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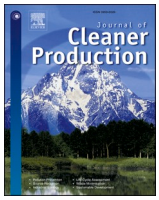

Review

Informal recyclers as stakeholders in a circular economy

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ABSTRACT

The inclusion of the informal recycling sector (IRS) in a circular economy (CE) is challenging and it is gaining increasing attention by the academic community in an exponential yet fragmented way. In this narrative review, we demarcate the direct and indirect contributions of the IRS to various domains of the CE by drawing knowledge from relevant literature. First, we capture the modi operandi of different forms of recycling value chains into a typology. We do so based on distinct foci and policy approaches towards the IRS which have been adopted across different countries. Second, we synthesize various threads of information on reported forms of collaboration, tensions, and challenges in the context of urban waste management, into a conceptual framework to facilitate transitions towards circular and inclusive wise-waste systems. Finally, we discuss important aspects related to circular business models and integration approaches towards the IRS, and we propose avenues for further research.

1. Introduction

The informal recycling sector (IRS) can play a decisive role in curbing the negative impacts of a linear economy (Valencia, 2019). Its integration in formal urban waste management systems (UMWSs), and consequently in a circular economy (CE), will support progress towards gender equality, improvement of occupational health, reduced inequalities, and the eradication of poverty and hunger (Rutkowski, 2020; Sharma et al., 2021) whereas its exclusion can be *"highly counterproductive"* (Wilson et al., 2006). In this context, the exploration of the various facets of social embeddedness of the IRS in a CE, particularly in terms of interactions between material and non-material flows, is necessary for improving our understanding of the potential positive and negative impacts of integration mechanisms of the IRS (Blomsma and Brennan, 2017; Liu et al., 2023).

According to Scheinberg et al. (2011) the IRS is generally understood as two distinct sub-sectors: a) the **informal service sector** which consists of *"individuals and micro enterprise informal service providers (ISPs) earning fees for removal of waste, excreta, litter, and, more broadly considered 'dirt'"*, and b) the **informal valorization sector** which consists of *"individuals, co-operatives, and family and micro-enterprises – which functions as an extractive resource industry. The main activity of this sector is identifying and removing valuable materials from the waste stream and the places where waste accumulates, and valorising (extracting value from) it"*.

The low threshold for trading discarded items or their products (e.g., e-waste) in combination with the potential of earning from commerce, can be strong incentives for many impoverished people to become informal recyclers (International Labour Organization, 2014). The level of urban informality is context specific and depends on the varying degrees of actor involvement, inter-actor coordination, value chain structures, and the interdependence of service provision for waste collection and processing. This latter pattern is often co-shaped to varying degrees by both the formal sector and the IRS (Guibrunet, 2019). Typically, informal recycling manifests when three conditions co-occur i.e., when the socio-economic circumstances push poor and marginalized people in engaging with waste scavenging, when generated waste materials feature some monetary potential, and when these are physically accessible (Velis, 2017).

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Past research suggests that two key factors which encouraged the emergence of an IRS in several low-income countries were the rising opportunities for the private sector to exercise its market power, and its dependency on accessing large volumes of high-quality recyclable materials (Moreno-sanchez et al., 2004). But nearly two decades later, a few steps forward are being taken by the private sector. For example, a small number of large multinational companies plan to commit in improving the rights of informal recyclers by buying directly from them recyclable materials in fairer prices and under better health safety standards (O'Hare and Fernandez, 2022). In other cases, such as in Brazil, the legislation obligates companies to include the IRS at the formal recycling chain, organizing street collectors in cooperatives, improving their work conditions, and scaling the production through investments in high-quality equipment, appropriated warehouses and paying for the reverse logistics service (Guarnieri et al., 2020). However, some argue that corporate circularity is still largely concerned with improving its recycling practices rather than redesigning their products and services, and with managing material flows rather than supporting the people who move them (Barford and Ahmad, 2021).

By using machine learning and non-linear regression models on socioeconomic development variables such as Gross Domestic Product, Social Progress Index, and Corruption Perceptions Index, Velis et al. (2023) showed that while the performance of UWMSs can be captured by the variability of these proxies, there were no evidence to support the decoupling of socioeconomic growth from waste generation, and they argued that cities should pay more attention to addressing systemic failures for unlocking the potential of their UWMSs. Also, considering the magnitude of the ongoing debate between *green-growth* and *degrowth* proponents and its relation to a CE (Global Governance Institute, 2022; O'Neill, 2020), more research is needed to illuminate the grey areas of contradictions, benefits, and of the resilience potential of formalization of the IRS in line with CE principles (Dewick et al., 2022) as well as with the targets of the Sustainable Development Goals (SDGs) in an effort to reduce mismanagement practices such as open dumping and burning which can have local, regional, and global impacts (Ferronato and Torretta, 2019). At any rate, the inclusion of the IRS in a CE should not be seen as an idealized solution given the plurality of issues it faces which include criminality, exploitation, power asymmetries, child labor, and high health risks (Velis, 2017).

By studying relevant literature our research aims to answer the following question: *"how does the informal recycling sector contribute to the waste hierarchy principles and how can it be included in a circular economy for UWMSs?"*. In section 2, we list the steps that we followed in this narrative review. In section 3, we present the results of the search in Science Direct, we demarcate the various *"hardware"* and *"software"* elements of UWMSs, and we propose a typology of operational modes of recycling values chains by considering different policy approaches towards the integration of the IRS to a CE. Then, we focus on the IRS as a stakeholder by examining the tensions and challenges emerging around waste-related infrastructures, and we illuminate its direct and indirect contribution to a CE which we summarize into a conceptual framework. Subsequently, we highlight important aspects which need to be considered when including the IRS in a CE, and we propose avenues for future research. Finally, in section 4 we draw the main conclusions.

2. Methodology

We position our analysis as a non-exhaustive narrative review of relevant literature, addressing the topic of interest in the form of an in-depth discussion of empirical findings. Besides academic literature obtained from desktop search, our collective knowledge of the context of the IRS and the CE presented here, was accumulated over the past 2.5 years while conducting research within the Sino-Dutch collaborative research project *Inclusive Wise Waste Cities* (mentioned in the Funding section). This knowledge helped us to set clear criteria (i.e., pre-specified categories of interest) for selecting focused empirical findings directly related to the key subject of this study. The knowledge was synthesized: a) via a large body of literature compiled from various sources (e.g., ResearchGate, Google Scholar, and Google) and b) via interactions with experts in the IRS and/or CE (Fig. 1).

The desktop search was conducted in Science Direct on the 14th of December 2022 using the following query: TITLE-ABS-KEY("Informal") AND TITLE-ABS-KEY("Waste management") AND TITLE-ABS-KEY ("Circular economy"). This search query was not limited to a time horizon because it allowed us to capture the overall trend in the number of publications over the years, starting from the earliest occurrence in this database. The identified articles covered the years between 2005 and (part of) 2023 and were reduced to reviews the titles of which were checked for relevance. Those which were unclear were scanned throughout for the keywords *"informal"* and *"waste"* by considering referral to them as a sufficient criterion for inclusion in the analysis. Then, we aggregated some of the identified keywords to capture notions with similar meaning which appeared with relatively low frequencies. For example, the keyword *"circular economy"* appeared most frequently (as expected) and accounted for publications which had other similar keywords such as *"circular economy transition"*, *"circular procurement"*, *"circular economy business model"*, *"material circularity"*, *"resource circularity"*, *"circular resource management"*, *"circular strategy"*, and *"circular supply chain management"*).

We note that the terms *"recycling"* and *"recovery"* which were encountered throughout the studied literature were often arbitrarily defined, referring in general to the identification, collection, and mild processing of solid waste from dumpsites, landfills, streets, and households. Formally, the former term is about processing collected waste materials whereas the latter refers to the generation of energy (heat and/or electricity) as a last resort when all other options have been exhausted.

The additional scientific and grey literature found were analyzed in parallel. Prespecified categories of interest included the identification of UWMSs types, of the various roles of the IRS, of policies adopted in different countries, of different business models followed, and of the various tensions and challenges observed. The findings were then synthesized into conceptual frameworks (typology of recycling value chains and contributions of the IRS to the CE) which are discussed below.

