Towards a Circular Economy for the Plastic Packaging Sector: Insights from the Italian case

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Abstract:

Achieving a circular economy (CE) has become a strategic priority for the plastic packaging industry to implement long-term business sustainability while meeting legislative requirements. In this view, the evolution of circularity practices in relation to technological, regulatory, and socio-economic factors and the implications for different value chain actors are open streams of research. This study aims to assess trends and meaningful changes in the adoption of circularity practices from the perspective of different value chain actors, under the effects of leading CE barriers and enablers. A longitudinal analysis of the influence of these factors in relation to CE practices adopted by the Italian plastic packaging sector was conducted for the years 2011, 2015, and 2019. The involvement in plastic recovery became a predominant CE strategy over time, thanks to technological availability and a more mature regulatory framework. Our results suggest a gradual shift from scattered CE implementations to a more systemic approach to CE integrating upstream and downstream solutions. However, this transition occurred at different speeds and levels across the supply chain, as companies perceived factors differently and, consequently, implemented different types of CE practices. Therefore, increased collaboration and alignment across the supply chain are still required to overcome existing challenges. Based on our analysis, a focus group with stakeholders and experts of the plastic industry drew possible future avenues for the plastic packaging sector. Suggested priority actions include advancement of new and emerging recycling technologies, prioritization of economically viable and closed-loop alternatives to recover plastic waste, and alignment between national and international CE directives. These results extend our understanding of the CE transition and shed new light on the ways in which the industry can address existing barriers in different tiers for a system-wide impact.

Keywords: Circular economy; Plastic packaging; Barriers and enablers; Italy.

1. Introduction

Annual plastic production has increased nearly 200-fold since the 1950s (Ritchie and Roser, 2018). The social and economic benefits associated with plastic materials made them so popular that they have been documented in the most remote corners of the planet (Andrady and Neal, 2009; Thompson et al., 2009). While plastics are suitable for a multitude of applications due to their unique mechanical properties, they become problematic when plastic waste is not managed properly after disposal (Barnes et al., 2009). From 1950 to 2015, only 9% of all plastic ever produced had been recycled, 12% were incinerated, and the disproportionate majority were discarded in landfills and in the natural environment (Geyer et al., 2017). To face this plastic waste emergency, the implementation of a circular economy (CE) for plastics has been hailed as a sustainable alternative to existing production-consumption models via retention of plastic materials in closed-loops systems.

The transition to a CE for plastics is also high on socioeconomic and political agendas (Getor et al., 2020; Diaz et al., 2021; Mhatre et al., 2021). At the global level, the Ellen MacArthur Foundation launched a guiding framework to advance the CE for plastics. Its vision prioritizes solutions grounding on fundamental redesign and innovation actions, such as redesign of packaging formats to enhance distribution and after-use reprocessing, material and process innovation, replacement of less recyclable plastics with alternative materials, and scaling up of sustainable sourcing (EMF, 2016, 2017). Similarly, the United Nations argue in favor of this approach promoting measures for the containment of plastic losses and microplastics from land-based sources into the marine environment (UNEP, 2018, 2019a, 2019b). These measures provide a set of guidelines for the industry, from reducing unnecessary plastics along the supply chain, to establishing circular value chains, and investing in alternative materials (UNGC, 2020). At the European level, The European Commission released “A European Strategy for Plastics in a Circular Economy” to set new targets for plastic recycling and explore its unexploited potential (EC, 2018a). At the national level, Italy adopted the National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza, PNRR), as part of the Next generation EU program, with the aim of advancing a green and sustainable transition through material efficiency and retainment of resources in the material loop (MISE, 2021). However, there is a paucity of empirical evidence of the alignment between these CE strategy frameworks and industrial actions, making it more difficult to assess track progress towards circularity.

In spite of the numerous advantages linked to CE (e.g., social, economic, and environmental benefits) and its relevance for political agendas, several challenges to its implementation persist. Sarja et al. (2021) identified a number of obstacles that can affect the CE transition for companies, including economic, political, and technological aspects. When it comes to the CE of plastics, a first problem is that existing CE frameworks foster unilateral industrial solutions, aimed at addressing the problem upstream (e.g., assessment of production technologies, decoupling plastic production from fossil fuels via ecodesign or alternative sourcing) or downstream (e.g., evaluation of existing waste management systems and recycling) respectively (e.g., Shogren et al., 2019; Wu et al., 2021), neglecting the comprehensive effects of such interventions at the system level. Two notable exceptions, Lau et al. (2020) and The Pew Charitable

Trusts and SYSTEMIQ (2020), demonstrate that upstream and downstream industrial actors experience challenges and externalities differently. More specifically, these studies shifted the debate from unilateral solutions to sound system changes that are required to curb plastic pollution significantly, while bringing major opportunities for the plastic industry.

Furthermore, Bening et al. (2021) suggest that, despite the increasing number of studies treating potential barriers and enablers of CE, these factors are primarily addressed in a static and independent way. More specifically, existing frameworks of factors (e.g., Khan et al., 2020; De Oliveira et al., 2019) fail to capture how factors change over time and what effect these dynamics might have on the implementation of CE strategies. Hence, the adoption of alternative conceptual approaches that capture the evolution can be a crucible for exploring the transition to the CE of plastics, predicting future pathways, and advancing knowledge to end plastics waste entering the natural systems.

Recognizing the tremendous importance of filling these gaps, this study specifically focuses on practices and factors that can hinder or accelerate the transition to the CE of plastic packaging. To this end, the following research questions are set forth:

> RQ1: How has the implementation of CE practices in the plastic packaging supply chain evolved over the last decade?
>
> RQ2: What are the leading factors in the CE transition for plastic packaging, and how has their influence changed over the last decade?
>
> RQ3: What are the priority actions needed to accelerate the CE transition for plastic packaging in the short/medium term?

We investigate these questions in the context of the supply chain of plastic packaging in Italy. This context is well suited for our analysis for two reasons. First, the sector has been subject to new regulations towards circularity in the last decade, so companies are already aware of the issue and inclined to make progress towards CE (Bening et al., 2021). Second, the Italian plastic packaging sector is well established, with a leading role at the European scale, and has several ongoing activities aimed at meeting new national and international CE targets, allowing us to collect empirical evidence.

The remainder of the paper is structured as follows: Section 2 describes the barriers and enablers towards the CE of plastics discussed in the scientific literature. Section 3 reports the study's methodology. Section 4 reports on the main findings providing an evolutionary view of the transition to the CE of plastic packaging from the perspective of different supply chain actors. Section 5 discusses emergent trends in the CE transition and provides possible solutions to boost CE leveraging existing barriers and enablers. Finally, Section 6 draws conclusions and suggests future research directions.

2. Literature Review

Extant CE literature is characterized by multiplicity and heterogeneity of barriers and drivers of the CE transition (see Kirchherr et al., 2018; Sarja et al., 2021). A major constraint in the use of existing frameworks is that generalized taxonomies of factors fail to capture the complexity characterizing the plastic industry. General frameworks in fact aggregate factors into macro categories that limit the level of detail that is considered in sector-specific frameworks. For example, technical aspects related to alternative technologies, technological innovation, design, or recycling are often presented under the same category precluding the study of sector-specific technical challenges and drivers that can affect supply chain actors differently (e.g., Sarja et al., 2021; Kirchherr et al., 2018; Merli et al., 2018). Another limitation pertains to the lack of an actor-specific perspective, where factors are considered in relation to their influence and effect on different supply chain actors. For the purpose of this study, we developed a framework specifically designed to fully capture the peculiarities of to the system under investigation.

For our analysis, factors in the CE of plastics were derived from a systematic literature search on the Scopus database, using a single-string search approach (TITLE-ABS-KEY *plastic** AND "*circular economy*" AND *barrier** OR *enabl** OR *driv**) conducted in February 2021. A total of 152 studies were found, of which 139 met the author's filtering criteria on language (English) and subject area (Environmental Science; Engineering; Energy; Materials Science; Business, Management and Accounting; Chemical Engineering). After the abstract screening and full-text review, 17 studies were included in the analysis based on their relevance for the plastic's material system. Table 1 shows the final categorization of factors that are mentioned in the reviewed papers. A detailed table with examples of barriers and drivers analyzed in these studies is reported in Table S1.

