



Typology of municipal solid waste recycling value chains: A global perspective

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ABSTRACT

Municipal solid waste (MSW) management that seeks to recover wasted resources and return them to the system as secondary commodities (hence, it promotes circularity in resource recovery systems) is a process instigated by recycling value chains. Recycling value chains are termed 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. At present, recycling processes and structures are not well depicted in the global literature due to the heterogeneity of terms used across countries and disciplines, and the lack of holistic insight into the way recycling chains operate. This critical review aims to disentangle the diverse terminology used to describe recycling value chains globally and provides an overview of the current state-of-the-art of MSW recyclable waste materials management in developed and developing economies emphasising their potential in promoting circularity. The study proposes a typology for describing the management of recyclable waste materials across the globe, and highlights that each of the three types of recycling value chains developed is a highly complex, context-specific system, deeply constructed on long-term political, organisational, and institutional aspects. While this typology can be a simplistic way of depicting the type of recycling value chain that is most prevalent in different countries around the globe, it can reveal how different forms of governance affect coordination in recycling networks and, by extent, their recycling performance. Therefore, this study can help researchers and decision-makers understand how recycling value chain systems operate at large and explore different ways to improve resource recovery from waste that match the needs of each area.

1. Introduction

Solid waste management (SWM) has received renewed attention due to the urgent need of meeting the circular economy (CE) principles and recover value from waste rather than simply disposing of waste to the environment via landfilling or dumping (UNEP and ISWA, 2015). CE is a concept that emerged to preserve the value of materials, components, and products in the economy, and to slow down their degradation and value negation via maintenance, repair, refurbishment, remanufacturing, and recycling (Pires and Martinho, 2019). To achieve the CE, there is a need to establish processes wherein waste generated at all stages of

production and consumption value chains, either in the form of natural resources or man-made materials, components, products, are recovered and maintained in the system. This refers to *resource recovery* from waste. Resource recovery from waste is not a straightforward process. It depends on the varying composition of solid waste and the diverse collection and management regimes that are implemented around the globe. Most importantly, resource recovery from waste depends on 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 across the whole value chain, that bring together production, distribution, access, and management

; SWM, Solid waste management; CE, Circular economy; MSW, Municipal solid waste; LAs, Local authorities; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analysis; HICs, High-income countries; LICs, Low-income countries; MICs, Middle-income countries; WPs, Waste pickers; ISWM, Integrated solid waste management; MRFs, Material recovery facilities; EPR, Extended Producer Responsibility.

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(Iacovidou et al., 2020).

An important component of solid waste generated in any country is municipal solid waste (MSW). MSW refers to the waste generated via consumers' daily activities and may include packaging waste, food waste, paper/cardboard, green waste, batteries, that are largely produced in households (Sembiring and Nitivattananon, 2010). It also includes waste generated in public places such as parks and streets, stations, schools, and small businesses that are similar to households (Scheinberg et al., 2011). It is worth noting that some countries, e.g. Serbia (Mrkajić et al., 2018), Brazil (Pacheco et al., 2012) and India (Suthar et al., 2016), may also include *industrial waste* similar to household waste in their MSW definition.

The sustainable management of MSW is a prerequisite for achieving the CE, as it can promote environmental and human health protection, while it can boost the economic productivity of a region via resource recovery from waste; hence, creating an effective supply and demand market. Based on global data, on average, organic waste (e.g., food waste, grass clippings, leaves) and other recyclable waste materials (i.e., plastics, metals, glass, paper/cardboard) constitute around 44% and 40% of the materials present in MSW, respectively (Sharma and Jain, 2020). While there are variations in the composition of MSW due to geographic, seasonal, socio-economic, and technical conditions, it is generally accepted that post-consumer recyclable waste materials represent around half of the volume of MSW generated.

Recyclable waste materials in this study refer to plastic, metal, glass and paper/cardboard waste (usually packaging waste) and other paper-based components (e.g., magazines, newspapers, stationery paper) that are produced at high volumes, are non-hazardous, are not heavily soiled/contaminated (hence, excludes food take away containers, drinking cups); they can fetch a considerable value in the secondary commodities market, and can cross, regional and/or national boundaries to move around between various destinations for recycling. With *recycling* this study refers to the mechanical reprocessing of recyclable waste materials (may include cleaning, crushing/cutting/milling/pulping, smelting, melting, extrusion, forming, etc.), and involves their collection, sorting, distribution, trade into local, regional, national, or international markets, not necessarily in a linear order as commonly defined by Jaligot et al. (2016), Scheinberg et al. (2011) and Wilson et al. (2009).

To meet waste management goals in line with the CE concept, local authorities (LAs) (i.e., municipalities) around the globe strive to establish a recyclable waste materials management system, in collaboration with the public and private sectors that is tailored to their specific needs. This task is increasingly complex in practice, due to the varying dynamics of supply and demand from one region to another and the pertaining political, economic, institutional, cultural, and social drivers that often impede the implementation of effective region-specific recycling value chains of post-consumer recyclable waste. The *supply* dimension here refers to recyclable waste materials that are seen as secondary commodities (either as waste or reprocessed material) in demand due to economic reasons and, thus, they often cross boundaries and connect different sectors, products, and markets. For example, in developed economies, the collection and management of MSW recyclable waste materials occur via formal procedures set up by the national and local governments in collaboration with the waste management industry that often exports recyclable waste materials for recycling in emerging economies. The waste management industry in the context of this study refers to stakeholders involved in the collection, sorting, disposal, treatment and sometimes, but not always, export of recyclable waste (UNEP and ISWA, 2015). In emerging economies, there is a combined effort from both formal and informal recycling sectors to collect, sort and manage domestic and imported recyclable waste materials (Scheinberg et al., 2011). The contribution of the informal sector to recycling activities in emerging economies is believed to play an important role in achieving high recycling rates, and some studies suggest that the rate of recyclable waste materials collected by the informal

sector could be up to 30% (Jaligot et al., 2016). However, the role of the informal sector in the recyclable waste materials management is often not fully recognised due to the lack of reliable information on the volume and quality of recyclable waste materials collected, sorted and managed and to the informal, complex relations between stakeholders (Sasaki and Araki, 2014). As a result of these dynamics, the effectiveness of recyclable waste materials management varies widely in both developed and developing countries.

At present, there is a lack of insight on how well recycling chains promote circularity in recyclable waste materials management globally. This is partly due to the diverse terminology used that prevents understanding common challenges and opportunities in recycling value chains and the lack of insight on the stakeholders involved in recycling chains and their interrelationships. Some studies analysed and compared the recycling processes and structures at local (Aslam et al., 2021; Scheinberg and Simpson, 2015), regional (Pacheco et al., 2012), or national (Brouwer et al., 2018; Mrkajić et al., 2018; Nandy et al., 2015) levels and for different types of MSW recyclable waste materials (plastics – Jaligot et al., 2016; plastics and paper – Rutkowski and Rutkowski, 2017; all recyclables – Sandhu et al., 2017 and Steuer et al., 2017). Other studies compared different waste management systems, for example, Wilson et al. (2015) created an analytical framework for assessing waste management systems at city level and have tested it in 50 cities around the world. Scheinberg and Simpson (2015) compared waste management and recycling schemes between five cities from different countries. Aparcana (2017) mentioned experiences with informal sector formalisation for thirteen countries. Valencia (2019) discussed the terminology of waste pickers in Africa, Europe, Latin and North Americas. There is not yet a global overview of the terminology used in describing MSW recyclable waste materials management that could decipher the differences and similarities between recycling practices and compare their performances.

Understanding the current state of practice and effectiveness of recycling chains (in terms of capabilities, capacities and structures) is centre stage towards the implementation of regional CE. Therefore, this study aims to provide a state-of-the-art global overview of MSW recyclable waste materials management in developed and emerging economies and develop a typology of recycling practices that sheds light on recycling value chains' structure and circularity performance. The overarching goal of this global perspective is to highlight future directions and improvements in CE practices. To achieve that, the study disentangles the diverse terminology used in the field of MSW recyclable waste materials management, depicts the chain of processes involved in recyclable waste materials management, and describes recyclable waste materials management systems. While important, the study excludes exploring the factors that cause language barriers, their types and their impact on effective recycling practices. Finally, this study provides the knowledge base for a more grounded interpretation of value chain activities and formal/informal actor networks impact on recycling performance globally, benefitting future researchers and policy- and decision-makers at international level.

2. Methods

A systematic literature review (Siddaway et al., 2019) was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009). This involved development of a search strategy, collection of articles, screening, and selection of those relevant to the scope of the study. For both quantitative and qualitative secondary data collection, Scopus, Web of Science and Google Scholar literature databases were used, targeting studies from 1975 to 2021. The keywords and search operators used were as follows: "Municipal solid waste" AND "MSW" AND "municipal waste" AND "post-consumer waste" AND "recyclable waste materials" AND "recyclable materials" AND "recycling chain" OR "recycling value chain" OR "recycling" OR "collection for recycling" AND "informal

recycling”.