3. Results & discussion

3.1. Literature review

The search in Science Direct showed that the number of yearly scholarly output grew exponentially from 2005 reaching a total of 1100 to the end of 2022 (Fig. 2). About 18% of those were reviews with very broad coverage of UWMSs, ranging from governance issues to technological-oriented topics on environmental engineering. A filtering of the reviews for actual relevance revealed that only 69% of those (i.e., 132 or 12% of the total) were in fact about informal recycling. By excluding the most frequently occurring keywords *"circular economy"* and *"waste management"* (which were expected), the next most frequently used keywords were those which were related to *"e-waste"* (11%), to *"informal recycling"* (8%), to broader *"sustainability"* aspects (6%), to *"life cycle assessment"* (2%), and to *"resource recovery"* (2%). Miscellaneous output containing a tail of topics which were too small to earn a distinct category were allocated under the keyword *"other"* which had the largest share (47%), indicative of the fragmentation of viewpoints and approaches towards understanding the inclusion mechanisms of the IRS in a CE.

The broader literature contains an ample number of studies conducted across the world, for example, in Latin America and the Caribbean (Hettiarachchi et al., 2018), in Bolivia (Ferronato et al., 2021), in Nigeria (Ola and Adewale, 2022; Oguntoyinbo, 2012), in Tanzania (Omar and Bullu, 2022), in Uganda (Schluep et al., 2008), in Western Balkans (Gjorgjieska and Stanojevic, 2015), in South-East Europe

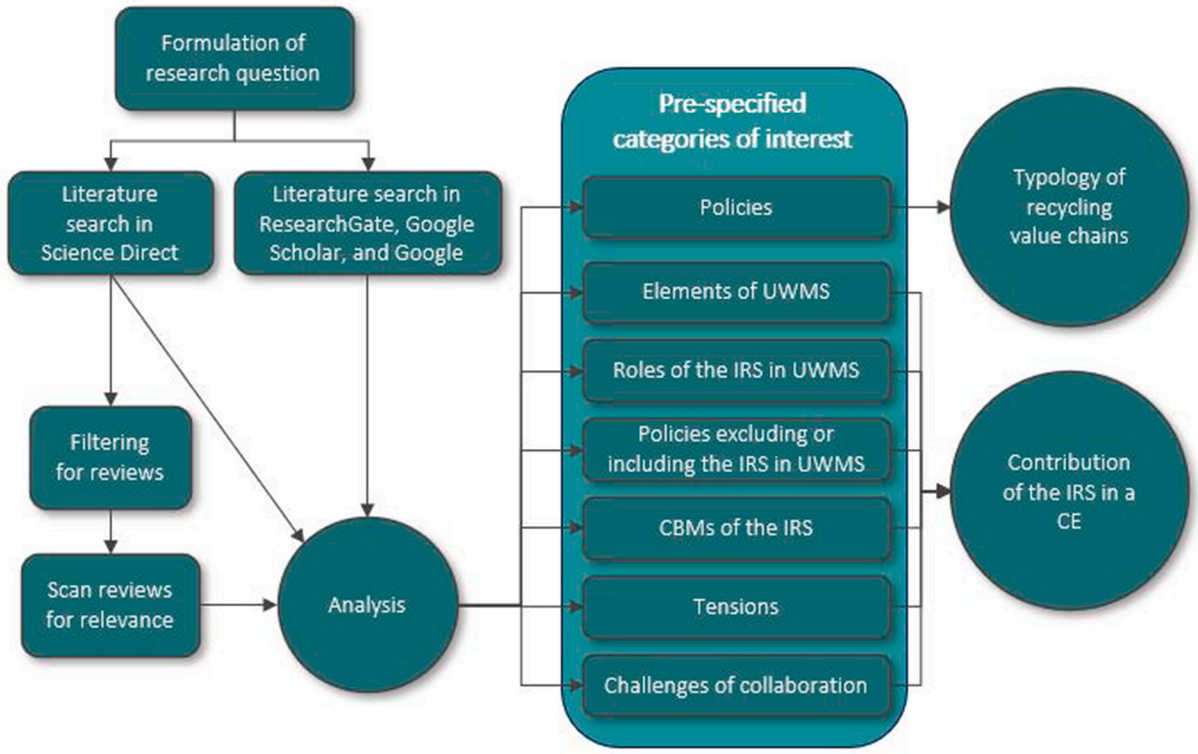

Fig. 1. Methodology followed.

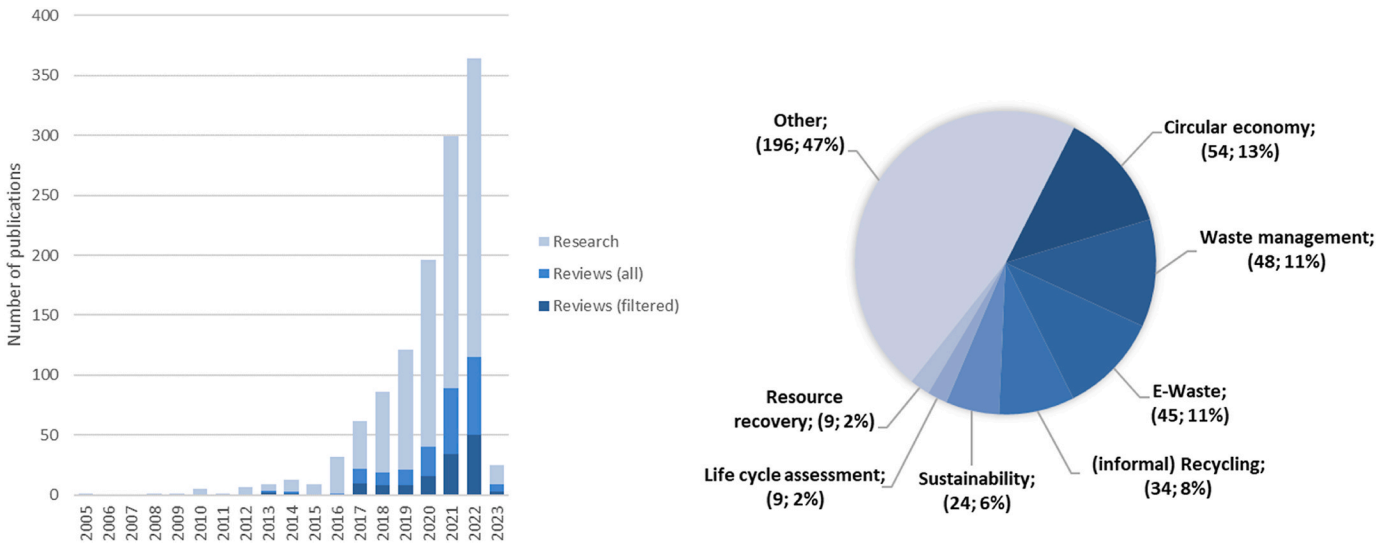

Fig. 2. Results of search conducted in Science Direct showing *left*: the number of publications per year between 2005 and (part of) 2023, and *right*: the frequency breakdown of the main summarized keywords used.

(Zivanov et al., 2017), in Spain (Bulla and Sanjuán, 2018; Rendon, 2020), in Iraq (Abdulredha et al., 2018), in Nepal (Parajuly et al., 2017), in Indonesia (Rumung and Dwipayanti, 2021), and in China (Li, 2002; Linzner and Salhofer, 2014; Schulz, 2015; Tong and Tao, 2016; Steuer et al., 2017; Steuer et al., 2017; Tong et al., 2018; Chen et al., 2018; Schulz and Lora-Wainwright, 2019; Goldstein, 2020; Steuer, 2021b).

3.2. Urban waste management systems in a circular economy

In the current draft version of the upcoming ISO standardization 59004, the CE has been defined as an *"economic system that uses a systemic approach to maintain a circular flow of resources, by regenerating, retaining or adding to their value, while contributing to sustainable development"* (Carlsson et al., 2022). To accentuate the intertwined nature of production and consumption patterns in the amalgam between society and culture, the concept of **necessity-driven circular economy** has been recently introduced as *"a set of locally embedded and interlinked formal and informal practices aimed at restoring and retaining the value of goods and materials for as long as possible, based on economic necessity and opportunities for income generation"* (Korsunova et al., 2022).

Undeniably, UWMSs and their assessment play a critical role for monitoring the transition to a CE (Campitelli et al., 2022) given that the

uncontrolled disposal of waste around the world is anticipated to keep rising at least until 2028 up to almost 730 million tonnes per year (Maalouf et al., 2020), and that under inaction, the global greenhouse gas emissions from solid waste management are estimated to increase up to 2.6 billion tonnes of carbon dioxide equivalents in 2050 (Kaza et al., 2018). Besides, the CE is also considered to be one of the four pillars which have been proposed to improve the adaptability and flexibility of UWMSs in the post-COVID-19 era, along with the acquisition of in-depth knowledge of interactions and effectiveness of systems, the development of information communication technology to map sources of waste generation, facilities and related markets, and the comprehensive assessment of the sustainability of management decisions (Mahyari et al., 2022). Yet the solutions offered by a CE have limitations and their promises should not exceed realistic expectations (Corvellec et al., 2021; Lehmann et al., 2023; Wijkman, 2021).

