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Current Opinion in Chemical Engineering

Non-household end-use plastics: the 'forgotten' plastics for the circular economy

Kerstin Kleinhans[1,2,3], Ruben Demets[1,2], Jo Dewulf[3], Kim Ragaert[2] and Steven De Meester[1]

It is commonly agreed in the current legislative and scientific discourse that plastics recycling rates should be increased. Many recycling studies are dedicated towards this, but often they focus on post-household plastic waste. Non-household end-use plastics seems to be forgotten in data gathering, policy making and research, but have promising potential for high quality recycling. In this manuscript we bring together the most recent existing literature on non-household end-use plastic waste and offer a framework for shifting future waste management plans to effectively help increasing recycling rates.

Addresses
[1] Laboratory for Circular Process Engineering (LCPE), Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium

[2] Center for Polymer and Material Technologies (CPMT), Department of Materials, Textiles and Chemical Engineering, Faculty of Engineering and Architecture, Ghent University, Technologiepark 130, 9052 Zwijnaarde, Belgium
[3] Sustainable Systems Engineering (STEN), Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

Corresponding author:
De Meester, Steven (Steven.DeMeester@UGent.be)

Current Opinion in Chemical Engineering 2021, **XX**:xx–yy

This review comes from a themed issue on **Frontiers: energy, environment and sustainability: plastics in the environment**

Edited by **Herb Cabezas** and **Sadhan Jana**

https://doi.org/10.1016/j.coche.2021.100680

Introduction

Currently the global average plastic recycling rate is below 20% [1•]. This low plastic recycling rate is widely addressed and targeted for example, in European policy or the U.S. Plastics Pact [2–6]. Increasing plastic recycling rates is important to become a sustainable and resource-efficient society as plastics released in the environment cause environmental problems and the traditional production of plastics is dependent on our fossil fuel reserves [7–9]. The focus of policy guidelines as well as research often lies on post-consumer packaging waste [10], as it is the largest plastic waste stream [7]. In this, the terminology of consumption means household consumption, whereas the ISO definition of 'post-consumer' in fact relates to all activities where waste is disposed by an end-user, including end-users that are for example, companies (industrial waste) or shops (commercial waste).

Post-consumer waste of industrial or commercial origins is quite diverse, in type, composition and level of contamination depending strongly on its disposing entity. However, this waste is significantly different from household waste. Some examples include flexible film that is used as secondary packaging (be it around pallets or for individual items like in clothing shops), EPS for packaging purposes and rigid plastics from temporary products like displays or crates (Pots, tubes, and trays (PTTs), crates, canisters/barrels). Quantities and recycling rates for these specific plastic waste streams are typically poorly reported in scientific and grey literature, if reported at all.

The goal of this manuscript is therefore twofold: firstly, to address the often confusing terminology regarding types of plastic waste and secondly, to review the most recent studies that address quantities, composition, collection, and recycling potential of non-household end-use plastic waste. Additionally, we discuss the bottlenecks and opportunities for this type of plastic waste to contribute to a circular economy for plastics.

