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Revealing the management of municipal textile waste and citizen practices: The case of Catalonia

Gemma Morell-Delgado [a], Laura Talens Peiró [a,*], Susana Toboso-Chavero [a,b,c]

[a] Sostenipra Research Group (2021SGR 00734), Institut de Ciència i Tecnologia Ambientals (ICTA-UAB, 'Maria de Maeztu' unit of excellence CEX2019-000940-M), Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Barcelona, Spain

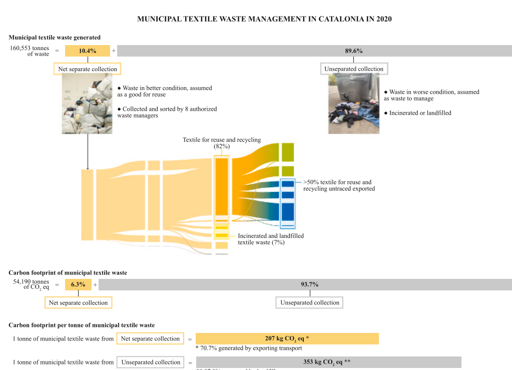
[b] Rotterdam School of Management, Erasmus University Rotterdam, Rotterdam, the Netherlands

[c] Integral Design and Management, Department of Materials, Mechanics, Management & Design, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands

HIGHLIGHTS

- Citizens assume specific textile waste containers for reuse rather than recycling.
- Textile waste containers collect municipal textile waste in better condition.
- Separate collection of textile waste emits 40 % less CO_2 eq than no separation.
- About 90 % of municipal textile waste from Catalonia ends up incinerated/landfilled.
- In Catalonia, at least half of textile for reuse and recycling is untraced exported.

GRAPHICAL ABSTRACT



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ABSTRACT

Although the number of studies assessing the textile sector is increasing, only a few focus on its waste management. This study aims to shed light on current textile waste disposal practices and account for their environmental impact. To do so, a combination of citizen surveying and environmental quantitative tools, such as material flow analysis and life cycle assessment, are used to assess municipal textile waste in Catalonia in 2020. The results show that only approximately 10 % of municipal textile waste is separately collected, while 90 % is landfilled/incinerated. Of the 10 % of textiles collected separately, almost 40 % are prepared for reuse and recycled in Catalonia and Spain, approximately 40 % are exported for reuse and recycling in Asia, Africa and the rest of Europe, and the remaining 20 % are incinerated or landfilled, stocked or treated as improper waste. The carbon footprint generated by 1 t of textile waste managed by unseparated collection is 353 kg CO_2 eq, which almost double that of 1 t of textile waste collected separately: 207 kg CO_2 eq. The results also show that the emissions of textiles collected separately could be considerably reduced by minimizing their exports. The conclusions indicate that a proper course of action includes raising awareness about textile waste management and secondhand buying habits among citizens while investing in better sorting and local recycling technologies to

* Corresponding author.
E-mail address: laura.talens@uab.cat (L. Talens Peiró).

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reduce exports. Identifying the existing limitations to creating a local reuse and recycling textile sector is crucial to reduce its carbon footprint.

1. Introduction

In recent years, the textile sector has become very popular among environmental concerns, as it is estimated to account for 10 % of global carbon dioxide (CO_2) emissions (Juanga-Labayen et al., 2022; Niinimäki et al., 2020). Extensive data exist about the environmental impacts generated in the production, consumption, and use stages of clothing (Daystar et al., 2019; Ellen MacArthur Foundation, 2017; Global Fashion Agenda and The Boston Consulting Group, 2017; Gözet et al., 2021; Niinimäki et al., 2020). In 2018, the major greenhouse gas (GHG) emissions of textiles were related to the production of materials (38 %), the energy for dyeing and finishing textiles (29 %) and the energy for laundering during the use phase (20 %) (McKinsey and Company and Global Fashion Agenda, 2020). These emissions will continue to rise in the future unless prevention measures are put in place (Boykoff et al., 2021; Niinimäki et al., 2020).

