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Exploring the industrial dynamics of waste management and recycling: A call for research and a proposed agenda

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ABSTRACT

The waste management sector is undergoing profound transformations that challenge its structures and institutions. The function and position of waste management and recycling companies have been changing, and this process accelerates as the circular economy consolidates as part of the strategy to implement green shifts. This article argues that scholars, practitioners and policymakers interested in waste management could benefit from building bridges with the field of industrial dynamics. Industrial dynamics is concerned with the driving forces of economic transformation, with focus on not just outcomes but processes and structures. This type of research is crucial in face of transformations going on in the sector. Three crucial themes for cross-disciplinary investigation are: (i) industry evolution and institutions, (ii) business organization and management, and (iii) technological change, innovation and entrepreneurship. Waste management is a lively, complex and diverse sector, whose process of reinvention present the opportunity to research profound industrial transformations in real time. By systematically investigating the industrial dynamics of waste management, it becomes possible to uncover the structural changes underpinning the transformation of waste into resources, their driving forces and the directions to which they point, while mindful of the evolving discourses and the wider technological and institutional landscape.

1. Introduction

The waste management and recycling sector (henceforth WM) has been going through profound structural changes, as the emergence of green shifts has contributed to the popularization of circular economy (henceforth CE) discourses and policies. In this paradigm, new pathways for waste valorization emerge and, more than the manipulation of discarded objects, WM becomes the engine by which wastes are transformed into resources (Pongrácz et al., 2004). In other words, these transformations shift the position of WM, from being a handler of economic liabilities to a provider of economic goods (Perey et al., 2018). This brings wide-ranging implications for diverse actors, ranging from radical changes in the evolutionary trajectory of the sector as a whole and individual firms, to the role of the governments in waste handling, and matters of environmental and innovation policy, which are crucial for setting the stage of transformations in an industry's dynamics toward sustainability (Bergek & Berggren, 2014; Deleidi & Mazzucato, 2021).

Research on circular economy transitions have not yet addressed underlying mechanisms of industrial change (Chizaryfard et al., 2021) and has only recently begun to tackle how the concept has been addressed in science and technology policy (Hermann et al., 2022). Economics is a diverse discipline, yet the most substantial share of research on the economics of waste has been limited to scholarship in the field of environmental economics, who apply orthodox economic thinking to waste-related questions (e.g., Aggarwal & Lichtenberg, 2005; Conrad, 1999; Kellenberg, 2012; Lager, 1998; Miyamoto, 2014; Nematian et al., 2021; Simões & Marques, 2012; Yamamoto & Kinnaman, 2022). From a heterodox economic perspective, the most prominent stream can be found in ecological economics (e.g., Abate et al., 2020; Bucciol et al., 2019; Nakamura, 1999), which considers more explicitly the relationship between economic activity and the physical limits of the environment. This article seeks to build bridges between research on WM and scholarship in a different heterodox economic branch, namely the field of industrial dynamics, which is anchored in Schumpeterian economics. As argued by Pyka and Lee (2021), industrial dynamics has a key role in the sustainability challenge, which is crucial for development in the twenty-first century.

Industrial dynamics is concerned with the driving forces of economic transformation, with focus on not just outcomes but processes and structures (Carlsson, 2016). Industries where change is central to the

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competitive environment are of special interest (Malerba & Pisano, 2019), something that has been abundant in the context of waste in recent years, whether through new policies or technological innovation. Scholars in industrial dynamics have engaged with sustainability transitions (e.g., Andersen et al., 2018; Andersen et al., 2017), nonetheless, little has been done from this perspective on the context of waste and secondary resources. Despite the important contributions of existing studies (e.g., Bugge et al., 2019; Chizaryfard et al., 2021; Madsen, 2022; Rainville, 2021), insights are still dispersed and does not form a cohesive body of knowledge regarding the mechanisms of industrial change in WM. Such knowledge would provide a perspective different than environmental economics and enrichen knowledge on the economics of waste.

As the notion of green shifts consolidates in the public debate and the circular economy discourses and policies institutionalize, the need to understand the industrial dynamics of WM gains new urgency. There are considerable expectations concerning transitions to the circular economy looking forward, and in this paradigm, waste ceases to be perceived as an unwanted output and becomes an untapped source of undervalued resources. Likewise, the understanding of WM as an industrial sector needs to be strengthened, and examining WM's evolutionary trajectory and industrial dynamics is a crucial step in this direction. Before exploring three areas of interest at the junction of industrial dynamics and WM, the section below outlines some key characteristics of WM as an economic sector of activity.