Terminology

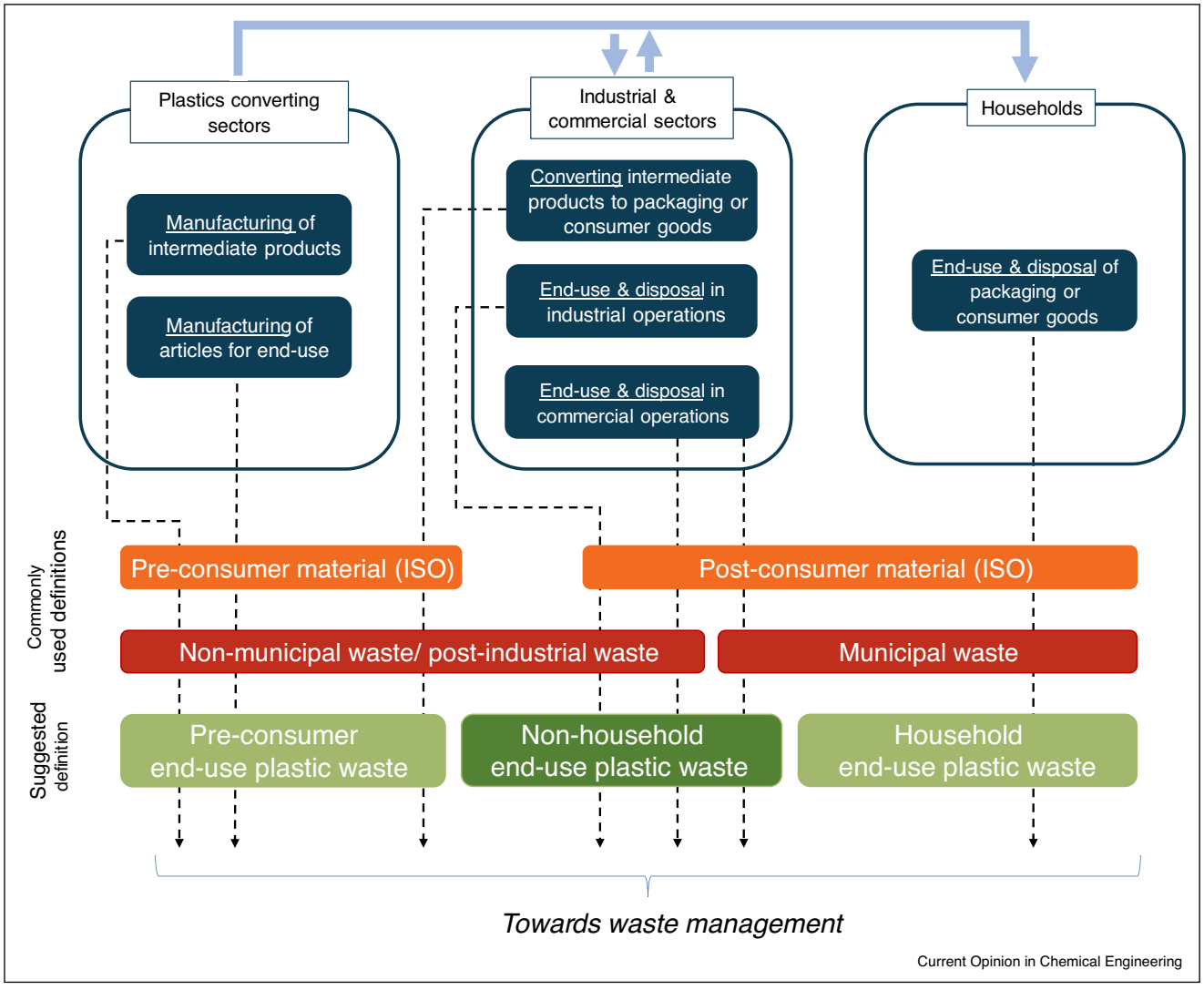
The first issue is that the terminology and commonly used definitions do not specifically address non-household end-use plastics. ISO 14021:2016 distinguishes pre- and post-consumer material [11]. Pre-consumer material, often referred to as post-industrial waste, is defined as 'material diverted from the waste stream during a manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.' [11]. The same ISO norm defines post-consumer material as waste generated by 'end-users such as commercial, industrial and institutional facilities, next to households' [11]. This definition is commonly used, for example, in Eurostat [12] or EPA [13] databases. In parallel, the term *municipal waste* is used to address wastes collected by municipalities no matter the origin (e.g. household, commercial, institutional) [14–

17]. The common terms 'post-consumer waste' and 'municipal waste' are thus a group term for both household and non-household waste. An overview of commonly used terminology can be found in Figure 1.

When looking deeper into these types of waste, we can see that they are inherently different. Plastic waste from households often comprises a complex material mix that is prone to contaminations, as it contains typical products bought for example, in supermarkets as PET Bottles, PET trays, PE bottles, PP bottles and trays, films such as food wraps, and so on. On the other hand, when the end-user is a business, industry or institution, typical plastic waste products are secondary packaging that might be eligible for high end recycling on their own but might not end up in a suitable recycling scheme. Looking to the difference in typology of waste, it can be questioned if they should fall within the same terminological classification, being 'post-consumer'.