To prevent these emissions, improvements in the production and use stages are necessary, as well as in other life cycle stages such as waste management. McKinsey estimated that the end-of-use phase contributed 3 % to the overall GHG emissions (McKinsey and Company and Global Fashion Agenda, 2020). However, other authors suggest that improved management of textile waste (TW) could contribute more importantly to reducing the overall environmental impacts. For instance, reuse practices could reduce the production of textiles from raw fibres and thus their related energy use (Sandin and Peters, 2018). An increase of 12 % in reuse and 15 % in recycling should reduce climate change impact by 8 % in the European Union (EU) (Beton et al., 2014). Most importantly, reuse and recycling practices could contribute to reducing the amount of TW to landfills and incineration. Therefore, a more complete and comprehensive analysis of the management of TW at the end of life (EoL) to understand the feasibility of improving reuse and recycling is necessary to reduce the environmental impacts across the entire value chain (Nencková et al., 2020).

The availability of data on the EoL routes for textiles is limited (Beton et al., 2014; Van Rensburg et al., 2020). Understanding the management of TW, including sorting, reusing, and recycling, is key to identifying potential areas of improvement and shedding light on the current environmental impacts generated by the sector (Nørup et al., 2018). Accounting for environmental impacts is also relevant to emphasizing the need to increase current TW collection rates, reducing the amount of clothes to landfill/incineration, and generating a behavioral change to reduce the amount of purchases and to optimize the use of clothes (Juanga-Labayen et al., 2022).

TW is generated at different life cycle stages across the value chain of textiles. Indeed, one of the difficulties when considering TW is the lack of a harmonized definition (Palma et al., 2023). Juanga-Labayen et al. (2022) define TW as "discarded or unwanted material from the production and use of fiber, textile and clothing, which can be categorized into three types, pre-consumer, post-consumer, and industrial textile waste" (Juanga-Labayen et al., 2022, p.176). Postconsumer TW includes all types of garments (mainly clothes and footwear) and house/interior textiles (bedlinen, towels, tablecloths, curtains, etc.) (Domina and Koch, 1997). Postconsumer TW is also the main typology in municipal TW (MTW).

The management of postconsumer TW in EU countries remains a novel unexplored topic (Nørup et al., 2019). Its separate collection system is not yet harmonized across the EU (Palma et al., 2023). Indeed, most postconsumer TW is collected along with mixed municipal waste (Gözet et al., 2021). As a result, it is estimated that 73 % of postconsumer TW is burned or landfilled (Ellen MacArthur Foundation, 2017). The remaining amount is declared to be prepared for reuse or recycling, although most of it is downcycled. Interviews with experts and some technical reports estimate that <0.1 % of postconsumer TW is effectively reused and recycled by the fashion industry itself (Ellen MacArthur Foundation, 2017). In developed countries, textiles that are defined as 'prepared for reuse' and recycling are normally exported to low-middle income countries (Lu, 2019), such as Africa for reuse and Asia for recycling (Sheng, 2015). The amount of exported textile effectively reused and recycled and the amount directly landfilled are uncertain (Cobbing et al., 2022). Overall, the information consulted suggests mismanagement of postconsumer TW according to the waste prevention hierarchy defined in 2008/98/EC (European Parliament and Council of the European Union, 2008). The lack of proper TW management results from poor information about the most appropriate management practices and influences citizen practices in TW disposal (Coskun and Basaran, 2019; Laitala, 2014; Rotimi et al., 2021). Additionally, MTW managers present difficulties in accurately and efficiently managing input and output flows (Kazancoglu et al., 2020). In general, postconsumer TW remains an untapped resource in EU countries.

In light of the above information, it is necessary to develop a more accurate analysis of the EoL management of MTW, as mentioned in the EU Strategy for Sustainable and Circular Textiles (European Commission and Directorate-General for Environment, 2022). Such a study will help understand the current practices for its disposal, collection and treatment, as well as identify potential improvements. This is especially relevant since MTW will be separately collected in the coming years, as announced by the European Commission (European Commission and Directorate-General for Environment, 2020; Jefatura del Estado, 2022). Improvements in current waste management systems depend not only on technical aspects but also on citizen engagement for their effective implementation. As a result, a combination of social and environmental methodologies is proposed to respond to two specific research objectives. First, a survey campaign is developed to obtain a better understanding of current citizen practices on MTW disposal in Catalonia. The outcome aims to identify the existing difficulties in increasing the current separate collection rates and minimizing the amount of TW in unseparated MTW (UMTW). Second, a combination of material flow analysis (MFA) and life cycle assessment (LCA) is performed to quantify the MTW flows and their respective environmental impacts. The results are later used to discuss the need to advance towards harmonized collection systems for TW, especially as their amount is expected to increase as a result of new regulation in the EU. Additionally, we provide a first estimate of the carbon footprint of the current TW management.