In the extant literature on barriers and enablers to the CE of plastics, three streams have emerged, addressing the topic at different levels of analysis. One stream focuses on CE barriers and drivers at a general level, e.g. the plastic value chain (Khan et al., 2020; Heller et al., 2020; Dijkstra et al., 2020; Tesfaye and Kitaw, 2020; Khandelwal and Barua, 2020; Hahladakis and Iacovidou, 2019; Wichai-utcha and Chavalparit, 2019; Tangwanichagapong et al., 2020; Milios et al., 2018; Cramer, 2018). The second emphasizes specific sectors of the plastic industry, such as plastic packaging and food packaging (Bening et al., 2021; Gong et al., 2020; Paletta et al., 2019; Hahladakis and Iacovidou, 2018; Van Eygen et al., 2018) or the use of plastics in fishing (Deshpande et al., 2020). Finally, one study analyzes specific plastic materials, e.g. the value chain of expanded polystyrene (De Oliveira et al., 2019).

In these studies, barriers and enablers are typically aggregated into categories such as economic, technical, environmental, regulatory, informational, and socio-cultural. The factors investigated in these studies span the six macro-categories, but only a few papers describe all categories in detail. For instance, environmental barriers are usually associated with other factors (e.g., technical and regulatory barriers) and their role in the CE transition is loosely discussed. Similarly, informational factors are often absent or merely discussed as “limited data availability”, failing to capture the importance of data traceability and proper reporting on plastic materials and pollution along the value chain.

In spite of the many authors examining the topic, two major problems remain. First, barriers and enablers are often discussed in isolation, neglecting to acknowledge that companies can experience multiple factors simultaneously and over time (Bening et al., 2021). Second, CE studies usually present the implications of these factors in relation to their effects on the plastic industry, or a subset of it, overlooking their implications for individual supply chain actors. In this research, both of these issues are addressed via investigation of the plastic packaging sector in light of the complex interactions between different contextual factors and related practices leading to non-uniform effects, and by drawing specific implications for individual actors within the plastic industrial system.

Table 1. Taxonomy and characterization of factors influencing the transition to a CE of plastics.

Categories of factors	Factor code	Factor	Description
Economic	F1.1	Process costs	It entails revenue and cost variations throughout the supply chain, such as technology and production systems, product and packaging design, waste collection and processing.
	F1.2	Consumer demand	It refers to the demand shift towards greener products that come from renewable and recyclable sources and contain recycled materials.
	F1.3	Market shift	It indicates a market shift towards sustainable plastic management. It is associated with sustainability strategies undertaken by industrial actors to comply with economic, environmental, and societal commitment towards a sustainable use of plastics.
	F1.4	Competition virgin/recycled plastics	It is affected by the value for use of secondary raw materials compared to virgin materials and can affect the feasibility and extent of a market shift. While recycled plastics can offer a substitute to virgin materials, they are associated with lower marginal costs. In addition, their suitability for original applications may be compromised by material contamination from additives and impurities and poor material properties, with subsequent loss of market value.
Technical	F2.1	Material properties	It refers to morphological and polymer-based aspects that can better the end-of-life management of plastic items. These include design for environment strategies (e.g., design for recycling, design for remanufacturing, design for disassembly and reassembly, etc.) aimed at reducing material use in packaging and products. In addition, it can encompass changes in the material composition, such as substituting virgin plastics with recycled plastics, reducing plastic content (either virgin or recycled) in packaging and products, and minimizing the use of different polymers into the same application
	F2.2	Technology readiness	It refers to technologies for production, manufacturing, sorting, and recycling of plastic materials, hence it varies between different actors. For example, it can refer to process difficulties during plastics production, incompatibility of recycled plastics with existing manufacturing processes, and lack of or insufficient sorting options within sorting facilities.
	F2.3	Industrial infrastructure development	It encompasses the development and maintenance of industrial facilities in forward and reverse supply chains (e.g. production and recovery plants, warehouses); and supporting transportation infrastructure.

Categories of factors	Factor code	Factor	Description
	F2.4	Urban infrastructure development	It encompasses the establishment of sound waste management infrastructure at the city level, including municipal waste collection, plastic waste recovery, and waste transport operations.
Environmental	F3.1	Toxic additives and substances	It refers to the use of hazardous substances that bear concerns for human and environmental health. While regulations can offer a tool to disincentivize the use of some substances, decisions at the company-level entail material innovation and improved sourcing to limit the environmental impacts of packaging and products.
	F3.2	Energy consumption	It refers to energy consumption associated with production, manufacturing, and treatment of plastics. For example, it can include energy savings related to changes in technologies and processes.
	F3.3	Environmental impact	It refers to the totality of environmental impacts associated with all stages of the plastic life cycle, including marine plastic pollution, plastic leakages into the environment, and contributions to global warming from plastic production, consumption, or waste treatment.
Regulatory	F4.1	CE and sustainable development directives	It refers to the existing institutional framework in which all the supply chain actors operate, including global policies, EU directives, national policies, and regulations. For example, it can include material standards that can prescribe legal obligations for all stakeholders, measures regulating end-of-life management and process safety, or a certain material composition.
	F4.2	Incentive/tax schemes	It refers to the introduction of government measures such as favorable tax reductions and economic incentives upon employment of recycled plastics in products and packaging, incentives for increasing capacity of waste treatment and recovery plants, incentives for the employment of new circular materials.
	F4.3	Market regulation	It entails all other market regulation policies not considered at the previous point and aimed at guaranteeing a continuous supply of large volumes of plastics at all stages of the closed-loop supply chain.
	F4.4	Engagement in EPR	It refers to the engagement in collection/sorting operations and reverse logistics at the company level.
Informational	F5.1	Data transparency and traceability along the value chain	It concerns the exchange of information on products and materials, including material composition, properties, and performance among all supply chain players; information on material flows; and transparency from production to end-of-life processes.
Socio-cultural	F6.1	Consumer awareness	It relates to civic awareness of products and packaging composition that pushes consumer demand towards recycled plastics, including amount of sustainably sourced material and absence of toxic substances; quality and safety of employed materials, including convenience, performance, and environmental benefits; and end-of-life options, including collection infrastructure, locally available facilities, and advantages of different end-of-life treatments.
	F6.2	Consumer behavior	It refers to societal movements, environmental campaigns, and engagement of the supply chain actors in beach cleanups oriented to solving the littering problem.

3. Methods

To understand existing CE practices and the influential factors in the transition to a CE of plastics, we conducted an exploratory qualitative study of the plastic packaging value chain in Italy. The qualitative approach is well suited for developing a systemic understanding of a complex phenomenon, as is the CE of plastics, and can yield generalizable results (Siltaloppi and Jähi, 2021). In this analysis, we adopted a two-stage approach to understand the development of the CE of plastic packaging over time and consequently provide implications for the short/medium future. For the first stage, we conducted a qualitative analysis of publicly available sources to map the changes in CE practices implemented by Italian plastic packaging companies over time (RQ1), as well as related factors and their influence on different supply chain players (RQ2). Consequently, we conducted a focus group with stakeholders of the plastic industry to draft a list of priority actions to accelerate the CE transition for the sector in the short/medium term (RQ3).

3.1. Sampling

Selected companies present leading operations and well-established practices with the Italian plastic packaging sector. Our final subset included 19 companies (Table 2) that were purposively sampled across seven supply chain positions (2-3 companies for each position): packaging producers, brand owners, users and distributors, waste management companies, packaging waste consortia, and recyclers (mechanical and chemical). The subset was selected to ensure diversity across the supply chain for what concerns the company's scale of operation (pilot, local, regional, national) and the types of plastic treated. Finally, selection considerations were made based on the availability of information on CE practices and factors for the selected companies.

Table 2. Overview of the 19 selected companies.