The retrieved literature was screened according to its relevance to the study’s aim and objectives, following a set of selection criteria (see Table S1 in Supplementary Materials for a complete list). The screening method included reading papers’ titles first, then abstracts and full texts to determine the relevancy of the paper to the study’s objectives. The information collected from the selected papers (Stake, 2005) includes data on MSW generation (in metric tonnes per annum), information on stakeholders involved in recovering recyclable materials from MSW generated, and the types/quantities of recyclable materials captured for recycling in metric tonnes. Further analysis was carried out to gather facts and/or gain insights with regards to the terminology and types of MSW recycling chains operating in different regions.

For profiling, the information retrieved from each paper included reference, city, country, and continent (see Table S2 in Supplementary Materials for a complete list). Then the papers were analysed based on 1) the terminology used to describe the recycling value chain; 2) stakeholders involved in the recycling value chains around the world; 3) structure and processes involved in the recycling value chain; 4) performance in the collection of MSW recyclable waste materials based on formal and informal sector activities (see Table S3 in Supplementary Materials for a complete list).

All papers published within the selected period concerning MSW recyclables fraction are included in the analysis, regardless of the field, they were published, from industrial or chemical engineering, environmental sciences to public health sciences. The set of papers used here is the most comprehensive review on the topic, including qualitative, quantitative, and mixed methods research.

3. Results and discussion

Using the PRISMA guidelines, 228 documents were retrieved.

Following the screening procedures (titles and abstracts), 96 documents were pre-selected for full-text reading. Finally, a total of 58 papers were included in the analysis (a step-by-step analysis is shown in Fig. S1 in Supplementary Materials).

The 58 papers included in the analysis present information and discuss aspects in relation to MSW recyclable waste materials management in 42 different countries across five continents. This is illustrated in Fig. 1, which also helps to deduce aspects specific to their contexts (e.g., formal and informal practices). Fig. 1 depicts the distribution of studies per continent (bar graph) and the intensity of research in different countries as per the number of studies conducted.

The majority of studies (35%) are from Latin America, followed by Asia and the Pacific (27%), Europe (16%), Africa (6%) and North America (4%). International studies represented the remaining 12% of the studies; in these studies countries from more than one continent are described and/or analysed. Brazil is analysed/discussed in 13 studies, while India is analysed in four studies. Indonesia, the United States of America (USA) and Bangladesh are described/analysed in three studies each. Table S2 in Supplementary Materials presents the list of all studies included in the analysis, the countries of reference and regional focus.

3.1. MSW recyclable waste materials management: evolution and terminology

Evidence suggests that MSW recyclable waste materials management dates to the 9th century in Japan where the recycling of paper was first recorded. Japanese people produced, consumed, and recycled paper almost simultaneously and it is believed that there was more value on recycled paper than in new one, because it was often used in paintings and poetry (NERC, 2019). In the 17th century, the first paper recycling plants appeared in Europe and North America, and it was in the 20th century that modern recycling emerged, where Second World War II

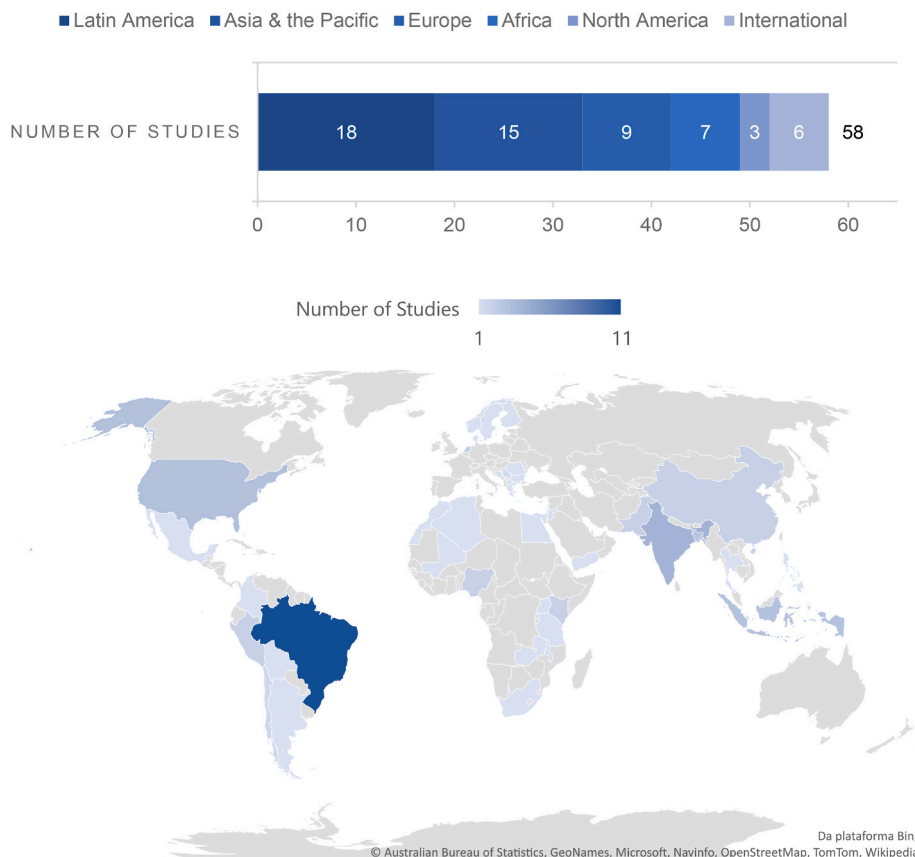


Fig. 1. Spatial distribution of analysed studies globally.

demanded giving a second life to materials, components, and products (NERC, 2019; PAPREC Group, n.d.).

In the 1970s, in the field of management science and industrial engineering in the USA recycling was emphatically discussed and the term *recycling chain* was first introduced to describe the *collection, distribution and reprocessing of recycled waste materials* (Guiltinan and Nwokoye, 1975). This term gained increased prominence through the 1990s and other terms such as “*reverse channel of distribution*” (Guiltinan and Nwokoye, 1975) and “*reverse logistics channel*” (Pohlen and Farris II, 1992) emerged to describe the movement of recyclable waste materials in the opposite direction of the traditional supply chain for their use into newly manufactured products (hence, the word ‘reverse’), what is now widely known as *recycled content*. *Reverse logistics* has since been used widely across the supply chain management field and is now by itself a contested term that is more widely used to refer to the process of taking back raw materials, components, and products to be used again in the supply chain (Kopicki et al., 1993; Rogers and Tibben-Lembke, 1999).

The reverse logistics system was understood to be different from the traditional distribution chain. While it needed specific private sector actions and government regulation, it required different stakeholders, had no clearly defined pathways and was sensitive to market price volatility (Guiltinan and Nwokoye, 1975; Pohlen and Farris II, 1992). A situation that still holds today. Nonetheless, reverse logistics systems insinuated not only the creation of financial value via a reverse distribution channel, but also, the extraction of ecological and social value that can be redistributed back to the economy (Prajapati et al., 2019). Correspondingly, this led to the present notion of *value* that is used by the CE proponents to argue for an understanding of the materials, components, and products transformations along the value chain and the capture (and/or create) of their embedded environmental, economic, social, and technical value at their end-of-life stage (Iacovidou et al., 2017).

In the late 20th century, scientific literature started featuring the terms “*waste recovery*” and “*recycling networks*” to describe post-consumer recyclable waste materials management through a chain of activities and stakeholders involved (Brouwer et al., 2018; Wilson et al., 2006). *Recycling networks* refer to constellations of various local, regional (e.g., villages, cities, provinces, districts), national enterprises, and individuals that are connected by ‘waste relationships’, where one man’s waste is another’s ‘treasure’ (Schwarz and Steininger, 1997). In a recycling network, stakeholders involved in the collection, sorting, distribution, and reprocessing of secondary raw materials could be the same or different, and they may sell their secondary commodities to brokers or directly to new products manufacturers (Shen and Worrell, 2014). In 2011, Scheinberg et al. (2011) described how recycling networks in high-income countries (HICs) differed historically from middle- and low-income countries (i.e., MICs and LICs, respectively). In HICs, MSW recycling activities brought about by different stakeholders (e.g., LAs, waste management companies, private enterprises) were part of an integrated solid waste management (ISWM) strategy, aimed at a diversion of MSW waste from landfills into a suite of options, such as incineration, mechanical biological treatment, recycling, and reuse. In the MICs and LICs, MSW recycling activities were hardly practised by LAs (this is still the case in many parts of the world), but where practised, especially in metro cities, a spur of “*private economic activity based on valorisation and trading with strong direct links to the industrial sector*” could be observed (Scheinberg et al., 2011: 189). This has highlighted the spatial dimensions of the recycling networks developed, and the importance of understanding the capacities (amounts of recyclable waste materials handled by waste pickers (WPs) and local traders) and structures (e.g., small local traders linked with bigger ones) that can enable recycling networks to flourish. As Navarrete-Hernandez and Navarrete-Hernandez (2018) pointed out, recycling networks evolved to expand at scale (from local to regional and global) connecting stakeholders operating within developed countries to those operating in developing economies, and vice versa.