Another commonly used terminology is *commercial and industrial (C&I)* waste. This might cause confusion, as pre-consumer waste is also referred to as *post-industrial* waste, which also includes industrial scraps of high purity. In this sense, there is a distinction between industry that produces, and industry that 'consumes'. Following a standardized classification for economic activities, for example, the European 'NACE' codes [https://ec.europa.eu/competition/mergers/cases/index/nace_all.html], plastic producing sectors include amongst others '20.16 Manufacture of plastics in primary forms' and '22.2 Manufacture of plastic products'. All other sectors in fact

Figure 1



Overview of used definitions on the example of plastic waste. Bold arrows represent material flows and dashed arrows waste flows.

consume plastic products from these sectors, which means that other manufacturing business or commercial activities act like end-users of plastic items. As an example, PET-trays and LDPE wrapping film that serves as packaging of car parts in a car manufacturing company and is disposed there, is not post-industrial waste, but should be more clearly classified separately. Therefore, we propose to consistently differentiate between the terminology 'non-household end-use plastics' and 'household end-use plastics'. Note that in this proposed terminology, the term 'consumption' is also replaced by 'end-use', as this seems more suited to capture what happens to plastic as consumption might be more suited for applications such as food.

Quantities

To our knowledge, there is hardly any scientific study with a systematic focus on solely non-household end-use plastics and its potential for the circular economy. The few studies on this topic focus on mixed commercial and industrial waste, including but not limited to plastics. Table 1 gives an overview on the studies available on non-household (plastic) waste typically performed with a specific regional focus.

Already in 2000 it was pointed out that literature with non-household type waste in general is scarce [27]. Several other authors confirm that this waste streams are not well recorded in the EU and that detailed global data are missing [1•,26•,28]. This is said very aptly by De Weerdt *et al.* in a study focusing on the effect of waste incineration taxation by noticing the asymmetry between the limited studies compared to its amounts of waste generation, calling it even 'paradoxical' [29]. This lack of data hinders policy makers to set clear target and recognition of opportunities [26•].

Those presented studies (Table 1) give a first glimpse on the quantities of non-household end-use plastic waste produced, but it remains hard to deduct numbers with great confidence. The scarce data sources indicate that non-household type waste streams, when collected comingled with other materials, have a plastic content of approximately 10–20%. Following the assumption that non-household end-use plastic waste mainly consist of secondary packaging, it allows the estimation based on the study of Hestin *et al.* of 5300 kt/a of non-household end-use plastic waste in the EU [26•]. Transferring the information of Australia (158.8 kt/a C&I plastic waste [1•] with 25.68 M inhabitants) and Germany (1385 kt/a municipal commercial plastic waste [24] with 83.19 M inhabitants) towards EU27 (447 M inhabitants) we estimate 2768 kt/a and 7453 kt/a non-household end-use plastics for the EU27, respectively, which are thus in the same order of magnitude compared to the first estimate based on Hestin *et al.* [26•].

Table 1

Average plastic content reported for non-household waste streams for the last recent years

Plastic content [w%]	Plastic quantities [kt/a]	Plastic quantities per capital [kg/capita·a][a]	Waste type specification according to authors	Region	Year	Source
17.65[a]	–	–	Municipal commercial waste	Austria	2018/2019	Weissenbach *et al.* [18]
–	116.5	10.16[c]	Commercial waste	Belgium	2018	Valipac [19]
10.1	–	–	Commercial waste	Hoi An City, Vietnam	2016	Phu *et al.* [20]
–	291–378	–	Industrial plastic containers and packaging	Japan	2015	Nakatani *et al.* [21]
7	–	–	Commercial and industrial waste	Australia	2013	Bremner *et al.* [22•]
–	158.8	6.18[d]	Commercial and industrial waste	Australia	2015/2016	OECD [1•]
–	736–924	–	Non-consumer	UK	2017	WRAP [23]
~20	1385[b]	16.64[e]	Municipal commercial waste	Germany	2012, 2013 and 2015	Dehne *et al.* [24]
21.8	–	–	Commercial solid waste	Mexicali, Baja California, Mexico	2012	Garduño-P. *et al.* [25]
–	5300[a]	–	Commercial and industrial polyolefin and PET waste	EU	2014	Hestin *et al.* [26•]