2. Waste management as an economic activity

Contemporary culture has a wealth of vocabulary to denote waste—garbage, trash, rubbish, scrap, debris, rummage, litter, discards, wreckage etc.—but a dearth of words that characterize these materials as sources of value. Likewise, conceptualizations of WM have emphasized its health and environmental attributes, at the expense of an understanding of how WM functions as an economic sector. While there is research on issues such as global trade of waste (Alexander and Reno (2012); Brown et al., 2022; Kellenberg, 2012; Minter, 2013), as well as research that reconstructs the pathways of waste materials through global value chains (Lepawsky, 2018), adopting the lenses of industrial dynamics can help systematize knowledge of the nature of economic activity in WM, including questions of value creation, quantification of this value and its appropriation. Economists have long engaged with questions concerning of valuation (Elder-Vass, 2019; Lowe & Genovese, 2022), but the implications of these issues in industrial activity and management represent an area for further research.

In addition, there are submarket dynamics at play, which can be seen in the various waste streams. For each stream, a distinct value chain ensues, alongside distinct organizational arrangements, not to mention specific regulations and market dynamics. What is more, each submarket is influenced by a completely distinct set of drivers. Take for example the exchange value of secondary plastics and metals, which exhibit almost polar opposite patterns. This occurs, among other reasons, because the material quality of recycled metals does not decay the same way plastics does (Rigamonti et al., 2018), resulting in better conditions for markets to emerge. Moreover, metals are affected by metal prices negotiated on commodity markets, whereas plastics lack such organized trading arenas. WM often involve cross-border trade and transport, both when waste is a resource and when it is a liability; this occurs amid strict export regulations, which also affect the how resources are valued and has implications for management. In contrast to both metals and plastics, biological waste such as sludge is completely distinct, as its localized applications lie outside global trade networks. This multiplicity of waste fractions points to the complexity of actors, processes and systems involved with each type of material and that WM companies must navigate and administer. Complexity is increased further if the multiple approaches to each WM function are considered (e.g., Ragaert et al., 2017; Yamamoto & Kinnaman, 2022). For instance, sorting waste in a centralized facility can be done by a range of methods (manual, mechanic, chemical, magnetic etc.), depending on the properties of materials, the economic viability and technological sophistication available. While these characteristics are familiar to scholars and practitioners in the field of waste, research that explicitly investigates the nature WM, questions of value, markets and sub-market dynamics can be beneficial to understanding the nature of WM as an economic sector beyond its role as a public utility (Massarutto, 2007). The field of industrial dynamics can contribute to this task, as will be explored in section 3.

Another central issue to the economics of WM is the dynamics of substitution between virgin and secondary resources, and the role of alternative materials (Omodara et al., 2019; Söderholm, 2011). For example, analyses on the economics of plastics must consider not only that (recycled) plastics are in competition with other materials for any given application (including virgin plastics, bioplastics, and even paper bags and metal cans in some cases), but also that there are multiple uses potentially competing for a material source. Questions concerning how non-uniform material quality and uncertain patterns of supply affect these competitive dynamics are also worthy of investigation (Rigamonti et al., 2018). As consumers increasingly value the environmental qualities of their purchases (Fraj & Martinez, 2007) and the demand for items made from recycled materials increases (White et al. (2019)), questions on the dynamics of substitution gain renewed interest. Moreover, as the socio-cultural conceptualization of waste changes from one of liabilities or externalities to one of resources and waste valorization processes unfold at scale, it becomes necessary to make decisions regarding the ownership, valuation, and conditions for exploitation of this resource pool (Cavé, 2020; Nogueira et al., 2021). From the gold that is stored in junk electronics forgotten in drawers and attics all over the world (Cossu & Williams, 2015), to the phosphorus that is available in sewage sludge (Scott, 2017) and whose scarcity threatens global food production, the emergence of previously untapped resource pools demands the design of an adequate management regime for a profitable and sustainable resource use.