In developing economies, the term “*chain of intermediates*” was introduced to describe networks of stakeholders involved in recyclable waste materials management, which can be more complex than those established in developed economies due to activities of small, local WPs and traders (Sembiring and Nitivattananon, 2010; Wilson et al., 2006). At the beginning of the 21st century, emphasis was largely placed on informal WPs and their role in capturing value from post-consumer recyclable waste materials. Gradually and with an increased understanding of recycling networks, attention had also been placed on intermediate traders and their role in the functioning of recycling chains (e.g., ability to handle large volumes, assess the quality of recyclable materials, and establish good relationships between suppliers and customers), especially in low- and middle-income countries (Sembiring and Nitivattananon, 2010; Wilson et al., 2006). Since then, small and medium-sized traders, recycling businesses, and other stakeholders operating in recyclable waste materials management in low- and middle-income countries took a prominent place in the description of recycling chains. This was signalled by other studies carried out in middle- and low-income countries, but the terminology used was different (see Tables S7 and S8 in Supplementary Materials for all references).

For instance, Torres and Cornejo (2016) in Peru used the term “*specialised logistic chains*” to define chains that form and operate based on WPs activities on streets or at open dumpsites that collect and sell recyclable materials to local scrap dealers. Local scrap dealers may then sell recyclable waste materials to local reprocessors, who turn them into recycled products that enter local markets. In India, the term “*chain*” is used to describe exchanges between WPs, small scrap dealers, medium scrap dealers and reprocessors (Sandhu et al., 2017, p. 548). In Brazil, the terms “*supply chain of the end*” and “*reverse supply chain*” are used to emphasise the connection of two ends of resource recovery systems, by the process of collection, sorting, distribution, reprocessing, and use in new goods as well as the trading in-between (Rutkowski and Rutkowski, 2017: 5).

The notion of *reverse supply chain* aligns with the emergence of the concept of a “*circular supply chain*” (Batista et al., 2018). A *circular supply chain* evolved simultaneously with the CE concept and thus refers to keeping materials in the economy for as long as possible via reuse, repairing, reconditioning, remanufacturing, and recycling. de Oliveira et al. (2019) note that the circular supply chain is a collaborative system that involves the movement of commodities from their point of consumption to their designated point for value capture, usually via treatment, and involves the collection, transportation, sorting, reprocessing, and sales to manufacturers. It connects consumers with LAs, the waste management industry, secondary commodity brokers, and manufacturers.

Using all terms collated from the studies included in the analysis (see Table S4 in Supplementary Materials for a complete list of terms), it was concluded that all studies tried to describe the one and same thing: recyclable waste materials management, termed here as the “*recycling value chain*”. It also led to the following definition for *recycling value chain*: ‘a chain of activities performed by a diverse set of stakeholders directly and/or indirectly involved in the recycling of post-consumer recyclable waste materials that aim to retain these in the economy in the form of secondary materials that can be used in similar and/or other uses, hence recovering some of the multidimensional value embedded in them’.

The set of stakeholders involved in the recycling value chains is equally broad in the global literature. Section 3.2 aims to disentangle the terminology related to the direct stakeholders involved in the recycling value chains and describe their role. *Direct stakeholders* are those who directly affect the generation and management of recyclable waste materials by being involved in their production, collection, and recycling, and who have a vested interest in the success or failure of recyclable waste materials recycling. *Indirect stakeholders* are those who influence (indirectly via policy and decision-making) or are influenced

by the generation, collection, and management of recyclable waste materials but are not engaged in the mass or monetary transactions accrued in the recycling value chain. These are characteristically called *secondary stakeholders* and may include national government(s), and non-governmental organisations, research institutes, local/regional/national/national/international consultants, and media, among others (de Oliveira et al., 2019; Oyake-Ombis et al., 2015; Sembiring and Nitivattananon, 2010). The description of roles of indirect stakeholders is not included in this analysis, as it falls outside the scope of the present work.

3.2. Stakeholders directly involved in the MSW recycling value chain

Even though there are studies that categorise direct stakeholders involved in the recycling value chains, particularly at the informal waste recycling sector – for example, see Jaligot et al. (2016), Scheinberg et al. (2011) and Wilson et al. (2006) –, there is still lack of consensus in global literature on the terminology used to describe the role (or activities) performed by these stakeholders. To avoid digressing from categorising stakeholders based on their main activity, or service provided in the recycling value chain using a global perspective, communication barriers due to terminology inconsistencies and contradictions are not discussed in this section.

The analysis of the terms/definitions used to describe the activities of direct stakeholders involved in MSW recyclable waste materials management hinted that direct stakeholders can be grouped into six categories, shown in Table 1. The categories correspond to the main activity/service that stakeholders perform in recycling value chains, namely recyclable waste materials generation, collection, sorting, trading, reprocessing, and use as recycled content in the manufacture of new goods. All terms used in the development of this categorisation for each group of stakeholders, country of reference and source can be found in *Supplementary Materials (Tables S5–S9)*.

There is a grey area between all the categories of stakeholders presented in Table 1, as all stakeholders are simultaneously waste generators (being members of the society) and some stakeholders can perform more than one activity (usually two or three, e.g., collection-sorting-processing) in the recycling value chain. For example, waste collection companies can be responsible for the sorting of recyclable waste materials as well as their storage (in developed countries), whilst waste collectors in emerging countries can also be small scrap dealers and even do some pre-processing, as is the case of WPs organisations in Latin America (Márquez and Rutkowski, 2020; Rutkowski, 2020). However, this diffusion of roles is disregarded for simplicity purposes and instead the word ‘*primarily*’ is used to emphasise the stakeholders’ group main activity. In this regard, the stakeholders’ activities that may fall into other categories were denoted as ‘*secondary role(s)*’ (see Table 1).

‘*Brokers/Large scrap dealers/Semi-reprocessors*’ is the only category of stakeholders that may trade materials amongst each other and are often points of recyclable waste materials exit and/or entry between developed and developing economies (Jaligot et al., 2016; Nandy et al., 2015; Oyake-Ombis et al., 2015; Scheinberg and Simpson, 2015; Suthar et al., 2016). This group is also the most critical to the recycling value chain, as they control and advance the flow of recyclable waste materials from the points at which they are regarded as waste to the points where these become secondary commodities (Fiore and Rutkowski, 2017; Jaligot et al., 2016). There are multiple modes of interaction between ‘*Brokers/Large scrap dealers/Semi-reprocessors*’ and ‘*Sorting centres/Small scrap dealers*’ (downstream of the recycling value chain) and between the first and ‘*Reprocessors*’ (upstream of the recycling value chain). These interactions may vary depending on the recyclable waste material type and value in the market and established relationships between stakeholders, which often may take years to build and require a certain level of trust in the quality of recyclable waste material supplied. These highlight complex interwoven relationships and factors that come into play in global recycling value chains. Whilst brokers are rarely involved

Table 1

Stakeholders operating in MSW recycling value chains (compiled based on studies included in this analysis; it may not represent an exhaustive list of potential descriptions).

Suggested Category	Activity/Service	Terms used to describe stakeholders that fall under this category
Waste generators	Primarily generate post-consumer or similar recyclable waste materials	Households; Consumers; Consumers on the go; Commercial establishments; Retail and service (hospitality) sectors; industrial sectors producing recyclable waste
Collectors	Primarily collect (or buy) recyclable waste materials from the points of generation and/or disposal (e.g., door-to-door, streets, parks, dumpsites, landfills) and sell them to Sorting centres/Small scrap dealers, or Brokers/Large scrap Dealers/Semi-reprocessors. <i>Secondary roles: sorting, storage and baling of recyclable waste materials</i>	LAs or municipal companies; Private businesses (waste management contractors with a permit); Scavengers; Independent waste pickers; Rag pickers; Itinerant waste buyers or waste merchants
Sorting centres/ Small scrap dealers	Primarily sort recyclable waste materials (incl. baling and storing), and they trade – they buy from Collectors and sell to Brokers/Large scrap dealers/Semi-reprocessors/Reprocessors. <i>Secondary role: collection</i>	Material Recovery Facilities; Sorting centres or units; Transfer stations; Cooperatives or associations of waste pickers; Small scrap dealers; Scrap yards, yard shops or junk shops; Buy-back/Drop-off centres
Brokers/Large scrap dealers/ Semi-reprocessors	Primarily store and trade recyclable waste materials (or recycled materials as secondary commodities) in big quantities – they buy from Collectors and Sorting centres/Small scrap dealers and sell them to Reprocessors (and from Reprocessors to Manufacturers in the case of recycled materials) <i>Secondary roles: sorting and semi-reprocessing (e.g. removal of impurities, cleaning, cutting, crushing)</i>	Brokers; Middlemen; Intermediaries; Intermediate business firms; Intermediate traders; Medium and big scrap dealers; Intermediate levels of the value chain; Intermediate processors; Semi-processors; Industrial semi-processing; Informal pre-processing
Reprocessors	Primarily convert materials into secondary commodities and trade them – they buy from Sorting centres/Small scrap dealers/Brokers/ Large scrap dealers/Semi-reprocessors and sell them to Manufacturers (via Brokers or not) <i>Secondary role: sorting</i>	Reprocessors; Recycling processing industries; Mechanical recycling facilities; Recyclers; Recycling enterprises
Manufacturers	Primarily the end-users of secondary materials in the production of new components and products – they buy from Brokers/ Large scrap dealers/Semi-reprocessors/Reprocessors. <i>Secondary role: reprocessing</i>	Local and foreign manufacturers; remanufacturing/ reprocessing industries; Value recapturing; Applicators or Transformers; End-user or retro-manufacturers; Formal private sector businesses ‘higher up’ in the industrial value chain

in any sorting or semi-reprocessing activities, large scrap dealers in some countries may carry out sorting, semi-reprocessing, and trading activities (Coelho et al., 2011; de Oliveira et al., 2019; Guiltinan and Nwokoye, 1975; Ibáñez-Forés et al., 2018; Jaligot et al., 2016; Meira de Sousa Dutra et al., 2018; Pohlen and Farris Ii, 1992; Scheinberg and Simpson, 2015; Sellitto, 2018; Sembiring and Nitivattananon, 2010).