[a] Calculated based on information given in the study.
[b] Under doubt of authors.
[c] Calculated based on 11.46 M inhabitants [https://statbel.fgov.be/en/themes/population/structure-population].
[d] Calculated based on 25.69 M inhabitants [https://www.abs.gov.au/statistics/people/population].
[e] Calculated based on 83.19 M inhabitants [https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/].

Table 2

Share of generated type and polymer of commercial and industrial packaging waste in the EU (2014) by Ref. [26•]. All values in [%]

	Share	PET	HDPE	LDPE	PP
Bottle/flask	24	9	86	/	5
PTTs	18	27	32	0	41
Films	58	1	0	83	16

Eurostat gives additional information on the origin of plastic waste by NACE activity in the EU27 [30], that can be found in the Supplementary Material Figure 1. Overall, 13 850 kt/a plastic waste from commercial or industrial origin are reported compared to 16 800 kt/a from households. The sectors C (Manufacturing) and G-U (Services) are reported to produce the largest amounts of plastic waste. For the manufacturing sector (C), data for additional 10 subsectors are available, whereas 'Manufacture of chemical, pharmaceutical, rubber and plastic products' (NACE 20-22) with 41.83%, 'Manufacture of food products; beverages and tobacco products' (NACE 10-12) with 19.69% and 'Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment' (NACE 26-30) with 14.09% are the three biggest plastic waste producing sectors.

Assuming that plastic waste reported for the NACE sectors E (Water supply; sewerage, waste management and remediation activities), G 46.77 (Wholesale of waste and scrap) and 20–22 (Manufacture of chemical, pharmaceutical, rubber and plastic products) does not fall under our definition of non-household end-use plastics the expected plastic quantities for the EU27 would reduce to 6310 kt/a that comes close to the estimation of 5300 kt/a by Hestin *et al.* [26•] who only accounting for packaging material.

There is the indication from a Belgian study [https://www.valipac.be/nl/waar-belandt-ons-bedrijfsmatig-plastic-verpakkingsafval-uiteindelijk/] that more than 50% of non-household plastic waste is exported outside of the EU. WRAP confirms this and gives an indication that the amounts estimated could be even higher than 50% [23]. Exported plastic waste and landfilling can be identified as one of the main pathways that release plastics towards the environment, for example, as ocean debris [31].

Composition

The recycling potential for plastics is, among others, dependent on the polymer types and contamination levels present in the waste stream [32]. Diving deeper into compositional data of non-household end-use waste, big varieties can be noted in the share of plastic, explained by the diversity of types and size of the businesses [18,33••]. Hestin *et al.* [26•] report specifically a share of 58% film, 24% bottles and flasks and 18% of Pots, Tubes and Trays (PPTs) in European commercial and industrial plastic packaging waste, see Table 2. Dehne *et al.* confirms that film and rigid plastic are the biggest types in municipal commercial waste [24].

Table 3

Waste stream sources of recyclate [kt/a] in Australia by polymer type (2015–2016) [1•]

Polymer	Municipal		Commercial and industrial	
PET	64.20	40%	8.40	5%
PE-HD	63.90	40%	31.00	20%
PVC	1.60	1%	2.70	2%
PE-LD/LLD	2.80	2%	66.00	42%
PP	19.00	12%	21.40	13%
PS	4.10	3%	4.10	3%
PS-E	0.10	0%	7.80	5%
ABS/SAN	–	0%	4.00	3%
PU	–	0%	6.20	4%
Nylon	–	0%	0.50	0%
Other	5.50	3%	4.20	3%
Unknown polymer	–	0%	2.50	2%
Total	161.2	100%	158.8	100%

A study from the United Nations Environment Programm reports that non-household end-use plastics mainly comprises PE, PP, PS and PVC [35]. This can be confirmed by other authors and the fact that these polymers make part of the biggest types of polymers produced [1•,21,23,26•,34]. Hestin *et al.* [26•] provides information on the share of polymer type per type that can be found in Table 2. Next to that, Table 3 gives data on the share of polymer type in C&I waste in Australia [1•].