3.3. Types of urban waste management systems

In general, UWMSs consist of value chains with three main steps: collection, preprocessing (sorting, cleaning, bailing etc.), and recycling for diverting as much waste as possible from disposal (van Velzen et al., 2021). In their recent review, Silva de Souza Lima Cano et al. (2022) summarized the various viewpoints found in literature on the elements which constitute a **recycling value chain**, and defined it as *"as the chain of processes (i.e., value chain activities and performance) and structures (formal/informal networks of stakeholders) created and shaped by the relations of stakeholders operating across the value chain, aimed at connecting production with the management of recyclable waste resources"*. According to their type, they can be categorized as **formal recycling value chains** with limited presence of the informal sector (mainly in high income countries), **suppressed recycling value chains** where the informal sector is exploited, punished or not recognized (mainly in upper middle, lower middle and low income countries), and **hybrid value chains** which promote the inclusion of the informal sector (present in some upper middle and lower middle income countries) (Silva de Souza Lima Cano et al., 2022). Their purpose is to manage municipal solid waste and to address the SDG indicator 11.6.1 which *"measures the progress of the performance of a city's municipal solid waste management"* (United Nations, 2021). In this context, municipal solid waste:

> *"… includes waste generated from: households, commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It also includes bulky waste (e.g. white goods, old furniture, mattresses) and waste from selected municipal services, e.g. waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), if managed as waste. The definition excludes waste from municipal sewage network and treatment, municipal construction and demolition waste"* (United Nations, 2021).

3.4. Hardware elements of urban waste management systems

Hardware elements of UWMSs are various waste-related infrastructures such as waste collection and upcycling sites (e.g., green points), recycling and reprocessing facilities, incineration plants, and landfills among others. The importance of developing rather than just growing urban assets (including UWMSs) is becoming more prominent and guided by strong sustainability principles in ways which are meant to suit the local community and environment (Spiliotopoulou et al., 2021). This is particularly relevant for low-income countries where UWMSs are seen as *"pre-modernized system(s) based on a single disposal technology (dumping or landfilling)"* which are typically controlled by local authorities and sometimes supported by the private sector while informal recyclers operate at the fringes (Scheinberg et al., 2006).

Clearly, accessibility to waste-related infrastructures is key for successful waste management but it might not always be sufficient, calling for the implementation of complementary measures such as waste separation at source (i.e., households). However, this approach can also be challenging. For example, a survey study in Delhi showed that most respondents lacked awareness of separating properly waste at source and many were sceptic about whether this practice could really solve their waste issue (Govind and Mahongnao, 2021). Correspondingly, the researchers involved in this study argued that policies should rather focus on integrating informal recyclers, on providing incentives for waste reduction and separation at source, and on discouraging defaulters (Govind and Mahongnao, 2021). Another example from a study in a Brazilian metropolis showed that besides poor separation at source, various other reasons hindered the selective collection of household waste which included the lack of or limited waste management coverage, idle public services and cooperatives, low efficiency, and corruption (de Pinna Mendez et al., 2022).

Undoubtedly, it is neither simple nor cheap to operate UWMSs since they require a large share of a city's budget ranging from 4% in high-income countries up to 20% in low-income countries, often competing with other important priorities such as education, healthcare, water sanitation etc. (Kaza et al., 2018). These aspects become critical when looking at global projections which show that *"from 2016 to 2030 an additional 10.7 billion Mt of waste will be driven to uncontrolled disposal in the form of open dumping, open burning, or leakages to the natural environment"* with an optimistic scenario of 2% annual rise in new urban infrastructures (Maalouf et al., 2020).

Besides formal infrastructures there are also informal ones. Informal recyclers are typically attracted to such heterogeneous infrastructure configurations which emerge *"naturally"* from discarded materials with potential usefulness or monetary value under unique circumstances and socio-technological mechanisms (Lawhon et al., 2018; Shreeves, 2020). Other waste-related facilities developed by public actors, such as thrift stores (Machado et al., 2019) and repair cafés (Charter and Keiller, 2014), can also contribute to the preservation and upcycling of materials that would otherwise end up as waste.

3.5. Software elements of urban waste management systems

Software elements include different types of governance [e.g., establishment of dedicated governmental bodies, of collaborative public-private partnerships, or of circular business models (CBMs)], standards (e.g., for soil protection, for secondary materials derived from waste, for organic fertilizers, for air quality etc.), policy instruments (e.g., legal, financial, communication, extended-producer responsibility schemes etc.) (Ministry of Infrastructure and Water Management (Rijkswaterstaat), n.d.), as well as of digital technologies [e.g., cloud-computing, Internet of Things, artificial intelligence etc. (Hedberg and Šipka, 2020; Lowe et al., 2014)]. Other *software* elements include culture and social norms such as social learning (Chen and Gao, 2021), peer pressure (Botetzagias et al., 2015), and environmental awareness (Meng et al., 2019). Here, we focus mainly on extended producer responsibility (EPR) schemes, on different types of business models, and on waste-related policies.

3.5.1. Extended producer responsibility (EPR) schemes

The last and most advanced stage of an *"evolutionary"* process of UWMSs in developing countries is thought to be the adoption of EPR schemes promoting principles of product redesign to reduce generated waste and thus the need for collection and treatment (Schmitz et al., 2022). Yet, these features are merely part of a larger objective of EPR schemes, which is to nudge producers and importers to shift towards developing long-lasting products (by design or through increased repair options) and consequently lower the required waste management service intensity. EPR schemes and other structured initiatives for packaging have been suggested to improve considerably the livelihoods of informal recyclers as well as the overall waste recycling rates in cities since they promote dry waste segregation at the source (Rutkowski,

2020).

However, empirical evidence has proven critical on EPR schemes as these promote linear rather than circular systems. Often, incentives pushing the private sector to radically change its business models are absent. Generally, participation fees are too low, and at least conceptually, there are good approaches around this issue such as the development of a know-how toolbox for EPR for packaging (Schmitz et al., 2022). Such negative performance has been documented for a case of exports of e-waste from EU to Nigeria whereby it was found that EPR systems did not address the global value chain, were untransparent, unaccountable, and inconsiderable of spatial equity, and, instead, the researchers proposed the adoption of ultimate producer responsibility (UPR) schemes which intend to foster justice and equity (Thapa et al., 2022). Some of these authors suggested that EPR design flaws could be tackled by formulating *"explicit policy targets for the short and middle long loop value retention options"* and by *"separating the role of financial and economic responsibility"* where *"all economic actors related to R3-R8 need to be represented"* (Vermeulen et al., 2022). Legislation should also foster the adoption of eco-design principles for products to be manufactured for longer life cycles and better repairability (International Solid Waste Association, 2022), and the focus should be directed on the timely phasing and sequencing of R-principle-related measures into corporate strategies.

3.5.2. Business models in the informal recycling sector

At least three types of business models have been observed for organized informal recyclers in the Global South which include **co-operatives** [also known as community-based organizations (Aparcana, 2017)], **micro-enterprises**, and **public-private partnerships** (Medina, 2008). Another study proposed a typology of four basic operational models which include a) waste collection service, b) waste collection service where recyclables are separated, c) collection of recyclables, and d) recyclable collection service where rejects are separated (Velis et al., 2017). The IRS engages also in reuse, repair, refurbishment, and remanufacturing activities. China is a typical example when considering the refurbishment of everyday consumer goods in second-hand markets (Goldstein, 2020), the repair, refurbishment, and trade of remanufactured devices from e-waste (Steuer, 2016), and in general, the recycling and reuse of e-waste (Schulz and Lora-Wainwright, 2019).

In theory, the integration of the IRS can be facilitated by applying the ***InteRa* multidimensional radar framework** which captures interventions taking place across four categories related to different interfaces with: a) the solid waste management system, b) the material and value chain, c) the organization and empowerment of informal recyclers, and d) the society (Velis et al., 2012). This framework has been applied in Pakistan where integration results did not become immediately apparent, but where an ideal solution was thought to be one balancing between the aforementioned four categories depending on the local context (Masood and Barlow, 2013). A follow-up case study in Bahawalpur city using the same framework, showed that such integration could work optimally both for the formal and the informal sector, generating an annual revenue of 6 million USD (Majeed et al., 2017).

Another model which was developed to facilitate the formalization process of the informal sector is the **viable system model** which has been proposed as a way which *"considers the primary recycling activities and the territory's characteristics (housing, colonies, and boroughs) and indicates those responsible for the coordination, management, monitoring, and planning legislation to ensure its viability with sufficient knowledge of the physical and socioeconomic characteristics of the territory"* (Gutierrez-Galicia et al., 2021).