Supply chain position	**Company**	**Scale of operation**	**Plastic types treated**	**Data source**	**Language**
Packaging producers	Albertazzi	Regional	PE, PP	Company website; Web news (2011, 2015, 2019)	Italian
	Arcoplastica	Regional	PS, PP, PE, PET, PVC, PLA	Company website; Web news (2011, 2015, 2019)	Italian
	Soulpack	Regional	PE, PET	Company website; Web news (2011, 2015, 2019)	Italian
Brand owners	Coca Cola HBC Italia	National	PET	Integrated Report (2011, 2015, 2019); Sustainability Report (2015, 2019)	English, Italian
	Ferrero	National	Packaging polymers	Sustainability Report (2011, 2015, 2019)	English
	Barilla	National	Packaging polymers	Sustainability Report (2011, 2015, 2019); Financial Report (2011, 2015, 2019)	English
Users/ distributors	Esselunga	National	Packaging polymers	Sustainability Report (2019); Company website; Web news (2011, 2015)	Italian
	Coop	National	Packaging polymers	Sustainability Report (2011, 2015, 2019); Social Report (2011, 2015, 2019)	Italian
	Lidl Italia	National	Packaging polymers	Sustainability Report (2019); Company website; Web news (2011, 2015)	Italian
Waste management companies	Hera	Regional	MSW	Sustainability Report (2011, 2015, 2019); Financial Report (2011, 2015, 2019)	Italian
	Iren	Regional	MSW	Sustainability Report (2011, 2015, 2019); Financial Report (2011, 2015, 2019)	English, Italian
	Amsa/a2a	Regional	MSW	Sustainability Report (2011, 2015, 2019); Financial Report (2011, 2015, 2019)	English
Waste management consortia	Conip	National	Packaging polymers	Green Economy Report (2015); Company website; Web news (2011, 2015, 2019)	Italian
	Corepla	National	Packaging polymers	Packaging Waste Report (2019); Sustainability Report (2015); Company website; Web news (2011, 2015, 2019)	Italian
Mechanical recyclers	Montello	Local	PET, HDPE, LDPE, PE, PP/PE	Company website; Web news (2011, 2015, 2019)	Italian
	Maire Tecnimont	Local	PP, HDPE, LDPE	Sustainability Report (2019); Financial Report (2011, 2015, 2019); Web news (2011, 2015)	English, Italian
	Aliplast	Local	LDPE, PET, PE	Sustainability Report (2019); Financial Report (2019); Web news	Italian

Supply chain position	Company	Scale of operation	Plastic types treated	Data source	Language
				(2011, 2015)	
Chemical recyclers	Nextchem	Pilot	Plasmix	Sustainability Report (2019)	English, Italian
	Eni Versalis	Pilot	Plasmix	Sustainability Report (2019); Integrated Report (2011, 2015, 2019); Company website	English, Italian

3.2. Data collection and analysis

Data collection covered three selected years - 2011, 2015, and 2019 - to investigate changes in CE practices and factors. These years are consistent with major policy changes at the EU and global level, including EU's waste and packaging directives (Commission Regulation (EU) No 10/2011; EC, 2011a, 2011b), EU action plan (EC, 2015), UN's Sustainable Development Goals (UN, 2015), and EU's plastic strategy (EC, 2018a). These changes were reflected by a growing interest in sustainability and sustainability reporting (sustainability report) from the sampled companies.

We analyzed publicly available secondary data sourced from web news, company websites, integrated reports, financial reports, and sustainability reports of the selected companies (Table 2). Following, data coding and analysis were performed to unveil the key practices, factors, and their role, that contributed the most in steering the transition towards the CE of plastic packaging over the past decade. Table 3 presents an excerpt of coding of factors and related CE practices.

A total of 224 CE practices were documented by the surveyed companies over the three selected years. Observed practices were then aggregated into four macro-categories to map some general trends towards CE. The first group of practices pertained to *End-of-life (EoL) management* solutions, such as the implementation of

Waste collection and sorting schemes, *Waste recycling*, and *Industrial plant scale-up*. Second, *Circular packaging* practices encompassed interventions in line with the four principles of CE – reuse, reduce, recycle, decouple – as defined by EMF (2016), including the use of *Reusable and recyclable packaging* and *Material efficiency*. A third set of practices were related to *Data & Information management*, ranging from measures for *Monitoring material flows and impacts, Awareness and information* on plastic waste, and *Labeling and communication* strategies aimed at transferring information on materials from producers to consumers and recyclers. The final group of practices was named *Partnerships* and included practices related to the establishment of *Cross value chain collaboration.* Prior to the analysis of practices, we checked for repetitions and similarities in company reporting across different documents and years to avoid double counting.

Overall, a total of 195 factors were publicly reported by the surveyed companies over the three selected years. Observations were coded into one or more of the 18 factors defined in Table 1. Factors were classified into barriers and enablers based on their influence on the system overall (hinder or help the transition to the CE of plastics respectively), as perceived by the examined companies. We then tracked possible connections (explicitly stated by the companies) between the factors and practices to understand if identified barriers and enablers had a role in the implementation of CE practices.

Similar to previous studies mapping relevant variables in the CE transition (e.g., Sarja et al., 2021; Tangwanichagapong et al., 2019), we performed basic statistical analysis (descriptive statistics, frequencies) on coded CE practices and factors. In our analysis, we assessed the overall number of CE practices adopted by each supply chain actor for the three selected years; the overall number of factors and their impact (barrier/enabler) from the perspective of different supply chain actors for the three selected years. This analysis helped understand the context within which packaging actors operate, commonalities, and differences within the same supply chain function, as well as trends towards the development of a CE for plastic packaging.

Table 3. Example of coding of factors and CE practices, 2019.

Company	**Factor**	**Description (translated)**	**Influence**	**CE practice**	**Sub-practice**	**Description (translated)**
Montello	F4.3 Market regulation	*Standard UNI 10667-1 focuses on the recycling and recovery of plastic waste as well as by-products of plastics.*	Enabler	EoL management	Waste recycling	100% post-consumer recycling for plastic waste.
Arcoplastica	F2.2 Technology readiness	*“The technology allows the company to produce trays for food made of recycled material contributing to the CE.”*	Enabler	Circular packaging	Reusable and recyclable packaging	*“Every year Arcoplastica uses over 3000 tons of recycled plastic from separate collection, equal to 100 million bottles.”*
Ferrero	F6.1 Consumer awareness	*“Consumers have an important role to play in the circular economy of packaging, yet access to information on how circular waste systems work and how people can help eliminate waste is not always readily available.”*	Barrier	Data availability	Labeling and communication	*“We add an end-use label on our packaging using simple icons to communicate the material that is made of so waste can be sorted.”*
Maire Tecnimont	F2.2 Technology readiness	*“[...] relying on technologies [...] to become more green”*	Enabler	Partnerships	Cross value chain collaboration	*“[...] investments focused on startups and partnerships, in order to build a*

Company	Factor	Description (translated)	Influence	CE practice	Sub-practice	Description (translated)
						technology portfolio [...].”

3.3. Focus group

Following our analysis of CE factors and practices, we conducted a focus group during one of the stakeholder meetings of the expert group “Tavolo Plastiche” of the “Observatory for Circular Economy and Energy Transition” of the Lombardy Regional Government (Italy), on February 3rd, 2022. The focus group was carried out via Microsoft Teams in Italian. It involved 51 participants with experience and influential roles in the CE of plastics, including (i) industrial actors of the plastic’s forward and reverse value chains in Italy, including CEOs, general or sectoral managers, and founding members of the sampled companies; (ii) institutional players from governmental and non-governmental organizations at the regional and local level; (iii) industry experts and researchers in the field of plastics and recycling technologies from major research institutes. The selection of focus group participants was based on their familiarity with and deeper knowledge of the context, rather than generalizability of the results stemming from a more heterogenous pool of participants. This allowed us to report richer, intrinsically coherent, and more insightful findings on the specific challenges experienced by the Italian plastic industry. The goal of the focus group was to review the results obtained at the first stage of this analysis and define priority actions needed to accelerate the CE transition for plastic packaging at the regional/national level in the short and medium term. During the meeting, participants discussed the current stage of development of the CE of plastics and offered insights on existing constraints hindering packaging circularity. The paper’s authors moderated the focus group, independently took notes about the insights emerged during the meeting, and finally used them to enrich the discussion of results and draw implications for research and practice.