Collection

The collection rate of commercial and industrial plastic packaging waste in the EU is stated to be 39% [26•]. Collection costs of non-household waste are significantly lower compared to post-household waste as there are more consistent and the amounts are generally large [28,35]. According to ongoing research and expert judgment from recyclers and collectors, it can be stated that significant amounts of non-household plastic waste still end up in the residual bin, especially from small and medium-sized enterprises (SMEs). Companies state that they either do not know other collection systems, think their waste amounts are insignificant or think that it is more convenient than a source separated collection. In comparison to post-household waste, the collection is often done by private operators instead of being organized by the local municipalities. Plastic waste from the commercial sector and SMEs, in contrast, might also be collected via a municipal collector but often as part of a mixed residual waste fraction [27]. Furthermore, they

are not always prone for the extended producer responsibility (EPR) schemes [26•]. Both these points have as consequence that data on these fractions is not systematically monitored per region and producing sector [26•,35].

Potential for the circular economy

Studies on the recycling potential of non-household end-use type materials are likewise scarce [36]. Whole fractions of *mixed* commercial waste, like plastics, could in fact be recyclable but due to technical issues (e.g. disassembling of composites) or contamination this is not economically feasible [18]. Therefore it is commonly used as solid recovered fuel (SRF) thanks to high caloric value and low water content [18,37].

To our knowledge, there are no studies yet on the recycling potential merely focusing on non-household end-use plastics. Some sources state that this waste tends to be of higher quality compared to household plastic waste [1•,26•]. According to the author's experience, this valuable material is often downgraded by mixed collection, which significantly contaminates the 'cleaner' plastics, turning recyclable plastics into residual waste.

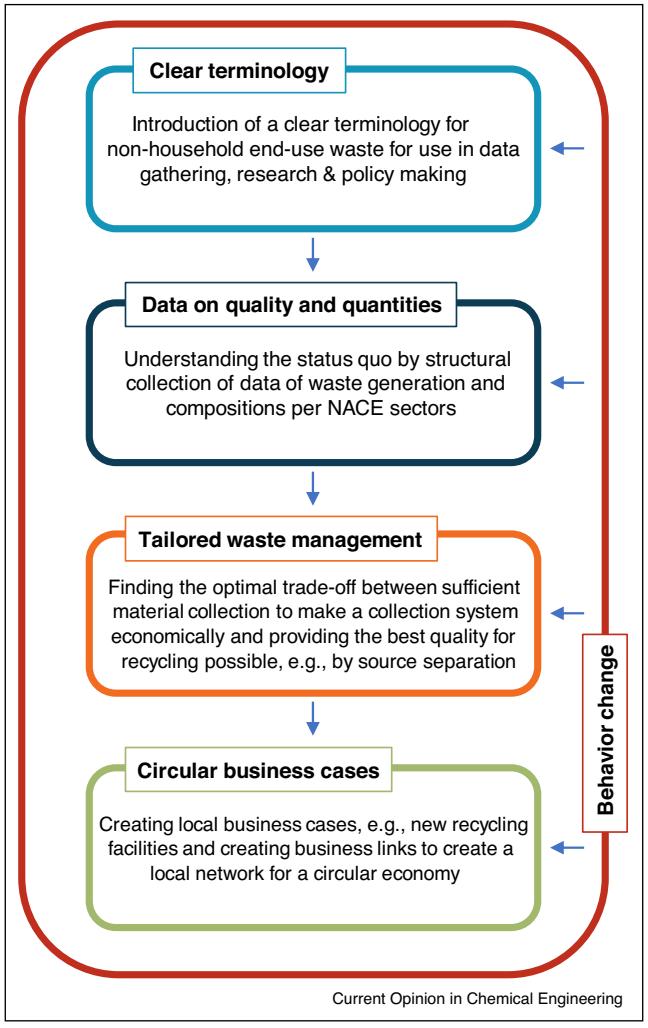
Analyzing the studies discussed in Sections 'Quantities' and 'Composition' gives a glimpse on the quantities of non-household end-use plastic, which can give a first estimation on their potential contribution to the circular economy. Knowing that total post-consumer plastic waste generated in the EU28 + NO/CH is 29.1 M t/a [34] or 23.7 M t/a in the EU27 [30], the quantities estimated in Section 'Quantities' (2–7 M t/a) shows that the non-household plastic waste is expected to contribute somewhere between 10–30% of the recycling rate of the EU, and it thus has a big potential to reach the ambitions plastic recycling targets of the EU and beyond. These numbers have a focus on the EU, but it is expected to be in the same order of magnitude for other areas such as the USA or Southeast Asian (data for plastic content in MSW for example, to be found in Refs. [38] or [39]).