Moving along the recycling value chain, stakeholders accumulate recyclable waste materials, which grow in volume (Jaligot et al., 2016; Rutkowski and Rutkowski, 2017; Sasaki et al., 2019; Vaccari and Perteghella, 2016; Wilson et al., 2006). Hence, there is a financial value creation from one stage to the next, due to the bargaining power between stakeholders (Wilson et al., 2006). Yet, the success of capturing value from recycling value chains relies not only on the proper functioning of the recycling network (that advances exchange of recyclable waste materials from one stage to another), but also on the capabilities and capacities of stakeholders involved in the network to deal with ever-increasing volumes of recyclable waste materials (Pohlen and Farris Ii, 1992). Storage space, equipment, technology, trading efficiency, and trust are some of the key attributes needed in weaving an efficient and effective recycling value chain (Jaligot et al., 2016; Matter et al., 2013; Oyake-Ombis et al., 2015; Rutkowski and Rutkowski, 2017).

Coincidentally, a key consideration in assessing recycling value chains' structure and performance is vis-à-vis the role of informal sector's activities. For example, in MICs and LICs, the majority of *Collectors* and/or *Small scrap dealers* that collect recyclable waste materials from households or commercial establishments, streets, landfills, or dumpsites are often marginalised by the local authority and lack organisational arrangements that would aid an increased resource recovery of recyclable waste materials. Formal collectors can often hinder informal collectors' activities by influencing political-economic processes to eliminate competition. Moreover, informal stakeholders that are not organised may be affected by other factors, such as low costs of labour and lack of awareness regarding the market price of recyclable waste materials, just to mention a few. On the contrary, the recycling network in MICs and LICs where informal stakeholders are arranged in formalised, organised networks, which recognise their activities and are supported by local/national government, appear to be well functioning and strong (Jaligot et al., 2016; Rutkowski and Rutkowski, 2017; Sasaki et al., 2019; Vaccari and Perteghella, 2016; Wilson et al., 2006). The following section presents the typology of MSW recycling value chains and discrepancies that ensued due to the way informal stakeholders are integrated into the system.

3.3. Typology of MSW recycling value chains

It is widely accepted that while there are heterogeneities in recycling value chains operating around the world, there are also many similarities. Based on similarities, Scheinberg and Simpson (2015) proposed a visualisation tool (the *Recycling Framework*) to show different recycling chain settings at a city level, but no research has attempted to identify a pattern in recycling value chains and typify them. Therefore, developing a typology that rationalises recycling value chains across the globe can cut through the complexities in recycling networks and concentrate efforts on understanding the surrounding 'enabling' environment (i.e. the ecosystems and provisioning services; technology, infrastructure and innovation; regulatory framework and political landscape; businesses activities and the market; human behaviour, needs and practices) that governs the operation and structure of recycling value chains. This level of understanding is a prerequisite to devising well-informed pathways of transitioning towards sustainable circularity in resource recovery systems (Iacovidou et al., 2020).

Following the review and harmonisation of terminologies used to describe and characterise MSW recycling value chains globally and the attempt made to homogenise the various descriptions of stakeholders involved in the recycling networks, a *typology* was developed for

describing the main types of MSW recycling value chains occurring globally, presented in Fig. 2. Acknowledging the importance of local public policies in dealing with informal recycling stakeholders, the typology was influenced by the work of Medina (2005) who distinguished four different kinds of informal recycling public policies, as follows:

- *Neglect*: informal recycling stakeholders are ignored, there is no persecution or support from authorities (Botello-Álvarez et al., 2018; Scheinberg et al., 2016).
- *Repression*: informal recycling stakeholders are declared illegal and punished (Steuer et al., 2017; Masood and Barlow, 2013).
- *Collusion*: authorities establish an exploitative relationship with informal recycling stakeholders (Sandhu et al., 2017).
- *Stimulation*: informal recycling stakeholders are recognised for their economic, social, and environmental contribution to the economy and society and are supported by policies such as legalisation of activities, the organisation in cooperatives, associations or social enterprises, and awarding concessions for collection services (Rutkowski, 2020; Villalba, 2020).

The three types of MSW recycling value chains (shown in Fig. 2) are described and discussed below. In all types, it is assumed that MSW recyclable waste generation mainly occurs in households, commercial establishments, streets, bins, parks, and other public areas.

3.3.1. Type 1: Formal recycling value chain

This type (Fig. 2-A) represents formal recycling value chains that usually prevail in high-income countries, such as the USA, Nordic countries, and European countries (see the complete list in Table S2 in *Supplementary Materials*). These countries generally have well established formal waste management systems that are costly and have been developing for a long time (Guiltinan and Nwokoye, 1975; Milios et al., 2018; Shen and Worrell, 2014).

The collection of waste is often the responsibility of LAs that either carry out these activities in-house or outsource them to paid waste collection contractors and/or permitted private waste management companies (Milios et al., 2018; Hahladakis et al., 2018; Iacovidou et al., 2020). Collected MSW recyclable waste materials are then sorted in transfer centres or material recovery facilities (MRFs), which are mainly run by private service providers (e.g., waste management companies) and in some cases by LAs as in Norway, Sweden, Finland, Denmark (Milios et al., 2018), the UK (Hahladakis et al., 2018) and the USA (Scheinberg and Simpson, 2015). These facilities demand large quantities of recyclable waste to be economically viable and employ a diverse range of sorting technologies, of which efficiency is measured upon their ability to deal with contamination of input materials. The quality of recyclable waste materials sorted is paramount in Type 1 recycling value chains as it will determine their fate (Hahladakis et al., 2018; Milios et al., 2018). Sorted recyclable waste materials are then baled and traded (via brokers or directly) to domestic reprocessors and wholesale exporters to foreign markets. Exporters trade baled recycled materials with foreign local traders (Iacovidou et al., 2020; Guiltinan and Nwokoye, 1975). Anecdotal evidence suggests that commercial establishments that generate waste similar to a household (therefore, considered to be MSW) may often bale recyclable materials themselves (usually, cardboard, plastic films) and use them as rebates to their waste collection contracts, or channel them directly to reprocessors via material brokers. These types of transactions are usually facilitated by *material brokers*, who connect the buyers with sellers of recyclable commodities (Milios et al., 2018; Pohlen and Farris Ii, 1992). It must be noted that in Type 1 recycling value chains, material brokers and their relationships with other stakeholders in recycling value chains are less mentioned in the literature.

In Type 1 contexts, there are usually many collectors and sorters, but fewer reprocessors and manufacturers. This is because the majority of reprocessing and manufacturing activities are undertaken abroad