4. Results

In this section we first provide an overview of the CE practices implemented by the surveyed companies for the three reference years, then we report on the main factors influencing the CE transition. Following, we present the main findings of the focus group discussion based on our analysis of CE practices and factors.

4.1. Distribution of CE practices over time

Our empirical analysis showed that a total of 224 CE practices were implemented across the three selected periods; out of these, 31 (13.8%) were collected for 2011 (T0), 51 (22.8%) for 2015 (T1), and 142 (63.4%) for 2019 (T2), as shown in Fig. 1. Meaningful changes in the number of observations made for each period denote a greater pressure on the sector to comply with sustainability targets, and more specifically CE targets, in the latest period. In addition, the differences across years can be partially attributed to an increasing degree of disclosure of CE and sustainability initiatives by the examined companies.

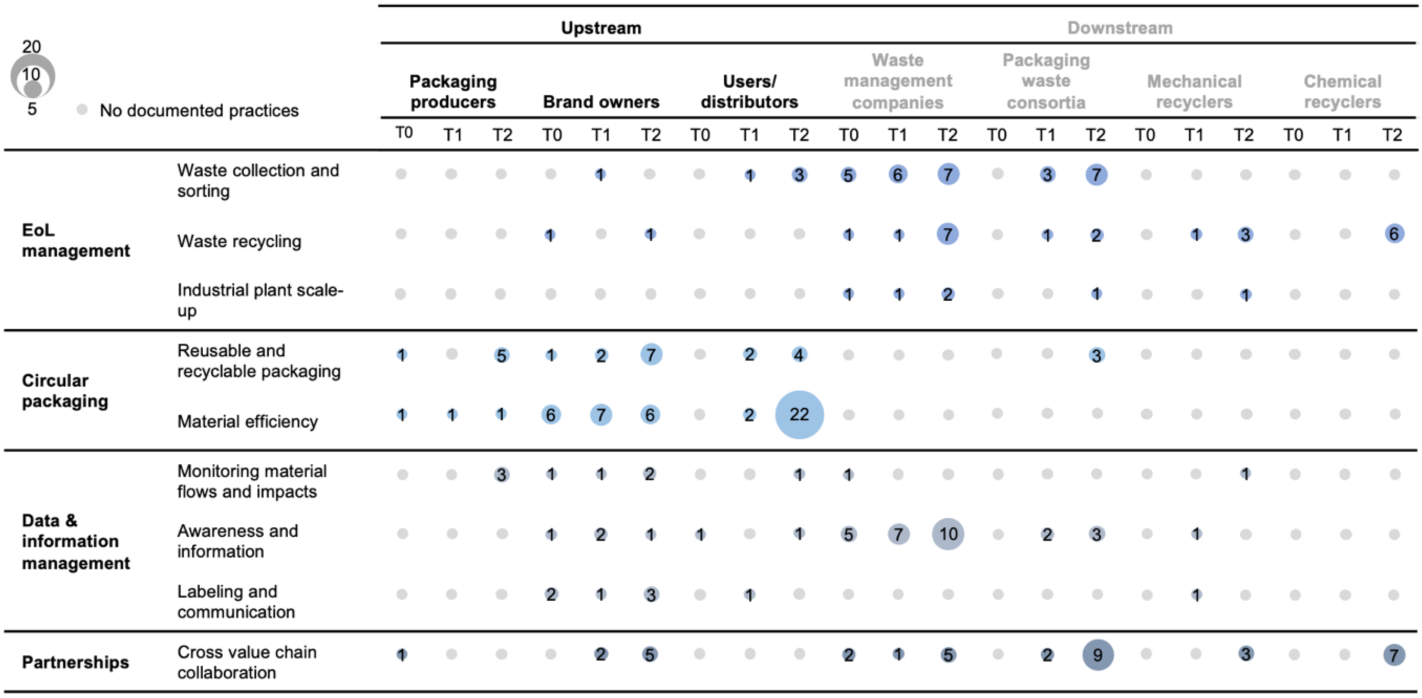

Fig. 1. Distribution of CE practices by supply chain actor for T0, T1, and T2.

Our analysis showed some clear trends in the distribution of CE practices across upstream and downstream actors of the packaging value chain. Such distribution is quite expectable and is aligned with the key business processes of analyzed actors. Here we present an overview of the most common CE practices reported by the analyzed companies (see Table S2 for more detailed information).

For all periods, *EoL management* practices were primarily implemented by downstream actors, namely waste management companies, mechanical and chemical recyclers, and packaging waste consortia. We identified a total of 63 practices related to (i) waste collection and sorting, (ii) plastic waste recycling, and (iii) scale-up of industrial plants for the treatment of plastic waste. Observed practices range from increased separate waste collection, including door-to-door collection and provision of waste collection to areas previously excluded from this service; increased capacity of sorting and recycling facilities, in terms of volumes and types of plastic waste treated; technology innovation; and scale-up of recycling operations. Plastic recycling became key in the CE transition, confirming the observations of Camana et al. (2021). In 2019, more companies across the waste management tier reported evidence of recycling projects, including more ambitious recycling targets, increased capacity of recycling plants, diversification of recycling technologies and materials treated, and retrofitting and/or conversion of existing plants to chemical treatments among others.

Circular packaging practices were mainly adopted by upstream actors, namely packaging producers, brand owners, and users/distributors. We identified a total of 71 practices that pertain to increased use of (i) reusable and/or recyclable packaging and (ii) material-efficient packaging, such as introduction of lighter weight packaging, redesign of packaging components to allow for material savings, and replacement of plastic packaging with materials coming from recycled or renewable sources. Our data confirmed the findings of Paletta et al. (2019) revealing particularly how companies in the production and distribution tiers increasingly engaged in plastic recycling via incorporation of recycled plastics in new packaging, denoting a substantial increment in material efficiency practices related to the use of recycled materials in 2019.

CE practices related to *Data & Information management* were adopted by both upstream and downstream actors, with some differences related to the specific sub-practices. We identified 52 practices pertaining to (i) monitoring of plastic material and waste flows and related impacts, (ii) awareness and information on packaging waste management and recycling, and (iii) improved use of labels and communication. In particular, our analysis revealed how examined companies improved communication and information on plastic packaging, its recyclability, and fate after use, with the aim of enhancing packaging waste management. This observation is supported by the literature. For example, Gong et al. (2020) indicated that companies increasingly engage in information campaigns, targeting a wide range of actors (e.g., consumers, supply chain actors, schools), in an attempt of securing an abundant and constant flow of recyclable plastics to recyclers.

Lastly, *Partnerships* practices were more relevant for downstream actors. We identified a total of 37 projects involving cross-value chain collaborations. Only a few observations were collected for 2011 and 2015; while we noticed greater efforts of recycling-oriented collaboration, knowledge sharing and technology transfer between companies in the waste management tier, and joint-operation of recycling facilities in 2019. As previous studies demonstrated (e.g., Siltaloppi and Jähi, 2021; Dijkstra et al., 2020), stronger multi-tier collaboration is required to return systemic benefits.

For almost all categories of practices, our data highlight an increase in the number of CE practices over time, suggesting a growing engagement of the examined companies in CE-related projects, within and across categories. The higher number of practices could also result from greater public disclosure of sustainability-related information over the years.

4.2. Distribution of factors over time

A total of 195 instances of factors were collected across the three selected periods; out of these, 28 (14.4%) observations were made for 2011 (T0), 42 (21.5%) for 2015

(T1), and 125 (64.1%) for 2019 (T2), as shown in Fig. 2. Similar to the analysis of CE practices, we noticed a remarkable increase in factor reporting over the years.