Information and communication technologies have also an important role to play in CBMs. Relevant applications of blockchain technology include payments, rewards for virtuous behavior for recycling and reuse of materials, waste traceability, smart contracts, and fraud prevention mechanisms (Steenmans et al., 2021; Baralla et al., 2023). For example, in Chennai in India, the connection of the informal ecosystem with the formal sector through a technological platform was said to lower operational costs while simultaneously servicing residents and small business and facilitating the sourcing of collected resources for municipalities and companies interested in implementing EPR schemes (Hande, 2019).

3.5.3. Waste-related policies

Policies are crucial for enabling the transition to a CE since they can boost the reuse and recycling practices and they should be tailored for addressing specific waste streams given their diversity in volume, composition, and spatiotemporal generation (D'Adamo et al., 2022). They can improve the economic efficiency of cities by internalizing externalities via the provision of subsidies for the collection of waste and via the taxation of virgin raw materials, consumption patterns, and disposal practices (del Pilar Moreno-Sanchez and Maldonado, 2006). Towards this end, policy classification frameworks can be particularly useful for mapping and scoping relevant policy mixes as it was recently demonstrated by an assessment of waste policies across sixteen zero-waste cities in China (Ma et al., 2023).

Policy design and characterization comes in different forms across countries. For example, in the Netherlands, waste policies are based on the waste hierarchy principles, they set strict waste treatment standards, they foster cooperation between different governmental tiers, they promote the adoption of EPR schemes (either voluntary or by legislation), and they make use of financial instruments (such as taxes for landfilling and incineration and volume-based waste fees) to promote prevention and recycling (van Eijk et al., 2022).

Policy design can also affect substantially the formalization of informal recyclers (Aparcana, 2017) where some argue that *"waste picker phenomena should be understood as a policy problem"* (Porras Bulla et al., 2021). The concept of **constructed governance** has also been proposed for studying the success or failures of public recycling policies as a social process (using the case of e-waste in São Paulo, Brazil) which, contrary to other theories of agency, resources, and stakeholders, follows an integrated view on people, organizations, and the environment (Pedro et al., 2021). Others have developed a typology with the ambition to inform policy development for more effective UWMSs in central and eastern European countries suggesting informal waste scavenging to be considered as an **entrepreneurial activity** (Gittins, 2020).

Policy tone also differs substantially between countries in the Global South and in the Global North with the former usually having a pro-inclusiveness character (e.g., in Latin American countries) and the latter being more demanding in terms of legalization, formalization or even elimination of informal recyclers (e.g., in north European countries) (German International Co-operation, 2018). Some also argue that policies should focus on **reparation** rather than on the formalization of the IRS to address historic wrongdoings, to redistribute resources, and to empower workers and grassroots initiatives all the while regenerating the environment (Tucker and Anantharaman, 2020).

In general, waste policies can be categorized in terms of **penalties and bans** (e.g., relocating waste pickers, declaring waste as municipal property, and penalizing waste picking as *"crime of disorder"*), of **social exclusion mitigation** (e.g., improving the quality of life of waste pickers by providing equipment or training programs to facilitate formalization), and of the **modernization of waste systems via integration of the informal recycling sector** (e.g., supporting with credits, recognizing, and rewarding publicly the recycling efforts of social co-operatives) (Porras Bulla et al., 2021).

Furthermore, waste policies can be shaped in different ways i.e. by following: a) the **dualist and voluntarist approach** (oppressive towards informal recyclers and in favor of formal systems), b) the **structuralist approach** (reinforcing informal recyclers), c) the **legalist approach** (promoting competition between informal recyclers and other recycling activities with no government intervention), or d) the **co-producing approach** (enhancing productivity of informal recyclers) (Navarrete-Hernandez and Navarrete-Hernandez, 2018).

We use the focus and the approach of different IRS-related policies as two distinct dimensions to synthesize the above information of the operation mode of recycling value chains in the context of a CE, into a **typology** (Fig. 3). Policies of a dualist or legalist approach towards informal recyclers which are enforced with penalties and bans, describe a *suppressed recycling value chain* which fails to recognize the benefits of including the IRS and maintains the business-as-usual attitude **operating in an exclusive linear economy**. A *suppressed recycling value chain* can also manifest when the policy focus shifts towards modernizing UWMSs to transition to a CE all the while preserving dualist or legalist approaches which still treat the IRS either in an oppressive manner or as a competitor in a free market **operating in an exclusive circular economy**. A *formal recycling value chain* might still **operate in a linear economy** despite efforts for supporting structurally any *limited presence of the IRS* due to the perseverance of old mentalities for enforcing penalties and bans and bureaucratic processes. Finally, when policies aim to modernize the UWMS by following a structuralist or co-production approach they describe *hybrid recycling value chains* **operating in an inclusive circular economy**.

3.6. Informal recyclers as stakeholders in a circular economy

The various actors who are typically involved in UWMSs are collectors, sorting centers, small and large scrap dealers, brokers, semi-processors, re-processors, and manufacturers (Silva de Souza Lima Cano et al., 2022). Other stakeholders include national and local governments, NGOs, citizens, consumers, workers, and informal recyclers who can also have multiple roles or partially overlapping functions and therefore their categorization in different groups is not mutually exclusive. Here, we focus explicitly on informal recyclers to demarcate their roles as stakeholders in UWMSs and their contribution to a CE.

Informal recyclers are prevalent mainly in countries where urbanization rate is rapidly growing, the socio-economic inequality is critical, secondary resources are high in market demand, and waste recycling offers lower-income people comparatively high profit margin. One such example is Namibia where the main drivers for informal recycling have been identified as poverty and unemployment (Nambuli et al., 2021). The total number of informal recyclers around the world is difficult to estimate. According to different sources published at different points in time, it ranges from 11.4 million people (Lau et al., 2020; Velis et al., 2022) to at least 15 million people (Medina, 2008; Binion and Gutberlet, 2012) and to even more than 20 million people (Gutberlet, 2021; Sanders, 2022).

With their tacit knowledge, informal recyclers create value by identifying, collecting, segregating, refurbishing, and recycling different types of solid waste streams, amongst other activities (Dias, 2016; Ogwueleka and Naveen, 2021). They service poor or marginalized and otherwise inaccessible urban areas, and they are often the main if not the only recyclers who are present locally to divert considerable amounts of waste away from landfills (German International Co-operation, 2015).

3.6.1. Hardships of informal recyclers

Informal work is often characterized by long working hours, low incomes, unfair payments, insecurity, social rejection, exploitation, and poverty (Aparcana and Salhofer, 2013). The resulting waste trade provides a source of income albeit at inappropriate conditions which endanger the actors' health and safety given the multitude of occupational hazards (Zolnikov et al., 2021). Informal recyclers are faced not only with health hazards, but they are also exploited by scrap dealers, they are subject to discrimination and harassment from local authorities, and they are considered illegal as in the case of Abuja in Nigeria (Ogwueleka and Naveen, 2021). In another example in Pakistan, informal recyclers are largely stigmatized due to their refugee background, possessing dual identities where their vast majority, when interviewed, deny even their own existence as waste pickers (Yousafzai et al., 2020). Similar phenomena of discrimination due to the rural-urban migratory background and lower levels of education among informal recyclers have been documented for China (Schulz, 2019).

Besides the large risk of losing their livelihoods from accelerating modernization (formalization and privatization) processes, their role in waste management is often left unrecognized (Linzner and Lange, 2013; Shreeves, 2020). They are also one of the most exposed societal groups particularly during pandemics. To make a living and in turn protect the community, they compromise their health. This particularity warrants not only a fair inclusion in UWMSs, but also a reevaluation of their function with potential support via comprehensive healthcare, personal protective equipment, and financial assistance (M. S. Haque et al., 2021). During disease outbreaks, informal recyclers are at great risk both physically and mentally as a general health questionnaire in Bangladesh revealed that many were suffering from psychological distress, anxiety, depression, social dysfunction, and loss of confidence (R. Haque et al., 2022). Seasonal variation can also threaten the job security of informal recyclers and increase pollution due to excessive burning as it has been shown in the case of Nigeria (Wahab and Ola, 2018), where the authorities have been attempting to engage the IRS through inclusive waste management policies as a central strategy to address the SDGs (Mbah and Nzeadibe, 2016).