The following section explores three themes that connects the theoretical apparatus of industrial dynamics with noteworthy empirical phenomena in WM. A comprehensive literature review on these themes is outside the scope of this article. Instead, its ambition is to illuminate where and how industrial dynamics can help making sense of the transformations relevant to the WM sector, as well as to outline a research agenda that supports both policymakers who are paving the way to sustainability transitions, and firms that are navigating these transformations.

3. Connecting the field of industrial dynamics and the context of waste management

This section explores, in the context of waste management, three themes that are at the core of industrial dynamics research: (i) industry evolution and institutions, (ii) business organization and management, and (iii) technological change, innovation and entrepreneurship. Relevant avenues for further research along on these themes are summarized in Fig. 1.

3.1. Industry evolution and institutions

Appreciating WM as an economic sector opens up room for investigating its industrial evolution, which is a central theme of industrial dynamics, as indicated in studies numerous sectors, such as semiconductors (Henderson & Clark, 1990), automobiles (Klepper, 2002), pharmaceuticals and healthcare technology (Garud & Rappa, 1994; Malerba et al., 2016), wind power (Nogueira, 2018), and craft brewing (Garavaglia, 2022).

WM has come a long way from its early public service days (Antonioli & Massarutto, 2012). Not only are individuals now more concerned than ever with environmental issues and the impact of their own