2. Materials and methods

2.1. Case study: MTW management in Catalonia

MTW in Catalonia, a region in northeastern Spain, is collected in separate MTW (SMTW) containers in the street and civic amenity sites managed by local entities. MTW disposal in SMTW containers and civic amenity sites is considered a correct source separation practice. Also considered a correct source separation practice is the recirculation of TW via donations between acquaintances or NGOs, second-hand selling, and other citizen-driven initiatives contributing to the lifespan extension of textiles. However, these flows are not captured by official municipal solid waste (MSW) system statistics. Therefore, these practices have been excluded from the scope of the study. MTW occurring in the mixed municipal waste with code 200301 (Eurostat, 2010) and other fractions as organic or packaging—this is UMTW—is considered an incorrect disposal practice as UMTW directly ends up burned or landfilled. In Catalonia, according to data from 2020, SMTW formal collection and sorting was developed by eight authorized managers to carry out such management: Cartaes, Ecosol, Emaús, Engrunes, Formació i Treball, Humana, Roba Amiga and Solidança (Agència de Residus de Catalunya, 2020a). MTW in Catalonia is managed by independent private organizations—many of which are socially based (Rezero, 2018)—as there is no Extended Producer Responsibility (EPR) scheme specific for TW in place. Citizens consider collection through private social organizations a charitable gesture instead of a way of reusing or recycling textiles (Generalitat de Catalunya, 2022).

According to the latest MSW data for Catalonia, MTW represents 4.11 % of the mass of the total waste contained in an MSW reference bag (Generalitat de Catalunya Departament de Territori i Sostenibilitat and Agència de Residus de Catalunya, 2014). In 2019, Catalonia generated 165,993 t of MTW (21.6 kg/inhabitant), but only 18,521 t (2.4 kg/inhabitant) were collected via SMTW collection systems (Llorens, 2020). Therefore, from all MTW generated in Catalonia, 88.8 %—which is UMTW—ended up mixed in other fractions, consequently not separately collected and sent to landfill or incineration (Llorens, 2020). UMTW is primarily present in the mixed-fraction, followed by the organic fraction, the packaging fraction, and less commonly, others (Agència de Residus de Catalunya ARC, personal communication, June 11, 2022). These data highlight the lack of systems improving MTW capture and information helping citizens make a more appropriate decision when discarding MTW, although the Waste Directive 2018/851 sets that all Member States must ensure separate collection of textiles by 2025 (European Parliament and Council of the European Union, 2018). Moreover, previous studies have already investigated citizens' behaviour and management of MTW at a regional level and highlighted low collection of SMTW as a key factor influencing the environmental impacts of the textile industry (Laitala, 2014; Nencková et al., 2020; Polajnar Horvat and Šrimpf Vendramin, 2021). Analogously, this paper aims to shed light on MTW management practices by citizens in Catalonia.

According to Nohales (2021), in Catalonia, 71 % of the SMTW was prepared for reuse, 23 % was recycled, and 6 % was valorized via energy recovery or landfilling in 2019. However, Llorens (2020) interviewed MTW managers who highlighted that SMTW output percentages may have changed in recent years. Tracing these flows and their verification remains difficult, if not impossible. Data from the ARC (Catalan Waste Agency) (Nohales, 2021) together with current TW management practices in developed countries illustrated in the literature available lead this research to deduce that a significant amount of SMTW generated in Catalonia is exported to low-middle income countries. Accordingly, the second part of this study quantifies the SMTW flows with special attention to the waste hierarchy and the first destinations after MTW sorting plants. This is done by combining material flow analysis (MFA) and life cycle assessment (LCA) methodologies. MFA is used to quantify the flows of SMTW across the diverse EoL management stages. LCA is applied to evaluate for the first time the potential global warming emissions, given as CO_2 equivalents, generated by the current management of MTW in Catalonia. Outputs of this study could contribute to the current development of the Catalan Circular Fashion Pact (Generalitat de Catalunya, 2022), which is of utmost importance in Catalonia.