The existence of second-hand markets can also determine the rise or

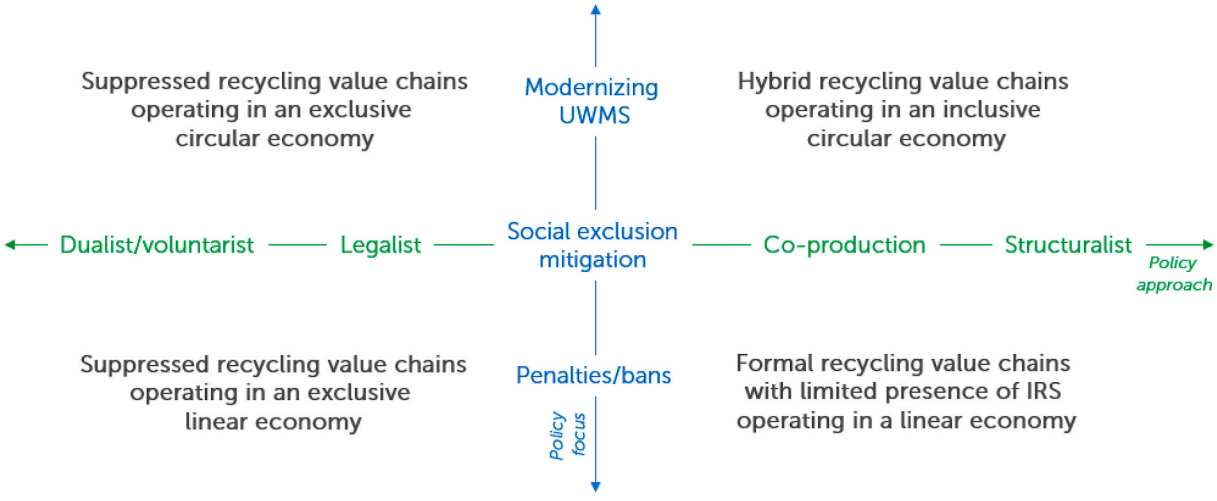

Fig. 3. Framework presenting a typology of recycling value chains (based on Silva de Souza Lima Cano et al., 2022) in the context of a CE by considering as dimensions the policy focus (based on Porras Bulla et al., 2021) and the policy approach (based on Navarrete-Hernandez and Navarrete-Hernandez, 2018).

fall of the IRS and, in some contexts (e.g., management of electrical and electronic equipment in India) they can even be superior to formal waste management systems (Ardi and Leisten, 2016; Kurniawan et al., 2022). A social network analysis in a case study in Philippines showed that waste pickers with high network centrality (i.e., the degree to which a person is central in a group) were more likely to collect recyclable waste of relatively low value but belonging in groups with strong relationships and improved performance indicated their contribution towards a more efficient UWMS (Tamura et al., 2018). A study in Kaduna in Nigeria showed that the bargaining power of informal recyclers can be affected by sociocultural aspects, age, and gender whereby relationships in these social networks are well-structured, inter-dependent, and mainly shaped by those who have access to financial and social capitals, yet where power is not monopolized (Adama, 2012). Furthermore, individual economic status and reputation can affect the *"fluid"* hierarchical position of informal recyclers within social networks as a study in a disposal site in Jakarta has shown (Sasaki and Araki, 2013).

3.6.2. On earnings of informal recyclers

The potential revenues achieved by informal recyclers can vary substantially in different contexts depending on the treatment (CE activities) they engage with and on the fractions of (recyclable) waste they manage. For example, among the various informal activities around e-waste in Cameroon which include discarding, collecting, dismantling, material extraction, refurbishing, selling refurbished electrical and electronic equipment (WEEE), aggregating and trading, and exporting materials, the latter two seem to be the most profitable (Hinchliffe et al., 2020). Another study regarding plastic solid waste and value creation in a CE at Ndola city in Zambia, showed that the various activities which were identified differed in terms of value addition where cleaning was the most prominent (36%) followed by classification (29%), drying and washing (18%), commercializing (5%), and others (12%) which were conducted by different types of actors including dumpsite pickers (43%), street waste collectors (28%), household waste collectors (17%), intermediate dealers (8%), and itinerant waste buyers (4%) (Mwanza et al., 2019). A study in Lagos State showed that full-time scavenging generated more than the national minimum wage, which was just enough to sustain families, corroborating that the *"dustbin economy"* is a catalyst of growth in Nigeria (Salau et al., 2017).

Past research showed that when informal recyclers self-organize under various modes of operation, they can earn between two to five times the minimum wage (Medina, 2008). By balancing effectively between collective organization and engagement in informal waste work, they can maintain some autonomy, they can improve their income in creative ways which protect them from fluctuating prices of recyclables and from customer unwillingness to pay, and they increase their potential to create novel forms of legitimization of their work (Coletto and Bisschop, 2017). Bottom-up ventures between the IRS and local recycling associations can also have considerably lower requirements than conventional systems in terms of costs and of novel organizational structures (Steuer and Li, 2022). Similar results were obtained by studying the formalization of the IRS in Colombia where it was found that financial sustainability and inclusive recycling were key drivers which improved the sustainability of the UWMS (Calderon Marquez and Rutkwoski, 2020).

3.6.3. Empowering informal recyclers

In contrast to the Global South where informal recyclers tend to progressively increase their levels of self-organization in cooperatives (Morais et al., 2022; Rutkowski, 2020), in the Global North they are still largely unknown urban actors who are often associated with social minorities (e.g., migrants, homeless, specific ethnicities, or people excluded from the labor market), who collect and process valuable waste streams in order to survive (i.e., contested waste materials which can simultaneously be perceived by the local authorities as property and/or as a common), and who are stigmatized and discriminated not because of engaging in this activity as such but mainly due to their gender, race, migratory status or housing situation (Porras Bulla et al., 2021; Schulz, 2019).

When informal recyclers are empowered by local governments and policies to organize in formalized groups, they can provide cities with selective waste collection services. Their formalization can offer them technological, environmental, economic, and social advantages (Environmental Protection Agency (EPA), 2020). In specific contexts (e.g., in Chinese cities), both informal and semi-formal systems offer substantial potential for innovation in UWMSs (Steuer, 2021b). A comparative study on grassroots waste picker organizations across five countries in Latin America and East Africa highlighted their contribution to the social, environmental, and economic sustainability of the societies they serve (Kain et al., 2022). A recent literature review revealed that the improvements brought by formalization to the livelihoods of informal recyclers included amongst others *"legal recognition, safe working conditions and fair bargaining mechanisms"* (Morais et al., 2022).

Often, the services of informal recyclers can be more effective than conventional recycling programs in capturing different types of materials, in creating jobs, in educating citizens about proper waste separation via door-to-door waste collection, and in fostering social inclusion by offering a sense of belonging, dignity, and safety to marginalized people (Gutberlet, 2016; Gutberlet and Carenzo, 2020). In their work, Ferronato and Torretta (2019) describe the IRS by highlighting the case of China as the typical example from developing countries with a particular focus on social inclusion.

The contribution of the IRS to recycling rates varies widely across several low and middle-income countries. Exact amounts at a global scale are difficult to quantify since informal recyclers are often invisible to the formal economy and to waste management statistics, and they are often excluded from various types of capitals on multiple grounds (Wilson et al., 2006; Dias, 2016; Chen et al., 2018; Gutberlet and Carenzo, 2020; Maalouf et al., 2020; Tong et al., 2021). One potential approach to arrive at sector specific recycling rates is to assess individual recycling rates, e.g., in kg/cap/day, and then extrapolate it by numbers of individuals counted at central nodes of recyclable waste exchanges in spatially delineated areas (Linzner and Salhofer, 2014; Steuer, 2021a).

Recycling rates can reach up to 17–38% for urban China (Linzner and Salhofer, 2014), and in some cases reaching even up to 70–80% of recyclable municipal solid waste as exemplified in the case of Nanjing and 74% for the case of Beijing in 2016 (Steuer et al., 2018). For example, in Tandril in Argentina where the global recuperation of municipal waste was only around 2%, the informal recycling sector had a critical role in collecting waste even in larger amounts than the official strategy (Villalba, 2020). Another study in Sorocaba city in Brazil, showed that co-operatives attained a 2% recycling rate which could even reach a 9% when considering the activities of autonomous pickers, surpassing greatly the official national figure of 1% (Silva de Souza Lima and Mancini, 2017). Furthermore, the Brazilian Recycling Atlas analysis showed that when waste cooperatives manage and operate selective collection in city, they can outperform private companies. This report gives the example of Brasilia, where, in 2020, the rate of rejects from cooperatives carrying out the work of collecting and sorting recyclable materials was 18.3%, while the rate of rejects from cooperatives which only sort the materials collected by companies was 63% (ANCAT, 2022). Brazil is one of these examples in Latin America, whereby the law 12, 305 related to Brazilian Policy of Solid Waste was enacted, in 2010. Some of its main innovations, is the *"principle of shared responsibility"* on waste management among supply chain actors, the adoption of reverse logistics enabling closed loop of materials and the inclusion of waste pickers in materials recovery processes (Guarnieri et al., 2020). In a sectorial agreement for logistics reverse to packaging in general was signed in 2015, companies brand owners have the commitment to invest in waste picker cooperatives as an inclusive solution to scale the performance of the recycling chain. Currently, at least 700 waste pickers cooperatives receive investments from companies that participate in

different logistics reverse system in Brazil (Instituto Pragma, 2022). This is a situation when a public policy can stimulate private investments in socio-environmental inclusion.