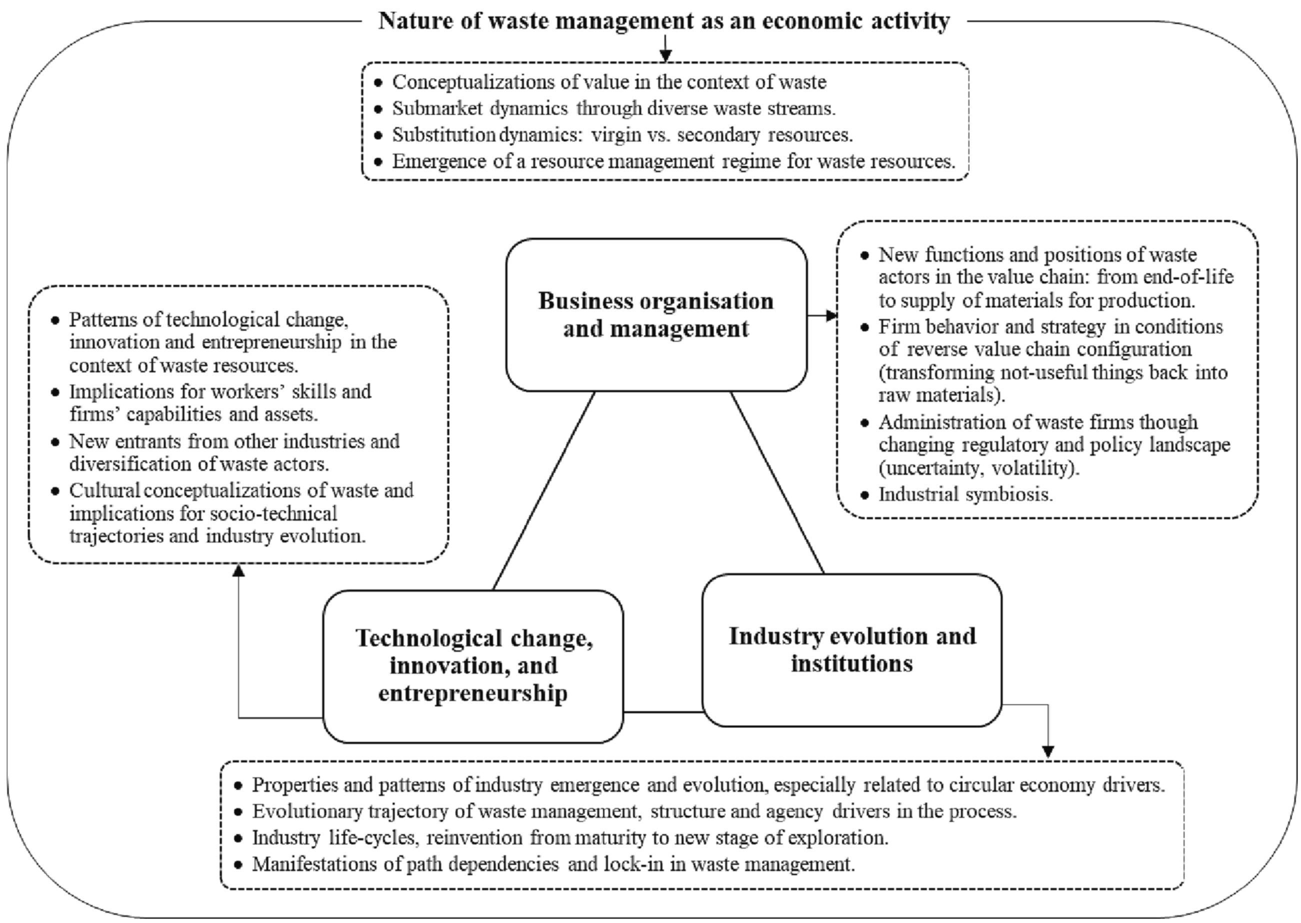

Fig. 1. A research agenda connecting Industrial Dynamics and waste management.

consumption habits (Fraj & Martinez, 2007), but the push for circular economy policies and business models also generates lofty expectations concerning waste as a source of value. The transformations that the WM sector has experienced, and the upcoming scenarios that the sector faces have the potential to disrupt the current order of how materials are sourced and how production systems are organized. These developments make up for a sector rich in phenomena of relevance to industrial dynamics, since industrial evolution is characterized by intense change in sector's structural features (Malerba & Pisano, 2019). Moreover, WM offers an empirical context of specific relevance regarding sustainability transitions, whose directionality adds a layer of complexity—namely in regard to socio-ecological concerns—in comparison to the industries traditionally investigated in the field (Bugge & Fevolden, 2020; Elzinga et al., 2021). Likewise, a more detailed and theoretically informed understanding of the properties and patterns of evolution in WM is crucial for better management of WM companies, and knowledge of drivers for industrial development in this context is essential for circular economy policymaking.

Examples of studies that mention the evolution of different branches of WM do exist, but they usually have a different focus than exploring this industrial evolution in depth. For instance, Favot et al. (2016) take stock of the evolution of extended producer responsibility for waste electrical and electronic equipment in Italy, and while the study does describe the main background policy events and economic performance indicators, its focus is to investigate technical and economic performance, instead of drivers and patterns that affect the developmental trajectory of the sector (as a study anchored in industrial dynamics would do). Specifically, Favot et al. (2016) are interested in whether competition among producer-responsibility organizations leads to reduced collection fees to producers or whether it leads to higher collection rates, and they find the first to be the case.

One fruitful approach for further research in the industrial dynamics of WM concerns industry life cycles. Extant theory posits three stages in industrial development: (i) exploration (ii) growth and (iii) maturity (Klepper, 1997; O'Sullivan, 2021). In spite of the many facets of WM, the sector can be considered to be mature (Antonioli & Massarutto, 2012); nonetheless because it represents an essential task in society, it is not conceivable that the sector will deteriorate to obsolescence or be disrupted out of existence, as could be the case with other industrial activities. The sector's reinvention in light of the circular economy agenda is leading it into a new stage of exploration. What new paths come about and how they unfold is a promising research area. Moreover, the increasing specialization involved in different waste fractions can represent the branching out of new industrial domains, as has been the case for instance with the emergence of offshore wind as a domain with distinct patterns than those found in onshore wind power (Andersen et al., 2017).

The development directions of the WM sector are subject to the incentive structures in place, and as a result to susceptible to path-dependencies and lock-in. One concrete example concerns the distinct approaches for waste handling. In circumstances where the cost of landfilling is low, the abundance of virgin materials is reasonably high, and the viability of recycling is challenging (whether for technical or financial reasons), the result is the absence of incentives to consider end-of-life concerns or material properties in product design. In contrast, if there is a penalty to landfilling, structures for material recovery and ecologically conscious product design can begin to emerge (Nogueira et al., 2022), provided that the appropriate regulatory and inspection apparatus is in place to prevent illegal dumping and cross-border transport of waste to regions with weaker environmental regulations

(D'Amato et al., 2015). Another example of a possible source of lock-in is the decision to build an incinerator. Because of the high upfront costs and the projected model for financial viability of the project, the decision to build may create a lock-in, since the plant will require a steady stream of materials; this can put barriers to fostering material recovery, which is preferred according to the waste hierarchy. A recent study with data from Japan finds that increased incineration capacity does discourage recycling (Yamamoto & Kinnaman, 2022). Interplays between recycling, landfilling, incineration, and even illegal disposal also bring upstream repercussions (Aalbers & Vollebergh, 2008). In fact, policy instruments such as extended producer responsibility seeks precisely to influence the upstream, by making manufacturers accountable to manage the product's end of life (Lifset et al., 2013).