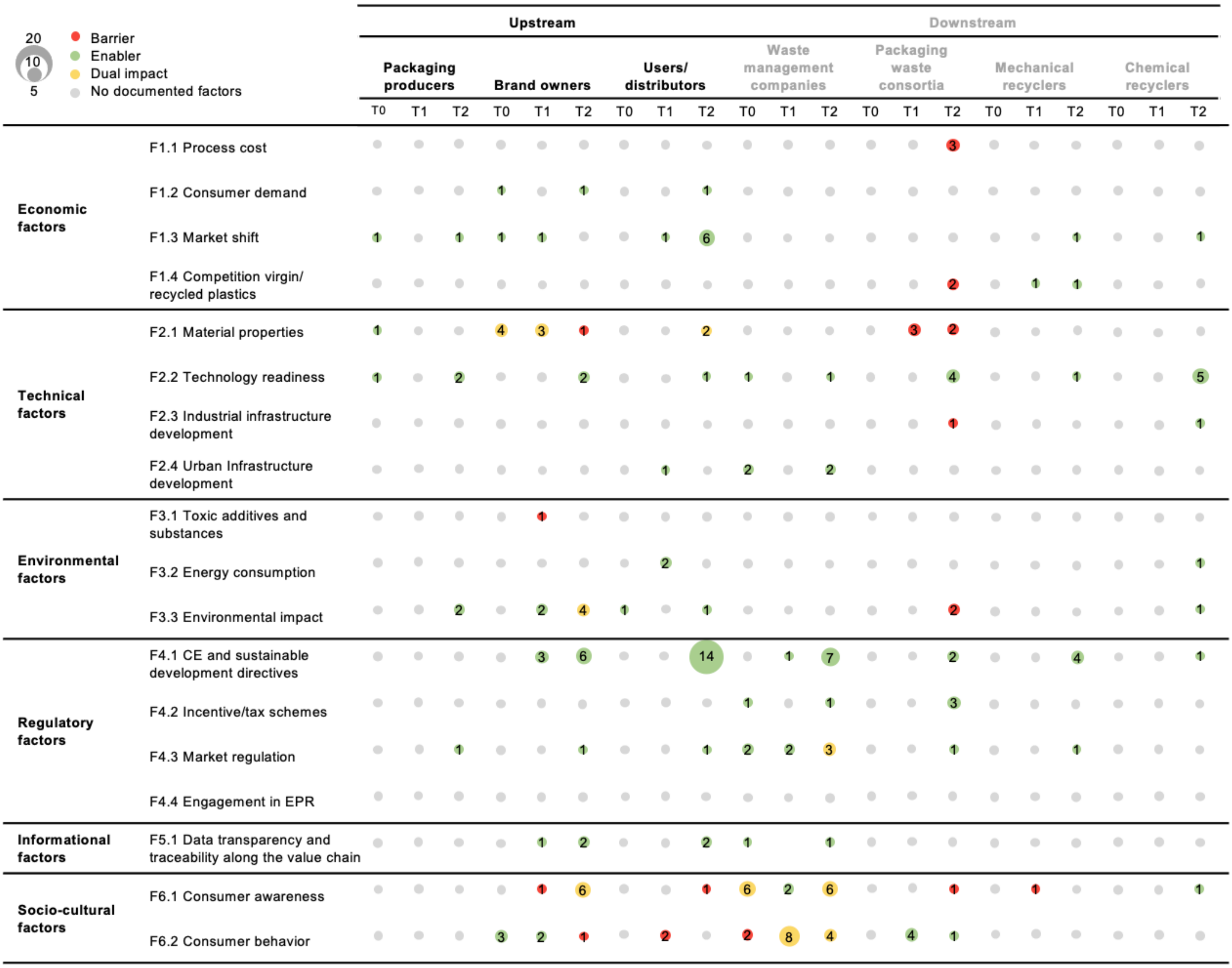

Fig. 2. Distribution of factors by supply chain actor for T0, T1, and T2.

For all analyzed periods, we found that technical (41) and socio-cultural (52) barriers and enablers were primary CE factors, confirming the findings of previous studies (e.g., Dijkstra et al., 2020; Paletta et al., 2019; Gong et al., 2020). We also noticed that regulatory factors (55) received greater attention over time, becoming leading CE enablers in 2019, like demonstrated by Bening et al. (2021); while economic (23), environmental (17), and informational (7) factors were mentioned by a smaller number of companies.

In general, it appears that economic, environmental, and informational factors were primarily reported by upstream actors, while technical, regulatory, and socio-cultural factors were equally discussed by upstream and downstream companies. Our analysis particularly revealed that F2.2 (Technology readiness) was the only factor reported by all value chain actors in 2019, and it always acted as a driver of CE. Similarly, the regulatory factors F4.1 (CE and sustainable development directives) and F4.3 (Market regulation) were reported by six out of seven value chain actors and were indicated as CE drivers in almost all cases. However, as our sampled companies operate in distinct contexts, the same factor can affect supply chain actors in different ways and trigger different practices. We present this complexity through two examples in the following.

First, the advance of technology (F2.2) enabled to offset some of the downsides of plastic waste, confirming the results of Cramer (2018). For upstream companies, new technologies helped incorporate higher percentage of recycled plastics in the production of new packaging (e.g., *"over 3000 tons of recyclable plastic from separate collection, equal to 100 million bottles"*, Arcoplastica, Company website 2019), increase the recyclability potential of plastic packaging (e.g., *"with the removal of color from Fanta Original bottles, we also contribute to the elimination of additives and improve the quality of PET in circulation, which can be recycled more easily in a new transparent bottle"*, Coca Cola HBC Italia, Sustainability Report 2019), and replacement of traditional products with their bioplastic counterparts (e.g., Esselunga's compostable PLA wrapping). On the downstream side, technology availability allowed waste management companies and recyclers to scaleup (e.g., via retrofitting and expansion of existing plants) collection, sorting, and recycling operations, thereby supplying a more abundant flow of secondary raw materials to packaging producers.

The second example illustrates the positive influence of CE regulations (F4.1) on the adoption of CE practices, which is widely reported in literature (e.g., Khan et al., 2020; Heller et al., 2020; Tesfaye and Kitaw, 2020; Van Eygen et al., 2018). Upstream companies updated their packaging requirements to meet European targets, e.g. new packaging should be 100% reusable and/or recyclable by 2030 (Lidl Italia), or beverage bottles should incorporate at least 25% of recycled-PET by 2025 (Coca Cola HBC Italia, Coop). Similarly, downstream actors set more ambitious recycling targets in line with European standards: e.g. over 70% packaging waste recycling by 2025 (Hera and Aliplast), guaranteed 95% recycling efficiency (NextChem), greater number of polymers treated with mechanical and chemical technologies (Corepla), cross-supply chain collaborations should enable wider and higher value applications for recycled materials by 2030 (Hera and Corepla).

Concerning the impact of identified factors, we found that companies were more inclined to publicly report CE enablers across all years, with the only exception of packaging waste consortia. However, our analysis yielded more heterogeneous and controversial results for F2.1 (Material properties), F6.1 (Consumer awareness), and F6.2 (Consumer behavior), highlighting some differences between upstream and downstream companies. These controversial aspects are captured by the following examples. When discussing F2.1, brand owners (e.g., Barilla, Ferrero) noted that considering material characteristics from early design stages can enable higher degrees of recyclability of packaging waste and reduce the overall environmental impacts associated with its production, use, and disposal. However, they also stressed that F2.1 can hinder the development of a CE of plastic packaging when specific material properties limit recovery, reuse, and recycling of packaging waste. Another example pertains to the nature of F6.1 and F6.2, which were often discussed together. Sampled waste management companies (e.g., Hera, Iren) indicated that lack of awareness of plastic packaging waste and persistent use of single-use plastics (e.g., plastic shopping bags) were major barriers to proper separation of domestic refuse and recovery of recyclables. However, surveyed brand owners (e.g., Ferrero, Barilla) indicated the positive pull of socio-cultural enablers in accelerating adequate procedures for disposal of packaging waste after its use.

Finally, our analysis revealed that some practices were triggered by the simultaneous presence of multiple barriers and enablers, which could also change over time. For example, sampled waste management companies (e.g., Iren, Hera) reported that increase in separate waste collection was driven by the pull of economic incentives (enabler: F4.2) and need for waste traceability (enabler: F5.1), as well as a lack of consumer awareness (barriers: F6.2, F6.2) in 2011. However, in the following periods, sampled companies (e.g., Iren, Hera, Amsa/a2a) adopted new waste collection practices thanks to the influence of European and national directives (enabler: F4.1) and the increased engagement of consumers in waste prevention and separation at its source (enabler: F6.2). A second example shows this heterogeneity of pressures from the perspective of sampled brand owners. In 2019, all companies reported evidence of introducing plastic substitutes: e.g., Coca Cola HBC Italia and Ferrero introduced new packaging to lower the environmental impact of their plastic packaging (barrier: F3.3), while Barilla implemented the same practice to meet European CE targets and national market regulations (enabler: F4.1, F4.3). However, it should be noted that this study included only explicitly stated associations of practices with factors, while more in-depth analysis is needed to establish causality mechanisms.