In Europe, the involvement of informal recyclers in the operations of an Italian paper mill led to the mitigation of its procurement risks, ensuring better quality of recovered materials, and lowering procurement costs while reducing its overall environmental impact (Zerbino et al., 2021). Another study which evaluated the environmental impacts of different viable alternatives for municipal solid waste collection, treatment, and recovery in Santiago de Chile showed that the scenario considering the commitment of the informal sector was the one that achieved the best performance in terms of recovering inorganic and organic materials but also of reducing the CO_2 emissions (Ailyn Rojas et al., 2018). An agent-based modelling study on post-consumer recycling in Beijing estimated that under a norm-based scenario (i.e., where the combination of formal intelligent sorting facilities implemented across neighborhoods in combination with door-to-door collection services offered by informal recyclers) could theoretically boost participation rates at over 70% and reduce CO_2 emissions to more than 4.5 million tonnes per year (Tong et al., 2023).

3.6.4. Tensions between formal and informal waste management

The CE focuses on the valorization of obsolete products, reshaping the view of waste being a resource. Yet, besides its potential benefits, it can also induce tensions among various stakeholders particularly between the formal and the informal sector. There are two main driving forces which seem to be prioritized differently in different development and economic contexts. On the one hand, the protection of people in terms of health and hygiene and the prevention of environmental pollution are traditional objectives for formal UWMSs. On the other hand, the economic value of secondary materials stimulates the existence of an economic agency and has in turn induced the rise of informal recycling activities.

Besides increasing waste generation, growing cities also suffer from **inequalities**. At present, more than 70% of the global population across most developed and in some middle-income countries, is experiencing socio-economic inequalities (United Nations, 2020). These inequalities can be linked to a strong entanglement between environmental and social issues in urban contexts. A prevalent example is that of handling of waste streams in controlled and uncontrolled landfills which function as easy entry points to marginalized and disadvantaged communities. A strong case can be made particularly for gender inequality where the waste sector is often male dominated (e.g., in Nigerian cities) virtually excluding women due to cultural norms (Nzeadibe and Adama, 2015).

Undoubtedly, the transition to a CE is complex especially regarding social inclusion. Particularly in countries in the Global South, an inclusive CE can manifest with two mechanisms of formalization which are anti-diametrically contrasting i.e., as **privatization of informality** (i.e., as private company CBMs which often mimic global North mainstream perspectives, omitting power relation dynamics) or as **formalization of commoning** (i.e., as cooperative *"bottom-up"* CBMs which are socially just and look beyond market and efficiency-driven targets) (Carenzo et al., 2022). Another challenge even for countries with advanced UWMSs like the Netherlands, is that the collection and processing of waste streams is often considered on an individual basis (i.e., per waste type) without accounting for potential consequences on other waste streams (van Velzen et al., 2021).

As urban assets, waste infrastructures can be heavily politicized given that they are directly related to how different actors can access and create value from waste, and they can even lead to conflicts between the informal and the formal sector (Butt, 2020). In general, **conflicts** around UWMSs can manifest in at least three fronts (Scheinberg et al., 2016): "*a) with public and private waste companies, inter-governmental entities, and public sector operators, b) with national ministries and institutions in the areas of social affairs, economics, migration, labour, and commerce, and c) with producers of consumer goods and packaging, and the extended producer responsibility (EPR) institutions and organizations that represent them*". In fact, it is the accessibility to waste materials along with their inherent potentialities for (re)use, circulation, disposal, and management which can be the essence of struggles between informal recyclers and stakeholders of asymmetrically larger power (Butt, 2020) such as officials of formal UWMSs who strive for meeting safety standards (Mumuni, 2016).

In post-colonial contexts, **waste revaluation** is not only affected by global production networks but also depends on how the local economy operates, where **waste devaluation** (i.e., due to reduction of prices of recyclable waste to unprofitable levels) differs from **waste devalorization** (i.e., due to material degradation) but both are critically shaped by the degree of political mobilization of informal recyclers as well as by their struggles to monopolize control over waste (Samson, 2017). **Practical legitimation** can also shape competition over urban waste and recycling through status-based relations and daily actions to address implicit social expectations, as was shown for a case in India (Kornberg, 2020).

The complexity and tensions related to the local history of IRS networks, to local politics, and to neoliberal reforms can also stall the revamping process of waste management systems (Calleja, 2021). For example, the city of Cairo in 2003 outsourced its waste management to several European multinational companies due to rapidly increasing amounts of municipal waste generation, a decision which failed to deliver in terms of ecological, economic, and social sustainability but instead increased the vulnerability of the Zabbaleen (i.e., the local community of informal waste collectors who have been servicing the city since the beginning of the century), depriving them of their entitlement to waste, and therefore their income (Didero, 2012).

3.6.5. Challenges of collaboration

Participatory inclusion will not necessarily resolve all the problems of informal recyclers, and it might also come with negative side-effects leading to the **restriction of their rights** (Morais et al., 2022). A study in Cape Town highlighted the implications of expanding waste collection services of the city to low-income areas through a public-private partnership by juxtaposing the arguments of its proponents (i.e., improving transparency on prices of recyclables, enabling the exchange of recyclable materials at market price, and reducing the distances to be travelled by informal recyclers) next to the severe disadvantages for informal recyclers (i.e., enclosing waste, encroaching their work, and not recognizing their services) (Timm, 2019).

Formalization initiatives can also fail. In South Africa, waste recycling cooperatives face a lot of challenges which include constrained accessibility to materials and markets, lack of business support, and substantial opportunistic focus on short-term grants, factors which resulted to a reported failure rate of 91.8% with many of their members returning to the IRS (Godfrey et al., 2017). An important reason for such failures is the lack of initiatives addressing different barriers (i.e., policy/legal, institutional/organizational, technical, social, and economic/financial) which can become persistent over time due to unfavorable country-specific conditions (Aparcana, 2017). Another reason is the lack of awareness of policy and decision makers on the interactions between these initiatives (Aparcana, 2017). In some cases, conflict resolution practices might have to be considered since individuals who have been marginalized for most of their lives might struggle to re-start working in a collective manner within cooperatives and they might manifest oppressive behaviors themselves due to conditioning from prior experiences of being oppressed (Gutberlet, 2016). A study in Blantyre in Malawi which involved interviews with 34 informal waste pickers, showed that many of them were unwilling to form a cooperative on their own because they were afraid of lower earnings, of potential conflicts during proceeds sharing, of free-riding behavior, and of losing independence, yet some would consider this option under the condition that the formalization process would be facilitated by a third party (Kasinja and Tilley, 2018).

Biases might also hinder collaboration processes. For example, in Pakistan stakeholders from the formal sector described the work of informal recyclers as *"a theft bargain and resale platform under the guise of waste collection and recycling"* (Nawaz et al., 2021). Formal-informal relationships might also be used by the state to progressively absorb and control the IRS to conform with formal objectives (Steuer, 2020). Evidently, formalization opportunities are not always for the benefit of the most vulnerable groups, and they might even be counterproductive for UWMSs (Coletto and Bisschop, 2017). Such an example is that of Addis Ababa where the *"partnership"* between an authoritarian government and numerous informal recyclers manifested as political dominance and surveillance, inducing resistance from the latter group towards collaboration and taxation (Baudouin et al., 2010). Another such example comes from Bangalore whereby the reforms which were introduced by the Indo-German-Swiss e-Waste Initiative largely modernized the e-waste recycling system through corporate privatization on the one hand but they also undermined the existing informal network which was historically taking care of the costs of disposing city's e-waste on the other hand (Reddy, 2013).

Problem perception by all involved stakeholders is vital because it can shape collaboration outcomes. For example, a study by Hedlund et al. (2022) on water governance issues of a drainage basin in Sweden (which could also hold in the context of UWMSs) suggests that policy actors often avoid engaging in collaboration due to a perceived infeasibility of reinforcing interdependencies (i.e., *"win-win")*, whereas when they do engage, they might fully neglect any counteracting interdependencies (i.e., *"trade-offs"*). Waste management issues can be largely shaped by cultural and organizational aspects of the IRS rather than by the enforcement of legislation: some countries incentivize the formalization of informal recyclers (mainly in Latin America) while other countries invest in technological approaches (e.g., China) or struggle to enforce legislation due to cultural and class-related aspects (e.g., India) or largely ignore them (e.g., Russia) (da Silva et al., 2019).