Against the background of industry evolution, another essential matter is that of structure vs. agency. While WM firms do have agency in the dynamic evolution of the sector and in a possible transition towards a circular economy, they are also constrained by institutional arrangements that are not yet sufficiently adapted to realize this vision. Because institutions give rise to social practices (and vice versa), assign roles to actors and govern their interactions, institutions form a framework for how people interact, and the way societies evolve (Hodgson, 2006). Institutional perspectives also matter for organizations, as they often need to reconcile operating simultaneously in old and new regimes, while new rules become institutionalized (Nogueira, 2018). In-depth analyses of the trajectory of the WM sector in different regions and countries would reveal structural elements and institutional forces that govern the current regime. The path-dependencies and lock-ins at place affect the directionality of transformations taking place today, and the possibility of new paths (Arapostathis & Pearson, 2019). Studies anchored in industrial dynamics can help elucidate core institutional roadblocks to industrial transformation and the role of policy.

3.2. Business organization and management

As waste becomes resources, the WM sector is pushed towards new functions, positions and relationships in the economy. While these firms have traditionally overseen the end-of-life of products and provided an environmental service, they are to become holders of materials that contain economic value in a much larger scale than what we have seen up to now, should visions of a circular economy materialize. Landfills, for example, present a significant potential for resource extraction, although landfill mining has thus far been restricted to dealing with concerns such as pollution and urban development (Krook et al., 2012). In the field of sanitation, Scott (2017) has illustrated the variety and scale of resources going through wastewater treatment plants that have thus far remained untouched. For incumbent WM and sanitation actors to be able to capture this value, they need to engage in a process that defies their original missions, their structures, and operations. That is, WM firms transition from handlers of economic liabilities to providers of economic goods (Perey et al., 2018). This has implications for all players in this diverse sector, and understanding these events though the light of industrial dynamics put them in a broader perspective, since industrial dynamics is concerned with the interaction between activities and capabilities inside firms with their competitive environment (Carlsson, 2016).

Despite the transformative potential of waste valorization, the current regulatory apparatus still gives little consideration for waste as a resource, markets for secondary resources/parts and second-hand products are immature and troubled by inconsistent demand, and also suffer from intense competition with virgin resources and brand-new products (Avfall Avfall Norge, 2021). Similarly, as circular economy visions become part of the strategy to realize the green shift through market mechanisms, WM walks a fine line between its environmental responsibilities and profit-seeking endeavors (Antonioli & Massarutto, 2012). The sector is also permeated by questions of how value is conceptualized in the economics of waste (Nogueira, 2019), what role public goods and non-market mechanisms play (Nogueira et al., 2023).

If we consider the WM sector as a provider of goods, we can appreciate that, while ordinary production is about transforming raw material into useful things, recycling operates by transforming not-useful things back into raw materials. That is, by consuming various products, households are turned into producers in the context of waste. Waste haulers function as reverse distributors. Where markets do exist, recycling businesses stand for buyers, thus realizing the transformation of economic liabilities into goods. It is this process that confers waste the renewed title of secondary resources. In contrast, where markets do not exist or function poorly, landfill operators or incinerators provide the service of handling the end-of-life, in effect 'consuming' the waste. These dynamics are, though, volatile and pose a substantial managerial challenge to WM firms. In practice, it can be troublesome to manage a waste company as a provider of materials (rather than as a provider of an environmental service) without predictability concerning whether materials have a positive or a negative economic value in the marketplace. Depending on the conjunction of economic forces such as price, demand, and availability of materials, waste can quickly turn from an asset to a liability (and vice-versa). Such volatility affects how firms behave, what entrepreneurial opportunities exist and how they can be addressed, as well as how the sector evolves more broadly. Transitions to a circular economic model heighten the importance of this issue, since even municipal WM companies that are publicly owned and operate on a self-cost principle are pushed to operate as businesses in a competitive market rather than as public services concerned with hygiene, pollution and environment.