2.2. Social and environmental analyses

As shown in Fig. 1, the initial steps of the method started by conducting bibliographic and field research on TW management. This was useful to set the basis and the framework of the study. As part of the field research, numerous actors involved in MTW management were contacted and interviewed (see Fig. A1 in the Supporting Information SI). Two quantitative analyses were combined to draw some initial conclusions about the EoL management of MTW in Catalonia. The first analysis consisted of a statistical analysis of the results obtained from a survey about MTW disposal practices by citizens. It helped determine citizens' awareness and practices when discarding MTW for its possible reuse and recycling. This information could help managers predict future MTW and SMTW flows. The second analysis used the environmental assessment tools MFA and LCA to analyse data declared by MTW managers available in the Annual Waste Declaration for Managers (DARIG) for 2020. The combination of MFA-LCA helped quantify the significance of MTW flows and their potential global warming emissions due to current MTW management practices. Both methodological approaches helped to obtain a more complete view and understanding of current practices of MTW management in Catalonia and to identify potential hotspots of improvement. Their combination represents a novel framework applicable to other waste streams likely to be collected separately in the future.

2.2.1. Statistical analysis of current social practices of MTW management

A survey was conducted to learn about the current practices of MTW management performed by citizens in Catalonia. Similar studies at a regional scale had previously been developed. Polajnar Horvat and Šrimpf Vendramin (2021) and Zhang et al. (2020) were used as a reference to create the questions and answers of the survey developed for this analysis. The study by Nencková et al. (2020), which presented an extensive statistical methodology, was also used as a reference analysis. The resulting survey (Section B from SI) was made available via the EUSurvey online platform (European Commission, 2022) and was answered by 1469 anonymous respondents.

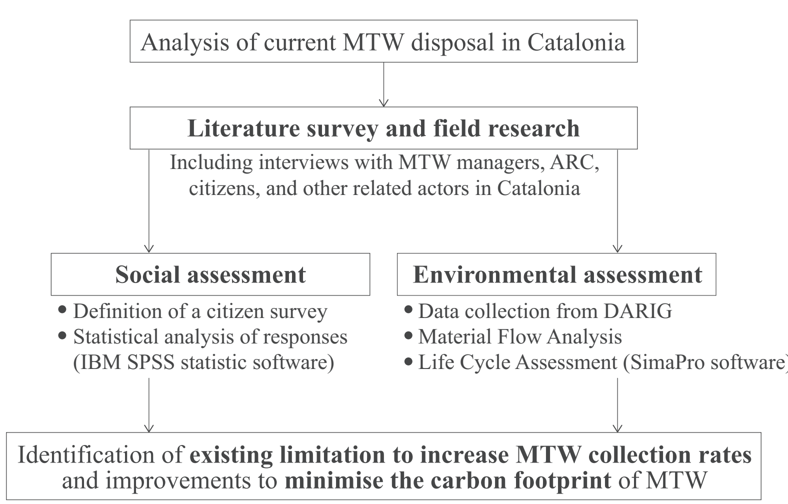

Fig. 1. Methodology used to assess the management of MTW and citizen practices in Catalonia.

The questionnaire was grouped into three parts. The first part was introductory and focused on the environmental concern of respondents (Table C1 of the SI, questions with codes F and G). The second part highlighted MTW disposal practices and awareness (Table C2 of the SI). The third part included a set of questions about demographic data of the sample for further statistical analysis (Table C1 of the SI, questions with codes A, B, C, D and E). The questions of the first part were also evaluated as demographic data, while the questions of the second part were displayed separately on the computer/mobile screen, so respondents could not read them all at a time. This strategy was used to reduce the influence on the tone of the following questions.