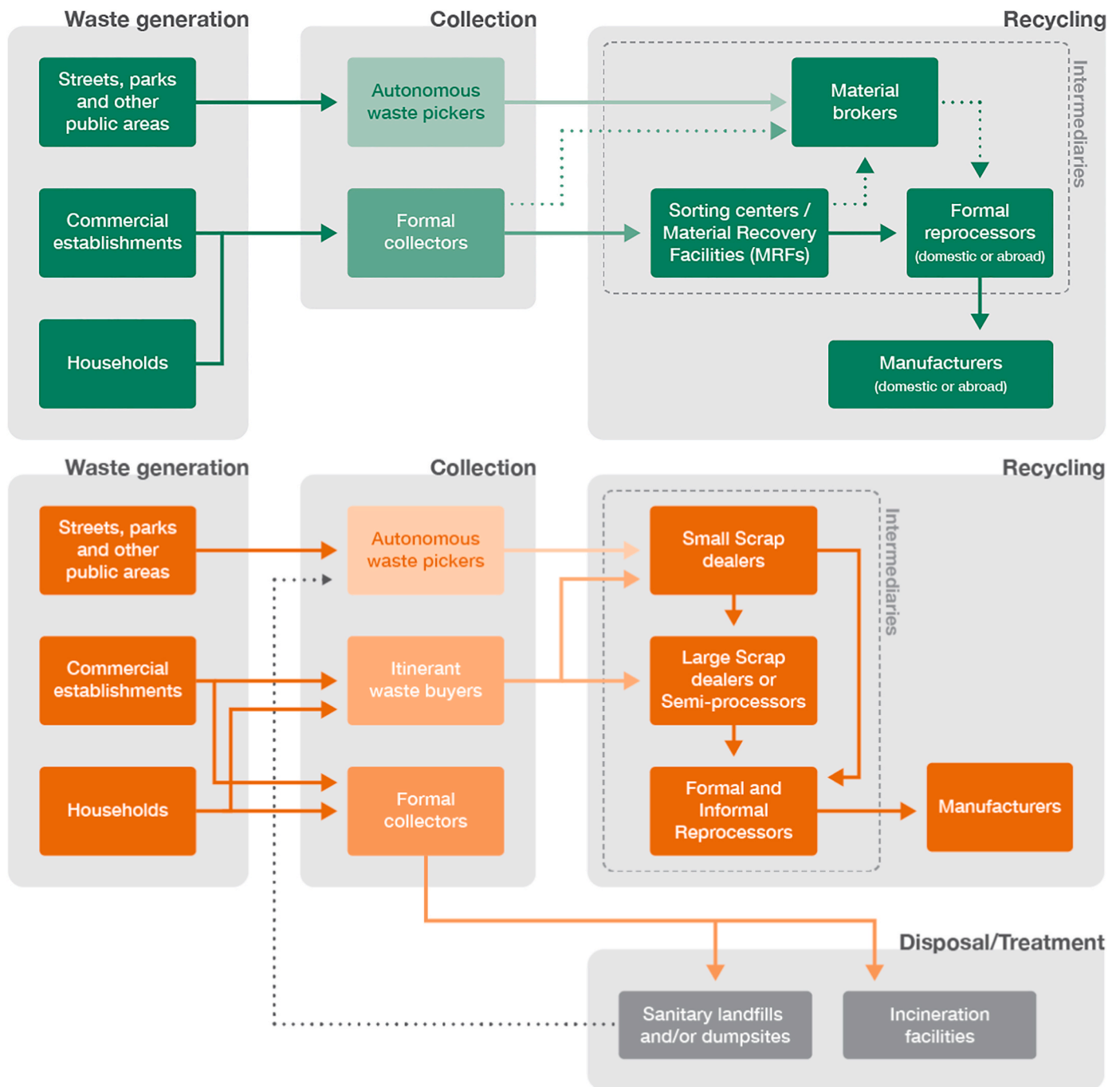


Fig. 2. Typology of pervasive MSW recycling value chains; (A) Formal recycling value chain; (B) Suppressed recycling value chain; (C) Hybrid recycling value chain. Dotted arrows denote flows of recyclable waste materials that are suggested to occur but lack evidence support.

(Brouwer et al., 2018; Hahladakis et al., 2018; Milios et al., 2018) and many countries have been exporting their waste as recyclable commodities. While this practice is now incriminating affluent societies in contributing to environmental pollution caused by waste shipped to developing countries, of which end-of-life fate remains elusive, the stringent quality standards introduced in the use of recycled materials, coupled with lack of production factories and small markets for recycled materials (Milios et al., 2018) make domestic reprocessing a major challenge.

It is worth noting that *autonomous WPs* may be present in Type 1, but their role is marginal, and has, presumably, little impact on the performance of recycling value chains; hence, they are often unrecognised

(Pohlen and Farris II, 1992; Scheinberg et al., 2016; Scheinberg and Simpson, 2015; Valencia, 2019). In some countries in Europe, economic austerity has pushed many people (usually those who belong to marginalised social groups) into the collection of recyclable waste materials from the kerbside, streets, and community bins to earn a living. According to Scheinberg et al. (2016), these informal recycling activities are in conflict with the formal recycling sector that is recognised by governments, packaging recovery schemes representatives and waste management companies. Lifting recyclable waste materials out of the MSW stream, which is unrecorded, creates blind transactions in the system and tampers with governments ability to soundly predict recyclable waste materials recycling performance and its economy (tax

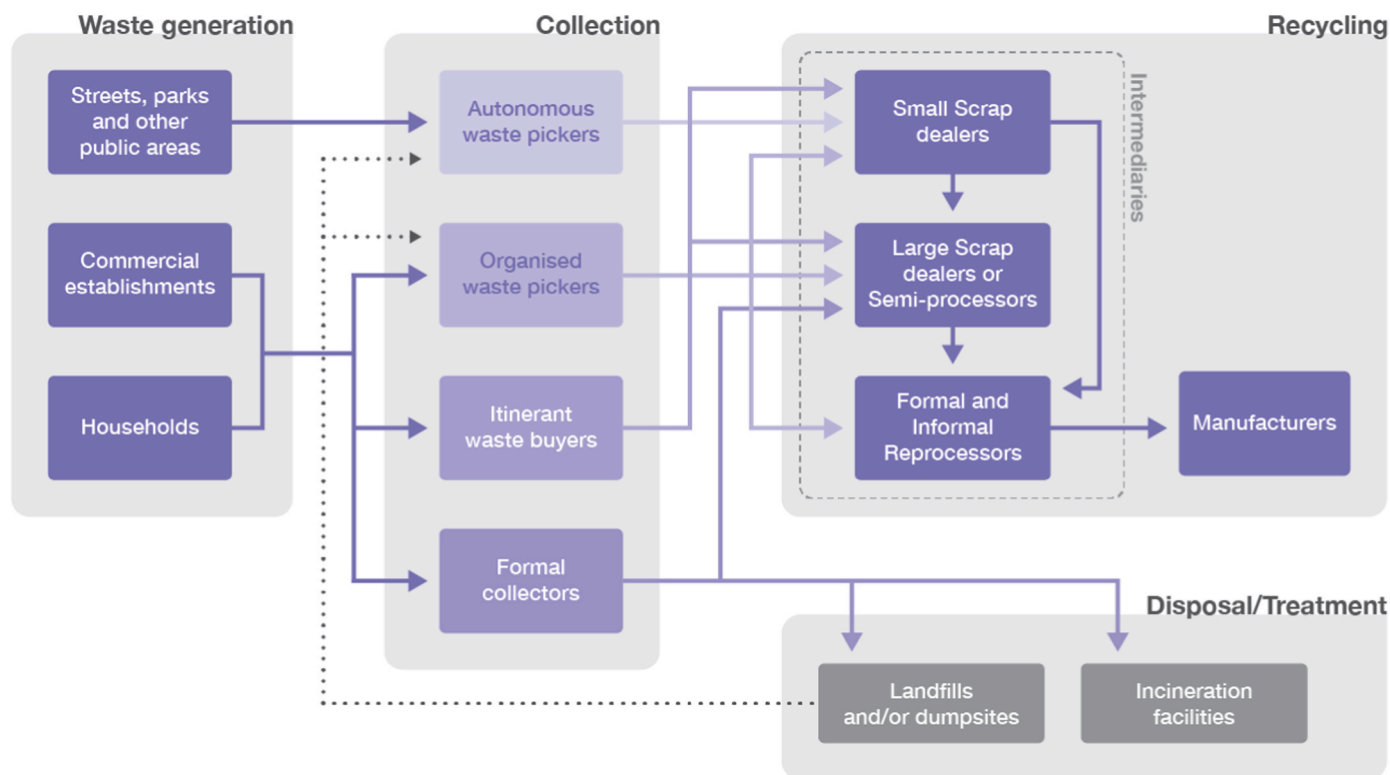


Fig. 2. (continued).

evasion); also, it competes economically with waste collection and disposal services (and the profitability of those). The latter is important in the successful operation of an established recycling value chain, whereas the former is particularly important in monitoring and eliminating fraud and complying with national (or European Union) recycling targets and Extended Producer Responsibility (EPR) schemes for waste packaging (Dahlbo et al., 2018; Diaz and Otoma, 2012; Milios et al., 2018). Public policies attitude concerning informal stakeholders for this recycling chain type would be following the *neglect* kind based on Medina (2005) since these stakeholders are usually ignored by society and LAs.

3.3.2. Type 2: Suppressed informal recycling value chain

Type 2 (Fig. 2-B) represents recycling value chains that are mostly present in Asian, African and East European contexts, such as Serbia, Macedonia, China, Indonesia, Nigeria, Kenya, South Africa, and others (see the complete list in Table S2 in Supplementary Materials). The MSW collection system in Type 2 might be well developed (e.g., Eastern European countries), but the treatment infrastructure might be lacking, hence, there is a large dependence on landfills. Rural populations (and in some cases peri-urban populations too) in these contexts may be inadequately serviced and MSW collection is inexistent. In these areas, the pervasive MSW management activities are usually illegal dumping or open burning (Aslam et al., 2021; Vaccari and Perteghella, 2016). In Type 2 there is formal and informal waste management sectors, both contributing to waste management and development efforts. The main feature of Type 2 is the fact that the state considers informal recycling activities to be illegal and, hence, unacceptable, while it recognises as legal activities carried out by the formal recycling sector only.