In addition, the fact that waste companies operate in a wide range of materials and treatment approaches, combined with society's ever-changing patterns of production and consumption, represents an important source of uncertainty to firms in this sector, which need to continuously adapt their operations to exogenous change. Although some recycling actors specialize in, say, metals or plastics, many other WM companies, such as those handling household waste must be proficient and versatile to manage a wide array of materials. They must also be flexible to adapt to ever-changing consumption patterns, which generate new types of waste to be handled. A simple example is the proportion of paper compared to plastics in waste streams over time. This implies the need for new operational methods and practices, not to mention facilities, equipment, and relationships with new actors. Upstream innovations in the material composition of various products also pose the need for incumbent WM firms and their workforce to catch up and adapt.

Another issue concerns industrial symbiosis, which has received much attention from the field of industrial ecology (Chertow, 2007; Jacobsen, 2006). There is a parallel between research on clusters and industrial symbiosis, as both are concerned with co-location and fruitful exchanges. While cluster research is more interested knowledge and innovation, industrial symbiosis addresses material resources synergies, for instance in industrial parks, which can promote better environmental performance. Research combining perspectives from industrial networks and clusters and industrial ecology (Yu & Zhang, 2021) is another area for this cross-fertilization.

In short, and similarly to the previous section, studies anchored in industrial dynamics can be useful in the exploration of how firms of very diverse profiles—varying from publicly-owned not-for-profit waste and sanitation actors to recycling firms owned by hedge funds—cope with transformative pressures that characterize WM at present, as well as how they themselves are vehicles of industrial transformation.

3.3. Technological change, innovation, and entrepreneurship

In recent years, the WM sector has witnessed knowledge accumulation (Cecere & Martinelli, 2017), technological innovation (Cecere & Corrocher, 2016; Park, 2014) and entrepreneurial activity (Minter, 2013). In addition, the combination of the technology-promoting discourse around the circular economy (Friant et al., 2020), the policy support to this agenda, and the anticipated increase in the competence level of the workforce (Nørstebø et al., 2020) give cause to expect that the degree of technological sophistication in the sector will increase further. Innovation and entrepreneurship are at the heart of the field of industrial dynamics. In the words of Bo Carlsson: *"the whole field of ID grew, in part, out of the concern that there was no place in conventional static equilibrium theory for the analysis of technological change, its supporting institutions, and its fundamental role in generating economic growth and industrial development"* (2016p. 25).

WM has experimented with various technological developments. Examples are varied and range from engineering solutions such as optical reading and near infrared technology to identify colors on trash bags dispensing with the need for labor (Martín-Lara et al., 2018), and the use of drones to manage landfills (Sliusar et al., 2022), to biotech solutions like ways to capture methane from landfills and sewage systems and use it as an energy source (Mills et al., 2014), and the use of larvae that decomposes biological waste, which could be used as animal feed (Gold et al., 2018). Moreover, waste actors and policymakers have increasingly discussed digitization, and artificial intelligence in service of waste sorting (Berg et al., 2020).

Digital innovations and their accompanying entrepreneurial opportunities can be grouped in three broad streams. The first refers to process innovations, which seek to improve WM operations. One example is the use of artificial intelligence in solid WM, such as the use of sensors to optimize logistics of waste collection (Abdallah et al., 2020). The second refers to product/service innovations, which are those that create new businesses for WM firms in fields where they did not have before the digital revolution. For instance, data analytics allows for epidemiological analysis and monitoring, for instance of opioid use or COVID-19 infections, based on wastewater (Jacobs et al., 2021). While this is not at present a concrete business for waste and sanitation actors, to the extent that new ways to monetize this type of data are developed, this is expected to change. Finally, the third stream, also a kind of product/service innovation, concerns the use of digital technologies to implement pay-as-you-throw models of waste collection and management (Elia et al., 2015). This not only incentivizes waste reduction, but it also facilitates better sorting of what is actually discarded and allows for targeted data-informed measures to change undesirable behaviors. These events represent a paradigmatic change that involves unprecedented opportunities and challenges.