All responses were processed and analysed with IBM SPSS statistics software (IBM Corp, 2021). Frequencies and percentages were calculated for every question (Tables C1 and C2 of the SI). Answers from multiple choice questions were evaluated and grouped to obtain a single choice structure (Tables C3, C4, C5 and C6 of the SI). Contingency tables between pairs of questions were created by coupling demographic variables with the questions relating to disposal behaviour. Relationships between these pairs were verified by the Pearson chi-square test (χ^2) using the Monte Carlo method, as data were too large to calculate the exact p value, while it did not meet necessary assumptions for the asymptotic method. Therefore, the Monte Carlo method with a sample size of 10,000 and a confidence level of 99 % provided unbiased estimates of exact p values. Pairs of questions were statistically significant when p values were < 0.05. To detect the nature of dependency between variables from a statistically significant pair of questions, cell-by-cell comparisons of p values were calculated from standardized residuals following (Agresti, 2002; Nencková et al., 2020).

2.2.2. Environmental analysis of MTW

A combination of MFA and LCA was used to quantify the amount of MTW from MTW sorting plants and its related environmental impact. The combination of MFA and LCA has been used before to assess MSW management systems and provide environmental performance information (De Meester et al., 2019; Haupt et al., 2018; Turner et al., 2016). The MFA is used to perform a mass balance within the inputs and outputs at the EoL stage. LCA helps estimate the potential environmental impacts generated by MTW quantities estimated by the MFA that are sent to reuse, recycling, incineration with energy recovery, and landfilling.

MFA was applied to assess mass flows of SMTW collected and sorted by MTW managers in Catalonia. Data were taken from the DARIG that MTW managers declared to the ARC in 2020. Inputs of the MFA were SMTW entering Catalan sorting plants, including stocks. Output flows were the final destinations of the resulting streams. The collected SMTW was classified according to the EU waste hierarchy. Final geographical locations for reuse and recycling output flows were assumed as destinations declared in DARIGs by authorized managers. In this study, such destinations are called *first geographical destinations*, as it is suspected that a part of output textiles could move to second or third geographical destinations (Engrunes, personal communication, March 22, 2022). Incineration (including energy recovery) and landfilling of MTW occurred in Catalonia. The input and output flows of the SMTW were adjusted to ensure a consistent mass balance, as data provided by the ARC did not allow a fully closed mass balance. A Sankey diagram illustrating SMTW flows was built.

The results of the output flows from the MFA, namely, the amount of MTW to each final treatment, were later used in an attributional LCA to evaluate their potential environmental impact in terms of global warming potential. To do so, the study assumed transport to the first geographical destination or treatment plant, and final treatment choices to SMTW in comparison with UMTW in Catalonia in 2020. The functional unit used was the total amount of MTW in tonnes managed in Catalonia in 2020. The reference flows were 16,653 t for SMTW and 143,899 t for UMTW (see Section D of the SI).

The SMTW system included transport from the sorting plant, which varies depending on the EoL management of the flow: reuse, recycling, incineration, or landfill. And it also considered the EoL management processes. For reuse and recycling, the transport distance used for the assessment from sorting plants to the geographical location was that requested and provided by the Catalan government (see Table E1 of the SI). For incineration and landfill, distances were assumed based on the location of the treatment facilities in the Catalan territory. The sorting process was excluded due to data limitations. The UMTW system included transport of the collected waste to treatment plants and the later process of incineration or landfill. See system boundaries scheme in Fig. E1 of the SI, and assumptions of the study in Table E1 of the SI.

The assessment of the carbon footprint of current MTW management was performed using ecoinvent v3.8 (Wernet et al., 2016) and SimaPro software (PRé Consultants, 2022). Inventory data are highly detailed in Table E1 of the SI. The Intergovernmental Panel on Climate Change (IPCC) 2021 100 years – Global Warming Potential (GWP) method was selected to account for the carbon footprint. The analysis was limited to this indicator, as it is one of the most common indicators used to evaluate the environmental performance of systems and products and communicate the effect on climate change. It has become an indicator frequently used to communicate environmental information to citizens as well.

