0	0	1	0	0	0	1	0	1	1	0	0	1	0	0	0	1	0
RegChem_PosList	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0
RegChem_NegList	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0
RegChem_MigLimit	0	0	1	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
EvidDB	1	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1	0	0
SSbD	0	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1

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