Formal MSW collectors can be the LAs that carry waste collection services themselves, or they can be private waste collection and/or waste management companies to whom LAs outsource these services to, as in Mexico (Botello-Álvarez et al., 2018), Malawi (Kasinja and Tilley, 2018), Serbia (Mrkajić et al., 2018) and Indonesia (Putri et al., 2018). Private waste collection and/or management companies collect a fee

from LAs according to the gate fee they pay per tonnage of MSW disposed of on landfills and/or off-loaded to other treatment facilities (i. e., the higher the amount of waste the higher the fee they collect). This creates rebound effects as it: 1) discourages diversion of waste from landfill that gives them the higher fee, hence perpetuates the landfilling of waste and creates a technological lock-in; and 2) incentivises illegal actions such as fly-tipping and dumping by formal waste collection companies to retain the full amount of money paid to them for their services, as in specific cities in India (Sandhu et al., 2017).

Informal ‘collectors’ that operate in a Type 2 recycling value chain include *itinerant waste buyers* and *autonomous WPs*. These ‘collectors’ are individuals, especially the poor, that consider their activities to be a legitimate way of generating an income. They often collect and trade recyclable waste materials at considerable volumes, contributing positively to economic and technical value recovery in the system. However, these informal pickers are regarded to be intellectually and socially inferior and compete with the formal recycling sector. According to Medina (2005), informal stakeholders in these contexts are often manipulated by LAs (collusion) as in China (Steuer et al., 2017) and Pakistan (Masood and Barlow, 2013), or are prosecuted and punished (repressed) as in Mexico (Botello-Álvarez et al., 2018) and for this reason, this type is denominated as the *suppressed informal recycling value chain*.

Itinerant waste buyers differ from autonomous WPs in the method by which they collect recyclables. They buy recyclable waste materials from residential areas and, hence, the public may be responsive towards them (Botello-Álvarez et al., 2018; Sembiring and Nitivattananon, 2010) despite their informality (e.g., one man, a group, or a company). They generate their income via securing a higher selling price for the recyclable waste materials they purchased and they often buy recyclables that can fetch a high market value (Sembiring and Nitivattananon, 2010). They use bicycles, tricycles (Kumar et al., 2018), or small vehicles (Steuer et al., 2017) as a means of transport. Even so, the public’s attitude towards itinerant buyers is negative, as they are perceived to lower the status of a city, which in turn can diminish the attraction of

investments (Sandhu et al., 2017).

Autonomous WPs collect materials door-to-door as in Egypt (Jaligot et al., 2016), from streets and public areas as mentioned for China (Fei et al., 2016; Matter et al., 2015), and from uncontrolled landfills and open dumpsites as in Nigeria (Afon, 2012) and Indonesia (Sasaki et al., 2019). In Type 2 recycling value chains, autonomous WPs are socially excluded and isolated and may have less access to recyclable waste materials (collecting what is publicly and freely available). They are often perceived by the public as illiterate, with poor skills, living and working under poor conditions in unhygienic environments. In general, autonomous WPs are discriminated against due to the stigma associated with their activities which further aggravates their suffering and lack of access to education, health services, and goods (Botello-Álvarez et al., 2018; Sandhu et al., 2017; Sembiring and Nitivattananon, 2010; Steuer et al., 2017).

National and local governments are well aware of the existence of informal stakeholders and their role on MSW recyclable waste management but categorically refuse to recognise their contribution to the economy and society as service providers (Aparcana, 2017; Botello-Álvarez et al., 2018; Mrkajić et al., 2018; Wilson et al., 2006). On the one hand, this is suppressing informal pickers from justifying their existence and leveraging their position in society that would, in turn, improve their quality of life. On the other hand, it diminishes the opportunity for the state to engage these informal stakeholders in productive economic activities that often require less investment than their formal underperforming counterparts. Besides economic implications associated with informal pickers marginalisation, there are also social implications. These relate to public health concerns and the livelihoods of people who rely on waste picking for earning an income, as well as the incompetence of the state to care for these people and cover their needs due to their weak political and economic systems. For example, in Lagos (Nigeria), WPs are vulnerable to work-related accidents and hazards such as wounds from sharp objects, malaria disease, dysentery, burns, skin infections, and many others, and are subject to exploitation by scrap dealers due to a lack of state intervention (Afon, 2012). The transactions between dealers and informal WPs are often built on social and personal connections but occur under terms that meet the interests of dealers, who often exercise power and control (Sasaki et al., 2019).

Small and large scrap dealers, reprocessors, and manufacturers likely operate in a similar manner in Type 2 and Type 3 recycling value chains. Hence, they are discussed after elaborating on the main difference between Type 2 and Type 3 recycling value chains.

3.3.3. Type 3: Hybrid recycling value chain

Type 3 (Fig. 2-C) recycling value chain differs from Type 2 in the way informal WPs are seen by the state and society at large. In Type 3, which prevails in Argentina, Brazil, Colombia, Peru, India, and Bangladesh (see the complete list in Table S2 in Supplementary Materials), informal WPs are recognised by the state and are formalised via urban cooperatives, unions, and public policies. Type 3 promotes inclusivity, with LAs and the general public accepting informal WPs and encouraging them to organise themselves into networks. There is a symbiotic relationship between formal and informal recycling sectors, contributing to the recyclability of waste materials and the development of the economy through combined financial contributions (Aparcana, 2017). In the informal sector of Type 3 recycling value chain, there is *autonomous WPs*, *organised WPs*, and *itinerant waste buyers*. Movements to organise autonomous WPs have started either at the city, regional (province/district), or national levels, and LAs usually try to encourage them to join associations and cooperatives via engaging with them and explaining the benefits of being formalised (Aparcana, 2017). This is a recent, ongoing, dynamic process and therefore this type of recycling value chain (i.e., Type 3) may still include informal WPs that perform their activities outside laws, hence its *hybrid* name.

According to Navarrete-Hernandez and Navarrete-Hernandez (2018), public regulations on informal WPs organisation, capital

acquisition (for personal protection equipment and means of transport), and the reduction of negative externalities (such as, physical health, child labour, waste dispersion, working conditions) help to mobilise WPs into organising themselves with the aim to improve their livelihoods. Several studies point to environmental and economic benefits gained via a reduced competition between formal and informal sectors. Namely, it can reduce the cost of formal waste management (savings from labour, infrastructure, and transport) and improve recycling efficiency in a gradual way (Aparcana, 2017). Concerning the former, Gunsilius et al. (2011) report that informal collection and recycling can contribute to high avoided costs compared to formal waste collection, amounting to 14 million EUR/year in Lima (Peru) and 3.4 million EUR/year in Quezon City (Philippines), whereas in India UNEP and ISWA (2015) reports that informal sector contributes to savings of around 13,700 USD/day for the Delhi and Bangalore LAs (UNEP and ISWA, 2015). In Lusaka (Zambia) the net cost of informal waste collection is only 1.6 USD/ton; 10.4 USD/ton less than in the formal sector. Regarding improving recycling efficiency, UNEP and ISWA (2015) refers to the cases of Jakarta, Delhi, and Bangalore, where informal recycling prevents around 30% (in Jakarta) and 15% of waste from going to landfill (Delhi and Bangalore).

The informal sector integration can bring many benefits to society and the economy, by creating jobs, improving working conditions, reducing the social and professional vulnerability of WPs and other informal stakeholders (Schenck et al., 2019; Valencia, 2019; Valenzuela-Levi, 2020) and possibly diminishing tax evasion and transport/landfilling costs for LAs (Meira de Sousa Dutra et al., 2018; Wilson et al., 2006). The quantities of valuable materials collected by the informal sector reduce costs for the formal sector in labour, transport, and infrastructure (Aparcana, 2017). Other benefits accrued in these contexts can be: 1) learning-related - educating the population to source-segregate their waste; 2) infrastructure-related - providing a location for waste disposal/accumulation and incentivising motorised vehicles for waste collection and personal protective equipment, or equipment (e.g., machinery, tools) for sorting waste; and 3) service-related - providing childcare access to prevent children working as WPs and helping women enrol in sorting and/or reprocessing activities that help them generate an income (Navarrete-Hernandez and Navarrete-Hernandez, 2018).

Latin American countries are leading on the integration of the informal recycling sector in MSW management systems (Aparcana, 2017; Valencia, 2019). Peru issued a solid waste management report in 2009 recognising the role of WPs at the national level and estimating 100,000 WPs (Diaz and Otoma, 2012; Torres and Cornejo, 2016). In 2010, Brazil approved the Solid Waste National Policy that prioritises the inclusion of WPs organisations by incentivising LAs to partner and/or hire them as service providers for separate collection and sorting of dry recyclables (Rutkowski and Rutkowski, 2015). However, since then only 10% of 300,000 WPs have organised themselves in 1232 organisations (associations or cooperatives) and even fewer organisations have been hired as official service providers by LAs (Guarnieri et al., 2020; Rutkowski, 2020). In 2011, the Colombian Constitutional Court decided that separate collection services in residential areas should formally include WPs who are part of a recycling cooperative and since 2016 cooperatives can be paid by their services through municipal waste management fees, however competing with private companies to do so (Márquez and Rutkowski, 2020; Valenzuela-Levi, 2020). In the province of Buenos Aires (Argentina) legislation from 2010 sets diversion from land disposal targets to be done in collaboration with organised WPs (Villalba, 2020). Other countries that include national-level legislation concerning the formalisation of the informal recycling sector are Jamaica, Morocco, India, the Philippines, and Bangladesh (Aparcana, 2017).