3. Results

3.1. Current practices of MTW disposal

The objective of this part of the study was to identify the existing MTW disposal practices and opinions from citizens. A total of 1469 respondents provided feedback on the survey via the EUSurvey website. Participants presented diverse demographic characteristics relating to gender, age, education, income, geographical context and concern about the environment and TW (see Table C1 of the SI). Frequencies and percentages of answers can be found in Tables C1 and C2 of the SI. One key objective was to understand the MTW disposal practices regarding their condition (questions 03 and 04 of the survey). The questions formulated to reflect on this subject are illustrated in Fig. 2. The responses showed that TW in worse condition (Q03) was perceived as waste; therefore, most citizens disposed of it in civic amenity sites (36.76 %), in mixed-fraction containers (30.30 %) and in SMTW containers (29.53 %). In contrast, TW under better conditions (Q04) was generally not perceived as waste. Thus, it was most discarded in SMTW containers (77.87 %), followed by civic amenity sites (17.93 %). The amount of TW in better condition disposed of in the undifferentiated container was small (3.45 %) compared to the amount of TW in worse condition collected in the same container.

According to the demographic characteristics, the most significant variables from the statistical analysis of the responses from the survey are age, concern about the environment and concern about TW generated as an individual, as summarized in Table 1. Expanded statistical results per demographic characteristic are included in Section F of the SI. Accordingly, young citizens performed more incorrect disposal practices (Tables F4 and F5 of the SI). Most likely, they were often not concerned about the relevance of TW, as suggested by the results shown in Table F12 of the SI. Citizens with no concern about TW tended to also use incorrect disposal practices (Table F9 of the SI). According to Fig. 2, these citizens generally disposed of TW in worse condition in the undifferentiated waste container. Additionally, they were sometimes unaware of the closest SMTW container or civic amenity site location (see Table F10 of the SI). In general, citizens concerned about environmental problems disposed of their clothes more correctly than those not interested in environmental issues (Table F8 of the SI).

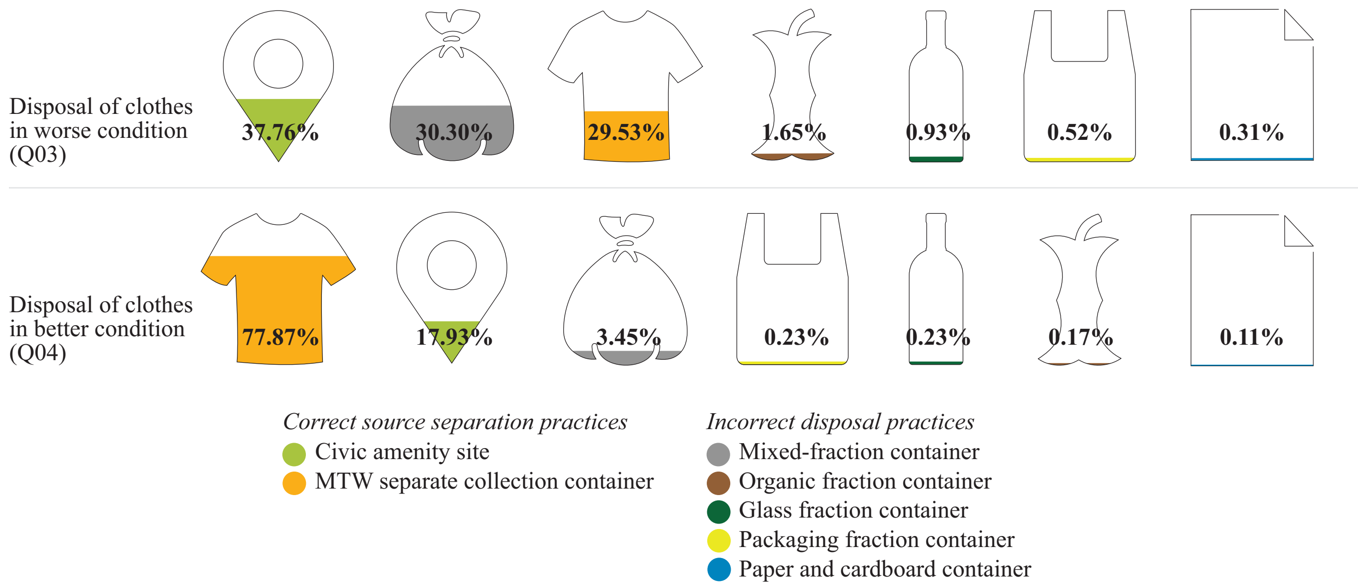

Fig. 2. Responses (in percentage) of the disposal of clothes in worse (question 03) and in better (question 04) condition by citizens.