The **initiators and brokers of circularity initiatives** in cities which intend to involve marginalized communities should be able to *"continuously manage a balance between uncertainty–certainty, disagreement–agreement and consensus- and domination-based management strategies"* acknowledging the beneficial role that those can have (Eikelenboom and Long, 2022). Urban locations where resource recovery seems to be robust, indicate a running supply chain network and therefore focus should rather be given on fixing the problematic parts of the local UWMS by implementing low-threshold formalization measures such as the provision of affordable practical technologies and carbon co-financing mechanisms, whereby having a *"recycling coordinator"* can be vital for strengthening the formal-informal links (Gunsilius et al., 2011).

Undoubtedly, the relationship between the formal and IRS in cities can be sometimes conflicting but it can also be **symbiotic** in very interdependent and unbalanced ways which are strongly impacted by global flows of people and materials (Rendon et al., 2021). Ultimately, the inclusion of informal recyclers should not be a mere functional extension of existing recycling facilities but rather it should empower them to be *"active enablers in sustainable community initiatives"* as relevant stakeholders in an inclusive CE (Tong and Tao, 2016). If cities aim to take concrete steps towards an inclusive CE which leaves no-one behind, then they will need to embrace initiatives not just from the private sector but also from the IRS.

3.6.6. Contributions of informal recyclers to a circular economy

The CE is thought to be largely operationalized through the broad adoption and deployment of CBMs and strategies occurring at the micro-, meso-, and macro-level (Kirchherr, J., Reike, D., & Hekkert, 2017) by following the waste hierarchy principles and by closing, narrowing, slowing, intensifying, or dematerializing loops (Geissdoerfer et al., 2020). The waste hierarchy as proposed by Potting et al. (2018) is chosen here as the foundational building block of the conceptual framework because it offers ten principles which are useful for portraying the influence of IRS on the transition towards a CE.

We summarize the information discussed in Fig. 4 to illustrate how the various activities of the IRS contribute directly and indirectly to these ten principles of the waste hierarchy framework and to the various CBMs, and ultimately, to an inclusive CE. Evidently, the IRS activities contribute directly to the principles reduce, reuse, repair, refurbish, remanufacture, repurpose, and recycle, and only indirectly to the principles rethink, refuse, and recover. Each business model has a different purpose in terms of service provision, following different strategies, and manifesting in various configurations [as proposed by Velis et al. (2017)] in terms of activities, of workforce and employment characteristics, of affiliations, of motivations, of contractual arrangements, and of commercial and political environments. It should also foster the recognition, redistribution, and remuneration of the IRS in terms of labor, care, and environmental justice (Valencia et al., 2023).

Ultimately, all the activities of the IRS have the potential to contribute to the transition towards a CE in numerous ways which among others include the prevention of landfilling waste and the reduction of greenhouse gas emissions in just ways which improve both the quality of life and income of informal recyclers as well as the social cohesion of the urban fabric.

3.7. Considerations towards circular business models

By drawing knowledge from literature, we find that IRS-based CBMs have the potential to raise the effectiveness of UWMSs in cooperation with formal structures by:

- offering very high collection rates, particularly across low-to middle-income countries of the Global South.
- recovering waste material and reduce pressure on landfills by means of networks and official support (fiscal, regulatory etc.).
- providing specific services (e.g., door-to-door collection) and pre-processing steps (cleaning, sorting, material extraction) which add to material value.
- developing alternative exchange networks (e.g., second-hand markets), which demonstrate the application of higher-ranked circular practices such as reuse, repair, and refurbishment (e.g., for electronics).

Nevertheless, it is stressed that CBMs are not always more profitable than business-as-usual as they are subject to uncertainties and risks both from the demand and supply side (Ijomah et al., 2022) which can be of regulatory, cultural, and market nature, and regardless of the available resources and capabilities (de la Cuesta-González and Morales-García, 2022). Care should be taken when implementing IRS-based CBMs to avoid locking them into linear socio-economic structures which depend on a perpetual demand for waste, contributing further to the negative impacts of continuous biophysical growth or to existing inequalities. Instead, IRS-based CBMs should aim to be regenerative by capturing, creating, and delivering value to all stakeholders in a net-positive, multi-capital accounting manner while respecting planetary boundaries and fostering societal well-being (Konietzko et al., 2023).

3.8. Considerations towards including informal recyclers in a circular economy

CE strategies and policies should be developed and rolled out in **coordination** with all stakeholders. This becomes apparent when considering the high dependence of cities on complex interconnected global supply chains for the provision of resources. The uneven market penetration for a plethora of products (e.g., batteries and fuel cells for electric vehicles) and the current geographical disparity in the supply and demand of critical raw materials (e.g., platinum) underscore that the recuperation of critical raw materials for a successful transition

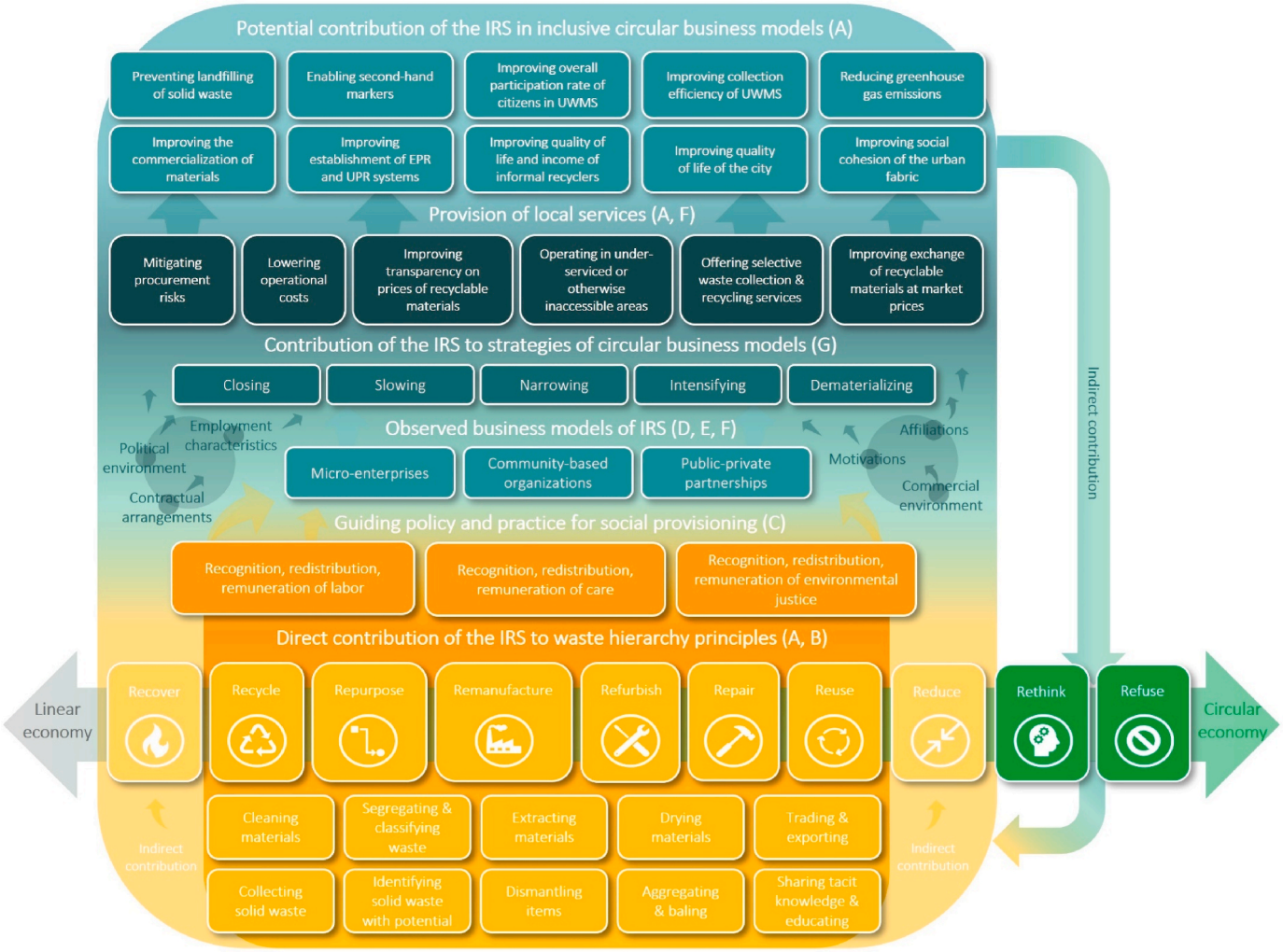

Fig. 4. Synthesized conceptual framework depicting from bottom to top: (A) the potential of direct and indirect contribution of the IRS identified in this study, (B) across the 10R strategies of the waste hierarchy framework [adopted by Potting et al. (2018)], (C) along with policy and practices for social provisioning [adopted by Valencia et al. (2023)], (D, E, F) the observed business models of the IRS and factors which can affect their formation [adopted by Medina (2008), by Aparcana (2017), and by Velis et al. (2017)], (G) their potential contribution to CBMs [adopted by Geissdoerfer et al. (2020)], and (A, F) their potential for the provision of local services. The IRS activities are placed under the waste hierarchy principles as direct contributions to a CE arbitrarily (i.e., without any specific order).

towards a circular and carbon-neutral future will rely heavily on the success of global coordination efforts between the recycling sector and worldwide supply chains (Tong et al., 2022). Coordination is also important because cities which strive to become circular just for the sake of increased circularity without considering the implications for all stakeholders carefully, can risk bringing undesirable outcomes to the local society.