Small and large scrap dealers are the intermediate stakeholders in both Type 2 and Type 3 recycling value chains. The formality/informality of scrap dealers is not well discussed in the literature, but some

studies suggest that these are not marginalised in the same way as collectors (Rutkowski and Rutkowski, 2017; Sasaki et al., 2019; Scheinberg and Simpson, 2015). Efforts to formalise these stakeholders remain restrained due to the heterogeneity of these stakeholders in the system (Rutkowski and Rutkowski, 2017), their spatial disparity (Scheinberg and Simpson, 2015), and lack of regulation (Scheinberg et al., 2016). According to Mourshed et al. (2017) in Bangladesh, and Sasaki et al. (2019) and Sembiring and Nitivattananon (2010) in Indonesia, scrap dealers usually buy recyclable waste materials from informal WPs. Scrap dealers may perform some sorting to improve recyclable waste materials quality before trading them, as it happens in Serbia (Mrkajić et al., 2018). Finally, they sell (clean) recyclable waste materials to reproducers or directly to manufacturers (Sembiring and Nitivattananon, 2010).

Reprocessors might do preliminary processing before sending to manufacturers, such as cutting, shredding, washing, cleaning, and drying; especially for plastic materials – as in Bangladesh (Hamidul Bari et al., 2012) and Kenya (Oyake-Ombis et al., 2015). Technologies and machinery vary widely in these contexts: they might be artisanal as in LICs as Bangladesh (Hamidul Bari et al., 2012), Indonesia (Sasaki et al., 2019), and India (Sandhu et al., 2017); or automated as in MICs in China, Indonesia, Nigeria, South Africa, and Brazil (Al-Salem et al., 2009). Countries that may lack the reprocessing infrastructure, such as Mexico (Botello-Álvarez et al., 2018), Egypt (Jaligot et al., 2016), Serbia (Mrkajić et al., 2018), Bosnia and Herzegovina (Vaccari and Perteghella, 2016), usually export the majority of their recyclable waste materials for processing elsewhere. The reprocessing of recyclable waste materials in Types 2 and 3 is seldom regulated, and moreover, there are limited standards and norms for controlling the quality of secondary materials, health safety, and labour (Al-Salem et al., 2009).

Manufacturers - the connecting link between recycling value chains and production - convert materials into a recycled granule similar to virgin materials and often mix it with virgin resins before manufacturing different products. Suthar et al. (2016) describe that paper manufacturers in India use wasted newspapers that have been reprocessed to produce new publications. Similarly, metals' industries in India can melt input wasted materials already clean and well-sorted to produce different products (Suthar et al., 2016). Glass can either be reused as bottles to be refilled with the same products by beverage industries or broken glass can be reused by moulding industries to produce other containers (Suthar et al., 2016). Concerning plastics, there is a greater diversity of possible products manufacturers produce, but most mechanical recycling that has been done has used this type of material for lower quality products, such as in Brazil (Coelho et al., 2011; Rutkowski and Rutkowski, 2017) and Kenya (Oyake-Ombis et al., 2015).

3.4. Overview of the typology developed

Fig. 3 presents the global distribution of the three types of recycling value chains (Types 1, 2 and 3) according to the GDP per capita across the 42 countries included in the analysis. The spread of the typology developed based on GDP per capita is fascinating. As expected, high-income countries usually operate based on a 'solely' formal recycling system as described in Type 1. Surprisingly, this is not the case for Types 2 and 3 recycling value chains which appear to be alienated from GDP per capita trends. For example, Chile, Romania and Argentina are designated as high-income countries, and yet they are operating based on Type 2 (Chile and Romania) and Type 3 (Argentina) recycling value chains. This is probably due to the immaturity of their waste management systems (as opposed to that of the other Type 1 countries) having recently gained their high-income status. Furthermore, their economic development might not have allowed for social inclusion of WPs, forcing them to continue in waste picking activities.

For lower-middle-income countries one may expect that Type 2 would be the prevailing recycling type largely due to their weak political and economic systems, however, this is not the case. Bangladesh, India,

Morocco, and the Philippines are leading by example by gradually changing their MSW management legislation to enable the inclusion of the informal sector in their waste management activities (Aparcana, 2017). The overarching aim of these countries is to recognise and accept informal WPs as part of the economy and society (hence shifting to Type 3) despite their low GDP, as opposed to the majority of countries in this category that operate based on Type 2.

In upper-middle-income countries, Latin American countries lead in efforts of creating an inclusive society (Type 3), an effort initiated not only from WPs themselves but from governments, civil society, and even the industry (Aparcana, 2017; Valencia, 2019). That might be because they have a political system that actively pursues the "social and solidarity economy" and a "participatory sustainable waste management" approach (Aparcana, 2017; Rutkowski and Rutkowski, 2015; Scheinberg et al., 2016; Valencia, 2019). These approaches are aimed at promoting "solid waste recovery, reuse and recycling practices with organised and empowered recycling cooperatives supported with public policies, embedded in solidarity economy, targeting social equity and environmental sustainability" (Gutberlet, 2010: 171). Nevertheless, as mentioned, other countries around the world (such as India) have also begun changing their MSW management legislation concerning including the informal sector (Aparcana, 2017).

Fig. 4 presents a summative overview of the three types of recycling value chains (Types 1, 2 and 3) developed in this study (or prevalence thereof) across the 42 countries that were included in the analysis. It presents their similarities and differences, as well as their performance on the recyclable waste materials collection and management based on formal and informal recycling sectors and illustrates the distribution of each Type around the globe (map).

As shown in Fig. 4, Type 1 recycling value chains can achieve up to 65% MSW collection rate (Scheinberg and Simpson, 2015) which makes this type of recycling value chain look particularly successful. However, it is important to point out two issues with this performance rate. First, some high-income countries consider incineration with energy recovery of MSW (including recyclable waste materials) known as energy from waste (EfW) or waste to energy (WtE), an option that recovers 'value' from waste in the form of electricity (and sometimes heat). While this process can indeed deliver some value from recyclable waste materials, it goes against the circularity principles of "keeping materials, components and products in use" and "designing out waste and pollution" that would have realised recyclable waste materials as secondary commodities that can displace their virgin counterparts. Furthermore, in the official reports (statistics) of countries like the UK and several European countries, recycling/recovery performance is often reported under one figure, making it hard to distinguish what is been directed to mechanical recycling (Hahladakis et al., 2018; Shen and Worrell, 2014). Second, as mentioned in the Type 1 description, most countries in this classification do not have an adequately large reprocessing capacity and therefore, they rely on the trade/export of their recyclables (and especially plastic packaging) to countries that (supposedly) have this capacity. Hence, their reprocessing efficiency is often overreported, as the fate of large amounts of recyclable waste materials shipped for recycling in emerging economies remains largely unknown.

Formal recyclables collection rates for Types 2 and 3 are consistently reported close to 0%. This may be largely attributed to LAs focusing their efforts and investments on reducing open dumping and littering by collecting MSW and disposing of it in landfills. Usually, they do not have technical or economic capacities, or even political will, to create and maintain *municipal recycling programs*. For example, in the 1980s, China's "municipal governments deprioritised waste collection and recycling and shifted respective budgets to increasingly support commercial activities to foster economic growth" (Steuer et al., 2017: 138) resulting in a takeover by informal waste collectors of earlier formal structures. On the other hand, the city of Celaya (Mexico) has more than 160 privately owned sites that buy, store, process, and sell approximately 10% of MSW (Botello-Álvarez et al., 2018).

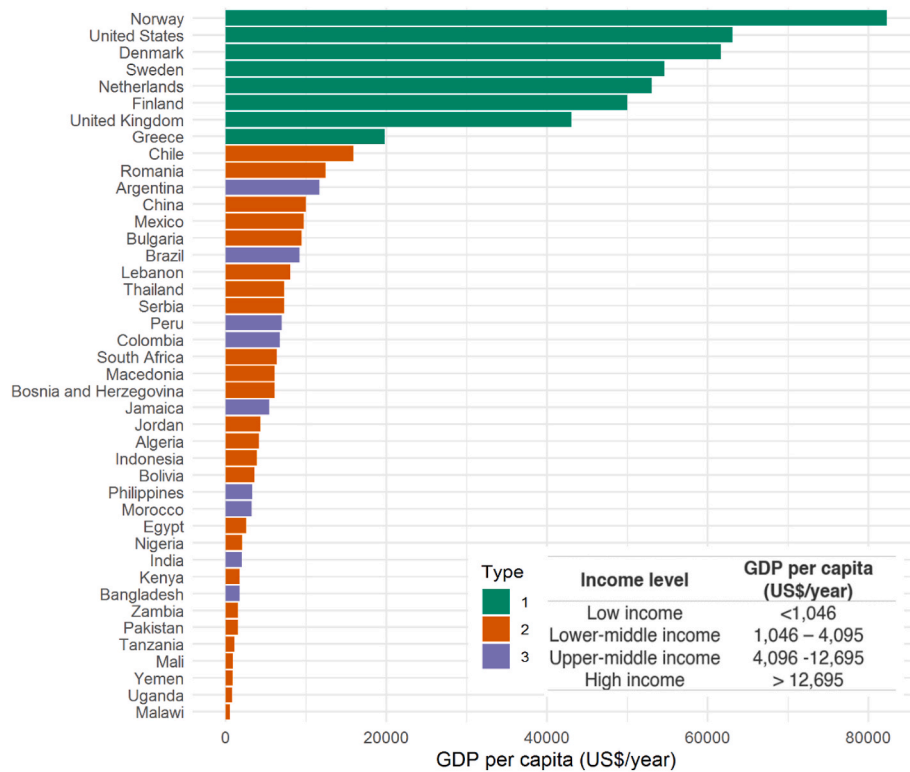


Fig. 3. Typology and Gross Domestic Product (GDP) per capita (US\$/year) of countries identified in this study for 2018. Note: Created based on World Bank 2021–2022 classification.¹¹