4.3. Focus group

According to our focus group participants, supply chain actors should take greater responsibility in *EoL management* practices, via product acquisition strategy and reuse (e.g., by engaging in deposit-return schemes and reuse of secondary packaging). Among discussed downstream solutions, plastic recycling received great emphasis. The group discussion revolved around the importance of integrating mechanical and chemical recycling processes to ensure that recycled plastics are fully competitive with virgin plastics, thereby decoupling the present market demand from the extraction of raw materials. One of the industry experts mentioned that "*chemical recycling complements mechanical recycling both in terms of technology and it allows to loop back to more performing materials, more similar to virgin plastics [monomers and polymers with mechanical and chemical characteristics similar to virgin ones], that can extend the useful life of plastic packaging*". In other words, chemical recycling offers a viable alternative to upcycle material through recovery of mass and value, when mechanical recycling is no longer convenient. The focus group participants highlighted the importance of the systemic perspective for a larger adoption of chemical recycling. In particular, the following was suggested: (i) the development of a nation-wide closed-loop infrastructure to treat plastic packaging waste; (ii) increased availability of recycled plastics for multiple sector applications, thanks to the quality and performance of the recycling outputs; (iii) increased sustainability and resilience along the entire value chain thanks to the development of new recycling infrastructure; (iv) reduction of CO2 emissions from plastic waste incineration; and (v) significant contributions to the achievement of EU recycling targets. Participants concluded that the effective integration of chemical recycling into the recycling value chain depends on the collaborative efforts of multiple actors of the plastic value chain (*Partnerships* practices). In fact, chemical recycling calls for structural changes to the entire industrial system, from advances in collection and separation of the plastic waste streams to optimize recycling, to redesign of the logistics for plastic waste flows especially for flows that are currently overlooked (e.g., industrial scraps and residual waste), to increased utilization of recycled and circular packaging in the value chain, among others (Siltaloppi and Jähi, 2021).

In order to advance recovery of plastic packaging waste, industrial and institutional experts mentioned the critical role of *Data & information management* practices. Experts raised several examples of possible awareness and information initiatives tailored to consumers (e.g., "*there is need for more consumer awareness on the differences among plastic types, best practices to ease domestic waste separation, [and therefore obtain] better quality recyclables*", Regional institution; "*need for investments in information and awareness using institutional channels to make consumers more aware and responsible for their own consumption/disposal behaviors*", Industry expert), the waste management sector (e.g., "*education programs for municipal workers*", Regional institution), and industrial stakeholder (e.g., "*educate on how to capture homogenous industrial scraps to send to recycling, […] and understand the best recycling options for their [supply chain actors] plastic packaging waste*", Local institution). Given the fragmentation and structural complexity of the plastic industry in Italy, another crucial element is a robust and consistent monitoring system to map all plastic and plastic waste flows and facilitate the implementation of a widespread reverse logistics infrastructure. This is especially important when dealing with small and medium firms that "*are not able to map their scraps and do not know what the best path for [recovering] their waste is*" (Local institution).

Finally, regulatory aspects emerged as another central element underpinning the successful implementation of downstream CE solutions. While regulatory pressures have been on the forefront of the CE transition over the past years, focus group participants highlighted a number of interrelated issues on the regulatory front inhibiting growth in plastic packaging recovery. Acknowledging these issues is of utmost importance in the definition of priority actions to understand favorable areas of intervention and challenges/opportunities of the existing policy framework. The first problem entails inconsistent and inadequate investments in the waste management sector, that is often originated by misalignment between political agendas and industrial needs ("*municipalities do not know how and where to invest*", Regional institution). Another problem regards the lack of standardized recycling targets and indicators, which altogether make it difficult to establish recycling goals and track progress towards their achievement. Thirdly, procedural gaps hinder the firms' ability to expand/retrofit existing recycling plants or to build new ones as "*firms struggle to receive authorization [for it]*" (Industrial expert). To address these problems, participants pointed out the importance of advancing collaboration (*Partnerships* practices) between industrial experts and local institutions to identify the areas that require significant investments to open avenues for scaling up plastic recycling.

Alongside downstream solutions, there was consensus among focus group participants that *Circular packaging* practices should be incentivized through two priority actions. A first solution recommended by industrial experts concerned the phaseout of complex multilayer packaging materials that are unsuitable for recycling with traditional mechanical technologies. Second, multiple informants reported that a major restraint to fully sustainable and circular packaging is the limited availability of circular bioplastics. In particular, three main issues persist: first, there is limited knowledge of how to dispose of and subsequently treat bioplastics, for instance one participant said that "*consumers dispose of bioplastics in the organic bin, unaware of their fate after waste collection*" (Regional institution). Second, Italy currently lacks adequate infrastructure to manage bioplastics waste via composting or recycling, making both avenues unsuitable to recover material and value from bioplastics. Third, new bioplastics are too expensive and far from competing with virgin or recycled plastic materials. To address these problems, experts have suggested the need for substantial investments in waste separation and management infrastructure to valorize bioplastics waste via bioplastic-to-bioplastic treatments and reintroduce it into the plastic's material system. In fact, without a significant increase in the availability of bioplastics, innovative material solutions cannot translate into large-scale implementations (Siltaloppi and Jähi, 2021).

5. Discussion

5.1. The increasing complexity of the impact of factors on practices

Our study focused on the CE practices implemented by the sampled companies and related influencing factors, and most categories resonate with similar studies. For example, we noticed the positive influence of the favorable policy landscape (EC, 2018a) on the implementation of downstream solutions, like scaleup of sorting and recycling facilities and reverse logistics schemes; nonetheless, some difficulties in recovery can be linked to economic (e.g., high process costs), technical (e.g., material contamination in the waste stream, inability to recover heterogenous plastic waste with traditional technologies), and socio-cultural challenges (e.g., limited knowledge of packaging recyclability) (see also Bening et al., 2021; Dijkstra et al., 2020; Paletta et al., 2019). Similarly, upstream solutions appeared to be well established thanks to a wide set of enablers and the more mature legislative framework (EC, 2011a, 2011b, 2018a); both aspects are also highlighted by prior studies (e.g., Accorsi et al., 2020; Gong et al., 2020).

However, besides providing more insightful descriptions of the barriers and enablers of the CE transition, we contextualized them in the plastic packaging supply chain and explored possible interrelations between specific practices and factors, as shown in Fig. 3 (see detailed descriptions in Table S2). As the number of practices and factors increased over time, factor-practice connections and their complexity did too.