Such developments will further change the industrial dynamics of the sector, which are complex yet poorly understood. Furthermore, they will also affect worker's need for new skills, and firms' need for new capabilities and assets. Although waste innovations are enabled by advances in information technology and/or biotech, it is useful to conceptualize them as waste innovations (rather than IT), since they provoke changes in the technological regimes that governs WM. The so-called fourth industrial revolution is precisely about information technology spreading from a sector of its own towards permeating all other sectors, thus *"blurring the lines between the physical, digital, and biological spheres"* (Schwab, 2016). In that case, devoting attention to the applications of these innovations gives us insight into how they challenge existing technological trajectories and competitive dynamics. Likewise, conceptualizing waste innovations as a group allows an appreciation of the technological advances and dynamics affecting the sector.

We can also expect that the new opportunities afforded by these innovations will bring about increased entrepreneurial activity in the sector, both among incumbents and through new entrants. This can take shape in various forms. Discussions on business model innovations (Bocken et al., 2021; Lüdeke-Freund et al. (2019)) often aim at increasing circularity in diverse sectors, but there is also ample room for entrepreneurship connected to the WM sector itself. In Norway, for example, publicly owned WM companies have been quite entrepreneurial by launching subsidiaries to address opportunities in different waste streams. Iris Salten, in northern Norway, has seven subsidiaries in diverse fields, from upcycling fishing gear to wastewater treatment. Some of these ventures stretch the sector boundaries and illustrate the potential for knowledge spillovers. The circular economy agenda, and the subsequent valorization of waste resources is also expected to give rise to new entrepreneurial opportunities (Hesselberg, 2021), invite new entrants from other sectors (Bjørndal, 2021c) and from other countries (Bjørndal, 2021a). Furthermore, WM companies are supplying their need for additional competences they need by acquiring actors in other sectors and turning their focus toward waste (Bjørndal, 2021b).

Lastly, research on the industrial dynamics of WM can bring knowledge of technological developments in WM into its socio-economic context and against the backdrop of the WM sector's evolutionary trajectory. This complements the rich knowledge the field has amassed on WM from a socio-economic perspective (Campitelli et al., 2023; Mazzanti and Zoboli, 2009; Soltani et al., 2015). Such contextualization is vital to address concerns that the transformations currently taking place in the sector, particularly those related to the circular economy, are primordially technocratic and divorced from socio-political concerns and interests (Friant et al., 2021; Hobson (2020)).

4. Conclusion

This article is among the first to discuss the industrial dynamics of WM, and to bring industrial dynamics considerations to the context of the circular economy. Its main argument is that WM actors are simultaneously enacting and witnessing the reinvention of a mature sector, which raises questions concerning the mechanisms of industrial change in WM.

Dominant circular economy discourses have portrayed the challenges of transitioning to a system in which waste as resources as being mostly of technical matter, which overlooks the socio-economic dimensions of technological change (Chizaryfard et al., 2021). By systematically investigating the industrial dynamics of WM, it becomes possible to uncover the structural changes underpinning the transformation of waste into resources, their driving forces and the directions to which they point, while mindful of the evolving discourses and the wider technological and institutional landscape. It is not easy to identify path-breaking events without the benefit of hindsight, but recent developments bring a unique possibility to research in real time the evolution of an essential sector to society and the economy.

Future research along the lines illustrated in Fig. 1, and expanded upon in section 3, can benefit not only stakeholders interested in waste, but also scholars of industrial dynamics, since the WM sector is rich in phenomena of interest to the field. This knowledge also matters to inform innovation policy that aligns the imaginaries of science, technology and innovation with imaginaries of a circular economy (Hermann et al., 2022), and which is vital for transforming the industrial dynamics of the waste management sector for sustainability transitions. For example, if policymakers have the ambition to design regulations and incentive systems that promote circular economy transitions, they will be better equipped to do so if they possess a deeper understanding of the patterns of technological change and of industry evolution, as well as the sources of lock-ins in the sector. Likewise, they will be better equipped to deal with unintended effects from the policies they propose, and course correct as needed. The research agenda advanced in this article is valuable in achieving these goals.

In summary, WM is a lively, complex and diverse sector, and knowledge of the sector's evolutionary trajectory in various countries and patterns of industrial dynamics in distinct waste fractions are still little underexplored. It is about time this changes, and this article provides some indication of the potential in this cross-disciplinary endeavor.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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