Examples of **undesirable outcomes** include the manifestation of trade-offs or lock-in situations leading to the waste-resource paradox whereby *"circularity"* measures boost the linear rather than the circular economy (Greer et al., 2021). One such example is the establishment of incineration plants for waste-to-energy purposes as the result of dominant logics which can hinder the exploration of other more sustainable waste management practices (Corvellec et al., 2013). Even though incineration has already helped many high-income countries in diverting large waste streams from landfilling towards the generation of heating and electricity, it has an uncertain and ambiguous role in a CE because, along with the expansion and diversification of other waste-related services (e.g., recycling), it might contribute to an ever-increasing demand for waste materials (Savini, 2021). Also, it capitalises on a one-time gain from energy extraction preventing alternative paths of circulation such as reuse which strive to preserve the original functionality of materials and products. Besides infrastructural lock-ins there are also different types of lock-ins relating, for example, to behavioral patterns and institutions, which can stall transition processes and progress towards the SDGs, indicating that there is an urgent need for studies to focus on a plurality of lock-in assessments (Buzasi and Csizovszky, 2022).

Clearly, **participatory approaches** which involve all stakeholders in the development of CE policies and strategies are very important for cities. If this is done mindfully, then it will be possible for decision makers to identify likely impacts along with potential winners and losers, and to shape effective cooperation mechanisms and partnerships which avoid risks of worsening working conditions, of reducing jobs, and of harming livelihoods (Schröder, 2020). To scale effectively CE initiatives in urban contexts where the IRS is dominant, organizations will need to engage in cooperation with social organizations to facilitate the creation of better job opportunities related to resource management activities (Goodwin Brown et al., 2020). The integration of informal recyclers in collaborative networks and cooperative enterprises could help them develop technical skills and access new technologies and markets for manufactured upcycled products (Buch et al., 2021). Environmental and social justice can be delivered when the support provided to informal recyclers is structural (de Bercegol et al., 2017) and when

new grassroots innovations in cooperative governance and long-term partnerships challenge established regimes while improving the productivity and income of informal recyclers (Gutberlet, 2023). Without including all urban stakeholders, cities risk causing asymmetric development across neighborhoods, areas, or regions which could result to a *"circular rift"* in terms of availability of resources and of accessibility to various types of capitals such as financial, innovation, digitalization, and trade (Barrie et al., 2022).

3.9. Potential avenues for future research

Our study also offers potential for further theoretical innovation. Besides governance practices and employment, other social impacts resulting from a transition to a CE are still largely underexplored (Vanhuyse et al., 2021). In this respect, perhaps the most crucial aspect to consider in future research is the demarcation of interlinkages occurring between the concepts of CE with the different dimensions of inclusion of the IRS and the overall relation of socio-economic activities with the biosphere. Some first steps towards this direction have already been made (Gutberlet et al., 2017; Liu et al., 2023).

Furthermore, the role of the IRS within the CE, its overall relation to the SDGs (Schroeder et al., 2019; Gutberlet, 2021), and its positioning within the debate on green-growth versus degrowth could be explored further by using quantitative methods such as bibliometrics (Belmonte-Ureña et al., 2021).

Considering that informal recyclers provide cities with *"metabolic value"* (Irvine, 2022), UWMSs can benefit greatly if research efforts are directed towards the assessment of informally influenced community co-design activities and of the *informal urban metabolism* for developing and monitoring relevant indicators (Kaviti Musango et al., 2020). To this end, socio-metabolic research (Haberl et al., 2019) and regenerative economics (Fath et al., 2019) offer a holistic, multi-disciplinary perspective along with tools for the assessment of systemic *"health"* properties of complex socio-economic systems.

Our work opens up the way for extending the current understanding of the role of the IRS in a CE, encouraging further research for confirming or challenging our findings.

4. Concluding remarks

Cities have massive socio-metabolic requirements in resources, they generate substantial amounts of waste, emissions, and experience the manifestation of different types of inequalities. All these aspects are strongly coupled to a city's waste infrastructural tissue, and they simultaneously affect and are affected by the rate of urban densification and area-based development. All waste-related infrastructures, formal or informal, are embedded within larger urban socio-economic networks where various types of resources are circulating be it material, energy, monetary or information flows and stocks, and therefore, their proper management is crucial for a just transition towards an inclusive and regenerative CE. To drive this transition, local governments will need to navigate through the complex intricacies of this coupling by developing and implementing tailor-made policies.

While a quantitative analysis of assessments in literature was not the aim, we present a set of qualitative arguments which highlight the potential of IRS systems for a CE transition. By searching in Science Direct, we found an exponential increase in academic publications studying the integration of the IRS to the CE during the past decades. By drawing knowledge from a rich compilation of literature, we looked at the formal-informal relationships within the ecosystems of stakeholders who are active in UWMSs, and we examined how they can be shaped by waste-related infrastructures. Evidence of past integration attempts worldwide indicate that enforced assimilation of the IRS into a CE are prone to fail, and that successful cooperation depends on effective consensus or compromises between formal domains and IRS groups.

Earlier literature inspired us to develop the IRS engagement typology framework to categorize different types of recycling value chains according to systemic nature (i.e., linear vs. circular) and to their integration approach (inclusion or exclusion) towards the IRS. These operational modes include the perpetuation of a business-as-usual linear economy, the transition to an inclusive linear economy, the transition to an exclusive circular economy, and the transition to an inclusive circular economy.

Recognizing that the various activities of the IRS are not mutually exclusive, we develop a conceptual framework to help policy makers and other interested stakeholders in identifying the ways in which the IRS contributes to a CE as a key stakeholder. Evidently, the IRS activities contribute directly to the waste hierarchy principles of reduce, reuse, repair, refurbish, remanufacture, and recycling, and indirectly to the principles of rethink, refuse, and recover. The overall (direct and indirect) contribution of the IRS to a CE can be captured through different business models such as micro-enterprises, community-based organizations, and public-private partnerships which focus on closing, narrowing, slowing, intensifying, or dematerializing resource loops, offering a plurality of services which among others include the prevention of landfilling, the reduction of GHGs, the improvement of waste collection efficiency and commercialization of recyclable materials, and the education of citizens on waste sorting at source.

We note that our analysis is not free of limitations which mainly relate to the choice of following a narrative review over a systematic bibliometric analysis. Yet, it offers possibilities for further research to confirm or challenge our findings.

Ultimately, an inclusive and circular UWMS should aim both for reducing the adverse effects of waste on health and the environment as well as for continuously improving its collective learning ability for urban regeneration. To facilitate the inclusion of the IRS, CE strategies and policies should be designed to match local contexts and prepare cities not just for managing their waste and resources but also for adapting to global developments. By constantly balancing effectively between the cross-circulation of resources throughout its urban fabric for increased efficiency, and the inclusion of a diverse ecosystem of actors for enhanced resilience, a city can provide vital functions and public services to ensure a high quality of life for all its inhabitants in just ways while anticipating external change.

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F.K.Z. conceived the main idea, conducted the literature review, developed the frameworks, and wrote the text as the main author. B.S. contributed with expertise on the formal and informal recycling sector, on circular economy, and on EPR schemes, R.A., Z.L., and T.X., provided valuable knowledge and insights on the formal and informal recycling sector, S.T. supported with expertise on circular economy, and D.S. shared knowledge on infrastructure management and contributed conceptually to the development of the framework. All authors contributed significantly to this work by reading, knowledge-sharing, providing constructive criticism, editing, and reviewing the text. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial

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Data availability

The data used are from a search in online scientific databases.

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