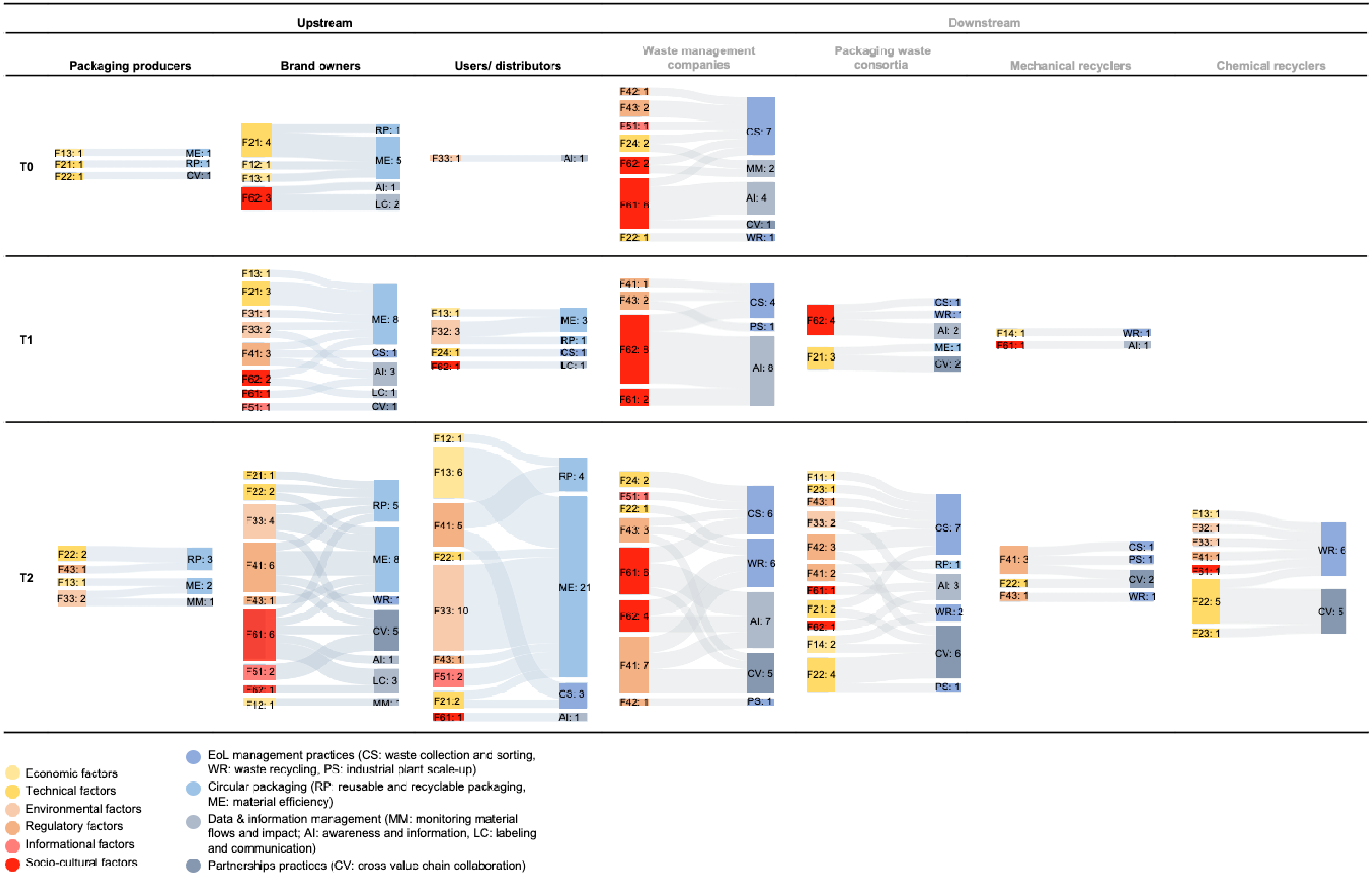

Fig. 3. Distribution of CE practices and influencing factors by supply chain actor for T0, T1, and T2.

Firstly, Fig. 3 shows an increase in the number of factors that impact on the same category of practices over time. In fact, in 2011, one category of practice tended to be driven by one/fewer factors, or even when more factors concurred in the implementation of a single category of practice, practices tended to be associated with factors belonging to the same category. For example, material efficiency practices implemented by brand owners appear to be driven mainly by technical and economic factors. Contrarily, in 2015 and even more in 2019, the analysis of factor-practice connections denoted a greater complexity for all analyzed actors. The same practice in fact resulted from the simultaneous manifestation of multiple influencing factors. For instance, in 2015 and 2019, material efficiency practices implemented by brand owners were driven by environmental, regulatory, and socio-cultural factors, in addition to economic and technical factors already recorded in 2011. This also reflect changes in the landscape, including different stakeholders becoming more aware of and engaged in the plastic waste issue, and subsequent market and regulatory pulls, which altogether increased the intrinsic commitment of companies to embed sustainability and circularity into their core business practices, as observed by Siltaloppi and Jähi (2021).

Secondly, it also noticeable in Fig. 3 that some factors developed impacts on multiple practices over the years. If we take the case of brand owners as an example, socio-cultural factors (F6.1 and F6.2) appeared to have an impact only on *Data & information management* practices (awareness and information, labeling and communication) in 2011. However, our analysis showed that they related to *Circular packaging* (material efficiency) and *Data & information management* (awareness and information, labeling and communication) practices in 2015, and further increased in 2019 with more

Circular packaging (reusable and recyclable packaging) and *Partnerships* (cross value chain collaboration) practices in 2019. Similarly, one regulatory factor (F4.1) that influenced the development of *Circular packaging* (material efficiency), *EoL management* (waste collection and sorting), and *Data & information management* (awareness and information) practices in 2015, showed an increase and a differentiation in the number of practices impacted in 2019, influencing *Circular packaging* (material efficiency, reusable and recyclable packaging), *EoL management* (waste recycling), and additionally *Partnerships* (cross value chain collaboration) practices. The examples presented above suggest the growing importance of these factors in the CE transition. The greater influence of socio-cultural factors denotes structural changes in the socio-technical landscape in which companies operate. In our analysis, these changes were due to increased socio-cultural pressures urging for greener, more sustainable products and changes in industrial behaviors (e.g., active involvement of companies in environmental campaigns). At the same time, the persistence of improper disposal practices required companies to adapt and change their CE practices to improve communication with end users and raise awareness on the role of consumers in plastic waste recovery. Additionally, a favorable and more mature regulatory landscape benefitted companies that engaged in circularity and sustainability solutions, accelerating the CE transition. Therefore, a more detailed analysis of the systemic impacts of these factors could bring critical implications for accelerating the transition to circular packaging and help define the next steps for the industry.

Thirdly, our findings indicate that each supply chain tier perceived factors differently and, consequently, implemented different types of CE practices. This complexity is summarized in three substantial differences: (i) different tiers appeared to report different category of factors, as upstream companies reported on all six categories while downstream companies mostly commented on technical, regulatory, and socio-technical factors. (ii) Even when all supply chain players discussed the same factor (e.g., F2.2), its implications were actor-specific, especially denoting major differences in the implementation of CE practices for upstream and downstream tier respectively. (iii) Lastly, in our sample, downstream companies seemed more incline to report CE barriers, while upstream companies commented on factors with positive or mixed impacts. This complexity calls for aligned and systematic development of CE solutions to steer the transition to circular packaging.

Finally, our findings suggest that the transition towards a mature CE of plastics tends to become a more complex process and a deep understanding of factor-practice connections is key for steering and boosting this transition. Exploring this complexity can in fact offer valuable insights into the challenges faced by different actors and allows for the identification of tier-specific interventions with system-level net improvements to accelerate the CE transition (Siltaloppi and Jähi, 2021).

5.2. Towards a more systemic CE transition

Our analysis suggests that the CE transition is occurring at different speeds and levels across different supply chain tiers. The implementation of CE practices in 2011 has been observed mainly in companies in the upstream tier (by number of practices/year), and concerned actions to reduce and substitute plastic use to decrease the companies' plastic demand, such as making packaging more efficient and performant and designing out unnecessary plastics. Despite their later and slower development stage, downstream solutions became essential to cope with the growing waste production, sustainably manage and recover plastic packaging waste, and thereby accelerate the CE transition in 2015 and 2019. This evidence of a more systemic approach resonates with the findings of The Pew Charitable Trusts and SYSTEMIQ (2020) that argue that one-sided solutions (only upstream or downstream) are a "*false dichotomy*" and fail to address the problem of plastic pollution in its totality, thereby hindering the CE transition.

We observed a gradual shift from scattered CE practices to a more systemic approach to closing the loop of plastic packaging over time. The integration of upstream and downstream CE solutions over time exemplifies this systemic shift. First, we noticed that industrial actors increasingly took actions across the supply chain. In 2015 and further in 2019, analyzed upstream supply chain actors, such as brand owners and users/distributors, showed a growing interest in downstream solutions and engaged in the EoL management of their own packaging waste. Second, 2019 denoted the creation of new stakeholder configurations, which became a steppingstone in the CE transition. For example, companies that were typically associated with upstream functions (e.g., oil and gas companies) became prominent plastic recyclers, converting part of their operations to chemical recycling of mixed plastic waste. Third, this integrative approach allowed for system-level net improvements. As observed by Bening et al. (2021), CE solutions that typically target downstream actors, such as those on plastic waste recovery, had a positive impact on upstream actors too, as packaging materials are retained longer in the system and become a valuable resource for packaging producers and manufacturers. Consequently, our data showed greater emphasis in exchange of information and collaborations across the value chain, suggesting that companies recognize their interconnectedness and the need for aligned collaborative efforts. This emphasis appears to be partly related to regulatory pulls, such as the EU's call for cross value chain partnerships and technology transfer to employ innovative and alternative feedstock, as well as for collaboration between the chemical industry and plastic recyclers for wider and higher value applications of recycled packaging (see EC, 2018a). It can also be partly attributed to the fact that supply chain players tend to share common interests and objectives in the CE transition, as suggested by the findings of our analysis and the focus group discussion.