Regarding informal recyclable waste materials collection rates, Type 1 studies do not report any figures as activities from the informal recycling sector in these recycling value chains are considered to be negligible. In Types 2 and 3 recycling value chains, they appear to perform up to the same range at around 30%. However, based on anecdotal evidence and personal field experience recycling performance can be higher in Type 3 than in Type 2 because the informal recycling sector is recognised and supported by national and local governments. An inclusive and supported informal recycling network can be operational and stable and it can provide consistent output over time (Navarrete-Hernandez and Navarrete-Hernandez, 2018). In suppressed recycling value chains (Type 2), there could be fluctuations in the recycling performance depending on contextual political, socio-economic, and organisational aspects that may cause multiple disruptions in those systems (Steuer et al., 2017). It is worth mentioning that in countries where Type 2 is the most prevalent type of recycling value chain there is sight of WPs beginning to organise themselves in associations and cooperatives and/or NGOs that try to support the organisation of the informal sector. For instance, informal WPs in:

- Several cities in South Africa - are allowed to collect on landfills (Schenck et al., 2019);
- Blantyre (Malawi) - are incorporated into cooperatives by formalising their operations (Kasinja and Tilley, 2018);
- Greater Santiago de Chile - are allowed to work both as part of a cooperative, as well as autonomously (Navarrete-Hernandez and Navarrete-Hernandez, 2018);
- Serbia - are recognised as a profession (Mrkajić et al., 2018; Scheinberg et al., 2016).

Another observation is that most efforts towards integrating the informal recycling sector and establishing a recyclable trading market are usually unruly and unregulated (Fuss et al., 2021; Meira de Sousa Dutra et al., 2018). To date, there are very few discussions on actions

towards the development of public policies that would support, empower, and encourage collective action among all stakeholders in the recycling value chain. Countries that have legislation and policy measures that seek to integrate the informal recycling sector with formal sector activities have also directed investments towards improving their MSW recyclable waste materials collection (separate collection, also called selective collection) and sorting (usually conceded to organised WPs), which is expected to deliver a higher return on recyclable waste materials recovered from the MSW stream. Nevertheless, this is not reflected in the studies included in this analysis, which may be due to the lack of data robustness in figures reported in most studies, as well as concealed calculations that authors used to arrive at these figures. Henceforth, this makes it difficult to benchmark case studies and compare numbers to aid public policy creation. It must be stressed that some recycling chains depicted and analysed in studies performed years before this review can operate differently today.

4. Conclusions

The study revealed that there is a diverse terminology used in describing recycling value chains that prevent individuals, groups, governments, nations, and the whole world to understand common challenges in improving the circularity of recyclable waste materials. Whereas there are specificities that need to be considered to devise well-targeted solutions in the management of recyclable waste materials, this study theoretically advances literature and contributes to practice by simplifying the way recycling value chains are depicted in different contexts through the development of a typology of recycling value chains. The typology elicits the potential of recycling chains to promote circularity in recyclable waste materials management by providing insights on how different forms of governance (including, structures, processes and social norms) can influence the development and coordination of recycling chains and, by extent, their recycling performance. The prevalence and nature (inclusive vs. exclusive) of informal recycling

	Type 1 – Formal	Type 2 – Suppressed informal	Type 3 – Hybrid
<i>Income level of countries</i>	High	Upper Middle, Lower Middle and Low	Upper Middle and Lower Middle
<i>MSW dry recyclables collection</i>	Formal companies (or municipalities); limited number of autonomous WPs (and other stakeholders) may perform informal collection and trade that is not following formal procedures	Formal companies (or municipalities); non-recognised organisations of WPs; large number of autonomous WPs and other informal stakeholders	Formal companies (or municipalities); recognised organisations of WPs that are embraced by society; autonomous WPs and other informal stakeholders still exist and operate but to a lesser extent than in Type 2
<i>National and/or local government policy concerning IRS</i>	<i>Neglect:</i> Autonomous WPs and other stakeholders are often unaccounted for	<i>Neglect, Repression or Collusion:</i> Autonomous WPs, are often ignored, punished, or exploited; some form of informal WPs group might exist	<i>Stimulation:</i> Recognition of organised WPs; autonomous WPs also exist but are encouraged to join WPs organisations
<i>Formal sector's recyclables collection rate</i>	30 - 65%	0 - 10%	0 - 2%
<i>Informal sector's recyclables collection rate</i>	0%	0 - 33%	2 - 31%

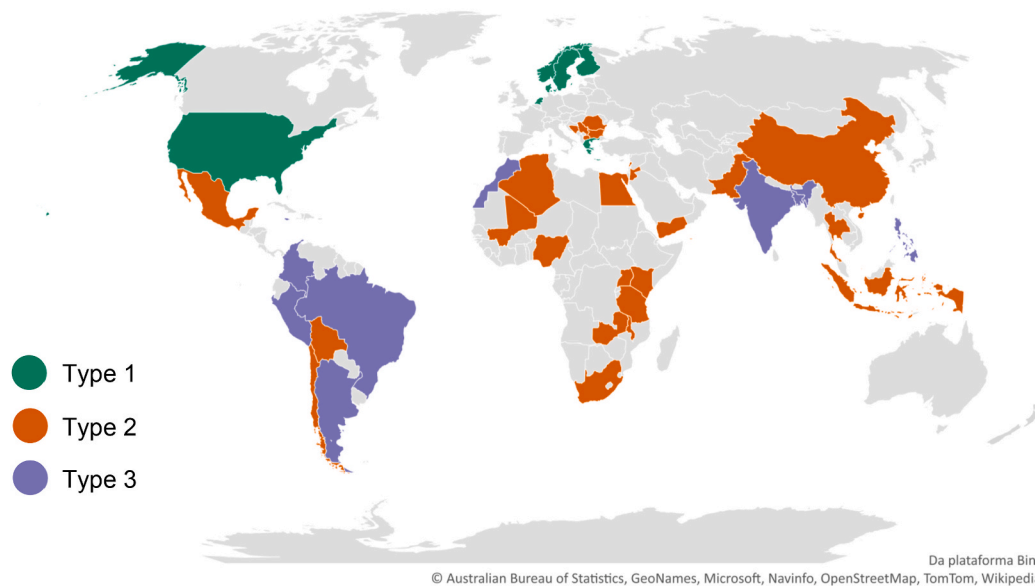


Fig. 4. Typology characteristics and world map of MSW recycling value chains around the world. Note: the number of countries per income class and type can be seen in Fig. S2 in Supplementary Materials and recyclable’s collection rates calculations can be viewed in Table S3 in Supplementary Materials.

chains based on GDP per capita of each country reveals the importance of developing strong governance systems that prioritise social inclusion and cohesion in promoting the circularity of recyclable waste materials,

as opposed to systems based on exclusion and discrimination.

Evidently, recycling value chains are highly complex systems that are built deeply into long-term political (political landscape and regulatory regimes), organisational (financial regulations, tax control, and capital investments), and institutional (social ties, trust, and value regimes) aspects. Obstacles related to terminology and a diversity of definitions in this field, as well as language barriers, present challenges that currently

¹ <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>.

obscure efforts to advance understanding of the deeply embedded factors that influence and affect processes (i.e., value chain activities) and structures (formal/informal networks of stakeholders) involved along entire recycling value chains and their performance. This study contributes to practice via illuminating broadly the political, economic, and social aspects of three prevailing types of recycling value chains and fostering communication via eliminating terminology barriers. It underpins the need to educate, train, support, and empower informal stakeholders within recycling value chains, as they are important contributing parts of society that positively add to economic growth and ultimately to the efforts of transitioning towards a circular economy. A limitation of this study is that there are still many countries pending analysis, which could shed light on additional aspects that may have been missed out. Future research could focus on exploring recycling value chains in countries other than those included in this analysis, tracking various modifications and extensions to the typology developed, and interpreting these via the lens of different forms of governance that further describe and explain each type of recycling value chain and the coordination between networks of stakeholders.

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Declaration of competing interest

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Appendix A. Supplementary data

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