Discussion

Based on the above findings we introduce the term 'forgotten plastics' for non-household end-use plastic. Generally, industrial actors and some policy makers are well aware that these waste streams exist, yet these potentially highly recyclable plastics typically disappear in the overall waste statistics and consequently, policies, and scientific research does not address it separately, also caused by the lack of data. Literature indicates that in terms of quantity and quality they could significantly contribute to the circular economy for plastics.

To give non-household end-use plastic waste a chance to become part of a circular economy, the lack of data and the related of lack of attention that has been lasting for a few decades [23] has to end. We therefore propose a strategy to mitigate the current status quo of recycling non-household end-use plastic waste, which is depicted in Figure 2.

Figure 2



Flowchart suggestion to bring focus on non-household end-use plastics in the future. Blue arrows indicate co-dependencies.

First, a *clear terminology* has to be introduced that allows setting the right focus on data collection, research, and policymaking. We propose to systematically subdivide the ISO definition of post-consumer waste into household and non-household material and thereby acknowledging the difference in origin, composition, and recycling potential.

Secondly, to mitigate arguments on the economic feasibility of recycling these non-household fraction, a *structural collection of data* on quantities and qualities has to be done based on the terminology as described above. Thereby it is crucial to analyze different sectors

separately by for example, using a NACE classification. Gathering data on this type of waste will be a challenge, as a statistically relevant number of business should be analyzed, preferably per NACE code to gain insight in the diversity of this type of waste. Furthermore, there is also a diversity within each NACE code related to for example company size. Data should thus preferably be analyzed per NACE codes and expressed as waste per employee or per turnover [33••]. Data on composition up to polymer level is lacking as well, despite this being crucial information for high-end recycling solutions.

Thirdly, based on this data *tailored waste management solutions* that find an optimal trade-off between collecting sufficient tonnages to be economically feasible but also providing highest qualities possible should be introduced. Some streams might be sufficiently clean to reprocess as such, whereas others need to be kept separate. Based on the experience of the author team, we tend to believe that it will be difficult to achieve the same qualities when performing post-separation instead of source separation, even with state-of-the-art technology. We encourage putting future research focus on this. Extended studies on lumping strategies of different kind of substreams (e.g. per sector, per polymer type, per contamination level) of non-household end-use plastics to optimize the trade-off between quality and quantity are needed. In this sense, lumping can be defined as the investigation on which plastic waste streams can be mixed or absolutely need to be excluded during collection and recycling to ensure best recycling quality possible. This can depend, amongst others, on polymer types, contamination level and quantities.

Further, we are convinced that especially urban areas have a big potential for developing tailored collection solutions due to the high density of business activities. Moreover, innovative, and sustainable collections solutions, for example, reverse logistics, electronic vehicles or transport bicycles should be investigated. Also introducing EPR schemes specifically for non-household end-use could provide more pronounced financial incentives [26•].