Based on our findings, it is tempting to conclude that transitioning to CE has become a key priority for the Italian plastic packaging sector over time. We with The Pew Charitable Trusts and SYSTEMIQ (2020) that more synergetic CE solutions and systemic interventions emerged as a result of increased collaboration and accountability across the plastic value chain. Furthermore, as the industrial system transitioned to a more circular model, such interventions bore implications and systemic effects for all players of the value chain, as acknowledged by Bening et al. (2021).

5.3. CE solutions and future avenues for the plastic packaging sector

The findings of the focus group confirmed the four categories of practices identified in this study (*EoL management, Circular packaging, Data & information management, Partnerships*) and revealed new insights on their implementation. For example, while participants confirmed the results of our analysis that recycling became a key element in the CE transition in 2019, they emphasized other *EoL management* practices (e.g., reuse and deposit-return schemes) that did not emerge from the analysis of industrial reports. In the context of *Data & information management*, they also emphasized the importance of providing awareness and information at different levels (as opposed to consumer level only) and for a variety of stakeholders with roles in the plastic value chain, thereby reinforcing the systemic dimension of the CE of plastics.

Furthermore, participants added a new layer of complexity to our analysis of CE practices as they highlighted possible interdependencies between analyzed practices. For example, they discussed how implementing *Data & information management* or *Parentships* practices can help advance downstream solutions, such as improved waste recovery and recycling (*EoL management* practices). This suggests that CE practices are deeply intertwined and co-dependent, and a more detailed analysis of practice-practice relationships is needed to further our understanding of the CE transition.

The results of the focus group discussion provide three possible lines of intervention to accelerate the CE transition for the plastic packaging sector in the short and medium term. These priority actions translate into implications for upstream and downstream actors of the supply chain to overcome barriers to CE while leveraging existing enablers.

First, piloting and techno-economic assessment of new and emerging recycling technologies (e.g., based on the chemical treatment of plastic waste and mixed packaging) emerged from the discussion as a crucial element to abate the costs of recycling. At the regional level, pilot plants are key assets to evaluate the risks of investments in CE before the commercial-scale implementation of new technologies (the principle of "*test before invest*") on one hand, and solve specific, local-based sustainability-oriented issues related to the management of material flows on the other (Regione Lombardia, 2020). For downstream companies, our analysis showed that the availability of emerging technologies to treat plastic waste with high TRL and potential to reach commercial scale and increase capacity constitute a viable path to address growing streams of plastic packaging waste. Second, the presence of structural funds to support local supply chains in the development of new technological solutions can foster engagement of prominent recyclers and newcomers in plastic recycling operations (see MISE, 2021). Third, initially observed collaborative efforts across the entire supply chain can abate part of the costs associated with building pilot plants and experimenting new treatment options for plastic packaging waste.

A second priority is reflected by the urgency to find economically viable and closed-loop alternatives to plastic waste incineration and landfilling ("*residual waste is currently sent to landfill because there is no value at the moment in valorizing it*", Industry expert) via introduction of economic incentives and supporting policies for companies to deal with the high costs and energy requirements of plastic's EoL management. According to our data, this is currently restrained by high process costs, high energy requirements, material properties, inefficiency in the management of plastic waste along the supply chain, and poor consumer practices. One deciding thing to address these issues, is the presence of structural funds to support closed-loop systems that can help abate existing costs associated with waste management operations for downstream companies, while making recycled plastics more competitive on the market (see MISE, 2021). Additionally, our analysis has shown that existing CE policies at the national and regional level can regulate and incentivize the use of recycled content in the upstream tier, ensuring that materials are retained longer within the industrial system (such as EC, 2018a; Regione Lombardia, 2020).

Lastly, the focus group results supported Bening et al. (2021) in calling for policy coherence and standardization of national and regional standards with those adopted at the EU level to enable large-scale implementations. For instance, industrial experts contested that the Italian system for coding waste classifies much of household plastic packaging as "residual waste" (see EC, 2018b), thus reducing the possibility for recycling it as plastic waste. In addition, increased transparency and alignment among all supply chain players can prove beneficial in this context. To give an example, upstream choices on packaging materials can determine their EoL treatment options; therefore, regulating the use of reusable and recyclable content in the production of new plastic products can reduce recovery issues. Transparency and traceability of materials along the supply chain too can help manage waste streams, e.g. improving communication about EoL treatment options.

5.4. Implications for practice and research

Relevant implications for managing the transition to a CE of plastics for all supply chain players can be drawn from the present study. Our findings provide industrial actors with a better and more detailed understanding of the influence and role of factors on different tiers of the plastic packaging value chain. A comprehensive and well-framed mapping of the existing efforts to develop CE solutions is also offered, along with priority areas of intervention to accelerate the CE transition. In general, we call for collaborative efforts to enable structural and systemic changes and more alignment across the supply chain to enhance waste recovery. For actors of the upstream value chain, this translates into greater engagement in reverse logistics, increased utilization of circular packaging materials, and improved communication and exchange of information about materials and related disposal options with downstream actors and consumers. For actors of the downstream value chain, this means developing technologies and operational solutions to overcome economic and technical challenges constraining a broader adoption of recycling, as well as to collaborate closely with upstream actors and consumers to ensure that a continuous and abundant flow of recyclables reaches recycling facilities.

As for contributions to research in the area of CE in general and CE of plastics in particular, this study offers an in-depth analysis and view of the complex landscape of the CE transition in the plastic packaging context enriching existing knowledge on the topic. This paper also introduces a longitudinal analysis, by adding the temporal dimension to the study of CE barriers and enablers, which has no prior examples in the extant literature, despite its relevance for a full understanding of the phenomenon. In particular, we mapped changes in factors and related CE practices between 2011 (T0), 2015 (T1), and 2019 (T2) in relation to specific supply chain actors. This type of evolutionary analysis can further the understanding of CE by analyzing the role, influence, and impacts of factors at all stages of the CE transition, and can be employed in future studies to track progress towards achieving closed-loop models. Finally, the methodological approach can be replicated and adapted to the analysis of CE transitions in other industrial sectors.

6. Conclusions

To the best of our knowledge, this is the first study analyzing the CE for the Italian plastic packaging sector. Our findings show that the transition to plastic circularity has accelerated over this period and companies have shifted from unilateral solutions to system-level interventions, particularly centered around packaging recycling. The study deploys a longitudinal approach to advance the understanding of CE factors and resulting practices adopted by sampled companies.

However, some limitations of this approach are associated with the timeline and the sample selection. First, our analysis depicted an overview of a 10-year transition based on the analysis of three meaningful years (2011, 2015, 2019). Expanding the analysis to all ten years could pinpoint additional time-specific changes and identify when specific practices first appeared. Second, similarities within each supply chain position may influence the adoption of CE practices and the pressures to which actors are exposed. To increase diversity of the results and capture possible actor-specific variations, we suggest increasing diversity within each supply chain position (e.g., companies with different scales of operation). In addition, the evolution of companies' factors deducted from publicly available data, thereby falling short of fully capturing the tacit companies' strategic intents and introducing some biases from assumptions.

A systematic investigation of the relationships between factors and the implementation of CE practices, as well as between different practices, will require a more in-depth analysis grounded on companies' primary data and confidential information. Finally, this study presents implications for managing the transition towards a CE of plastic packaging from the perspective of different supply chain actors. With this knowledge, practitioners can unearth new opportunities for targeted interventions and understand the systemic effects of such interventions towards CE.

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