This steps can be the starting point to also find linkages between industries, like recommended by Chertow *et al.*, to *create circular business cases* [40]. To reach this, studies like Bremner *et al.* or Patricio *et al.* for multiple business sectors with focus on plastic waste should be conducted [22•,33••]. The purpose of a circular economy for plastics, and thus for circular business models, is to maintain products and materials in the loop through several value-preserving cycles, such as repair, reuse, remanufacturing and recycling [9]. This can be done by tailoring business models and product design, amongst others, but since plastics often move fast through the value chain it might be important to apply for example, quadruple helix approaches to reach a broader group of stakeholders [9] Lüdeke-Freund give a comprehensive review on existing circular business models in literature and conclude that six major patterns for circular business models are: 'repair and maintenance; reuse and redistribution; refurbishment and remanufacturing; recycling; cascading and repurposing; and organic feedstock business models' [41]. Accenture strategy (2014) identifies the following five circular business models as most promising: resource recovery, product-service systems, product-life extensions, sharing platforms and circular value chains [42]. Especially the latter ('circular value chains') can be promising as local business cases for non-household plastic waste, for example, in forms of a local plastic hub with product makers and waste owners that share the (positive and negative) value of the circular plastics. All this is not possible without *behavior change* of businesses and business cases. Being open for setting up a recycling system for plastics in business, using more materials with recycled content or using recyclate in one's own production, needs engaged decision makers in the businesses. A recent study by Khan *et al.* analyzed the barriers and drivers towards recycling in several businesses [43]. They conclude that there is an intention-behavior gap: businesses have positive intentions towards best practices in plastics recycling but seem to fail to implement these. They recommend that governments have to offer incentives, disseminating knowledge, and creating networking platforms for collaboration among decision makers to overcome this [43].

Conclusions

Because of the lack of clear terminology and the commonly used division in pre-consumer and post-consumer waste, end-use plastic waste from non-household origin is not sufficiently addressed in policy making, data gathering nor in research, despite its high potential for recycling. Therefore, we address them as the 'forgotten plastics of the circular economy' and introduce the term non-household end-use plastic.

The limited number of current studies on quantities of non-household waste like streams indicate to have a plastic content of around 10–20%. We estimate a range of 2800−7500 kt/a of non-household end-use plastic waste in the EU, but this is prone to high variations as it depends on the number, type, and sizes of businesses. Non-household plastics can thus probably contribute by 10–30% to recycling rate targets and thus play an essential role in the circular economy.

Nevertheless, overall data availability is poor [1•,26•,27–29]. This holds also for compositional analyses. Only a few studies show that the main polymers in non-household end-use plastic are of PE, PP, PS and PVC and the biggest waste type is film material (58% according to Ref. [26•]), yet from a different typology compared to household plastic waste. Non-household end-use plastic from SMEs are often collected as a mixed waste fraction and which

decreases its potential for qualitative recycling as the separate waste stream would usually contain less contamination compared to household waste.

Non-household end-use plastic streams can play an important role to increase overall plastic recycling rates. To do so, it has to be brought into the picture of policy makers, statistical institutes, and research, by introducing clear terminology, structural data gathering, tailored waste management solutions and the creation of circular business cases. Moreover, general behavior changes of business play a roll into all these points.

This review hopes to have sufficiently highlighted these 'forgotten plastics' as a subject for further research and policy making.

Conflict of interest statement

Nothing declared.

CRediT authorship contribution statement

Kerstin Kleinhans: Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Ruben Demets:** Conceptualization, Writing - review & editing. **Jo Dewulf:** Conceptualization, Writing - review & editing, Supervision. **Kim Ragaert:** Conceptualization, Writing - review & editing, Supervision. **Steven De Meester:** Conceptualization, Writing - review & editing, Supervision, Project administration.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.coche.2021.100680.

Acknowledgements

We thank the Interreg 2 Seas program *PlastiCity* that is co-funded by the European Regional Development Fund under subsidy contract No. 2S05-021 and the province of East-Flanders for funding this research.

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- •• of outstanding interest

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