Table 1
p values between pairs of questions and demographic characteristics. Pairs of questions are statistically significant when *p* values are <0.05 (in bold).

	Gender	Age	Education	Monthly income	Geographical context	Concern about the environment	Concern about TW generated as an individual
Reasons why citizens dispose of clothes (Q01)	**0.000**	**0.000**	**0.045**	**0.003**	0.393	0.231	**<0.001**
Practices by citizens when disposing of clothes (Q02)	**0.019**	**0.000**	0.078	**0.014**	0.749	**0.002**	**0.010**
Disposal choices of clothes in worse condition (Q03)	0.792	**0.000**	0.153	0.179	0.101	**0.002**	**0.015**
Disposal choices of clothes in better condition (Q04)	0.695	0.105	0.510	0.573	0.220	**0.005**	**0.003**
Knowledge about SMTW containers and civic amenity site location (Q05)	0.144	**0.000**	0.239	0.283	**0.000**	**0.000**	**0.000**

3.2. EoL management of MTW

3.2.1. Material flow analysis

A comprehensive material flow diagram for SMTW management in Catalonia is illustrated in Fig. 3. The focus is on (1) the sorting process carried out in MTW sorting plants, (2) the output to SMTW according to the waste hierarchy, and (3) the first geographical destination of textiles for reuse and recycling.

In 2020, the total amount of SMTW input flows to Catalan sorting plants was a gross value of 18,630 t. Approximately 78 % was sorted. An important part was directly sold without previous classification (13.70 %) or kept as stock (8.99 %). Such quantity of stock was due to an increase in clothing disposal by citizens during the COVID-19 situation (Engrunes, personal communication, March 22, 2022). Indeed, the stock almost tripled when compared to the 2019 output stock values (Agència de Residus de Catalunya, 2020a). The net output flow was 16,653 t. Textiles for reuse was the principal output (79.62 %), while landfilling (4.52 %) was more frequent than incineration with energy recovery (2.96 %) and recycling (2.29 %). From the total input flows entering the sorting plants, almost 40 % were prepared for reuse and recycled in Catalonia and Spain, approximately 40 % were exported for reuse and recycling in Asia, Africa and the rest of Europe, and the remaining 20 % were incinerated or landfilled, stocked or treated as improper waste. From the output flows prepared for reuse and recycling, and regarding first geographical destinations, approximately 50 % of flows were at least exported outside the Iberian Peninsula, being this the most striking result of the MFA. Textiles for reuse and recycling sold in Catalonia (25.51 %) was as significant as exportation for reuse and recycling to Asia (25.50 %) due to major exports to Pakistan and the United Arab Emirates. Section G of the SI gives a detailed description of the first geographical destinations of these flows.

3.2.2. Life cycle assessment

In Catalonia in 2020, according to MTW reference flows (Section D of the SI), 10.37 % was net SMTW, while 89.63 % was UMTW. As briefly explained in Section 2.2.2, the carbon footprint was selected as a good environmental indicator to account for the potential CO_2 emissions of the EoL of MTW. The carbon footprint of transport to the first geographical destination and waste treatment of SMTW was estimated to be 3440 t CO_2 eq, in comparison with 50,750 t CO_2 eq for transport and final treatment of UMTW. This leads to 207 kg CO_2 eq per tonne of SMTW and 353 kg CO_2 eq per tonne of UMTW. Therefore, the total carbon footprint of waste transport and treatment of MTW from Catalonia in 2020 was estimated to be 54,190 t CO_2 eq. According to Table 2, <10 % of MTW was prepared for reuse and recycling; thus, >90 % of MTW was burned or landfilled, contributing to >94 % in terms of greenhouse gas (GHG) emissions. The environmental impacts associated with the transportation of textiles for reuse and recycling exported outside the Iberian Peninsula were 2433 t CO_2 eq. These contributed 70.72 % of the total carbon footprint of SMTW management in Catalonia. While transport had a significant environmental performance in outputs for reuse and recycling due to exportation, incineration with

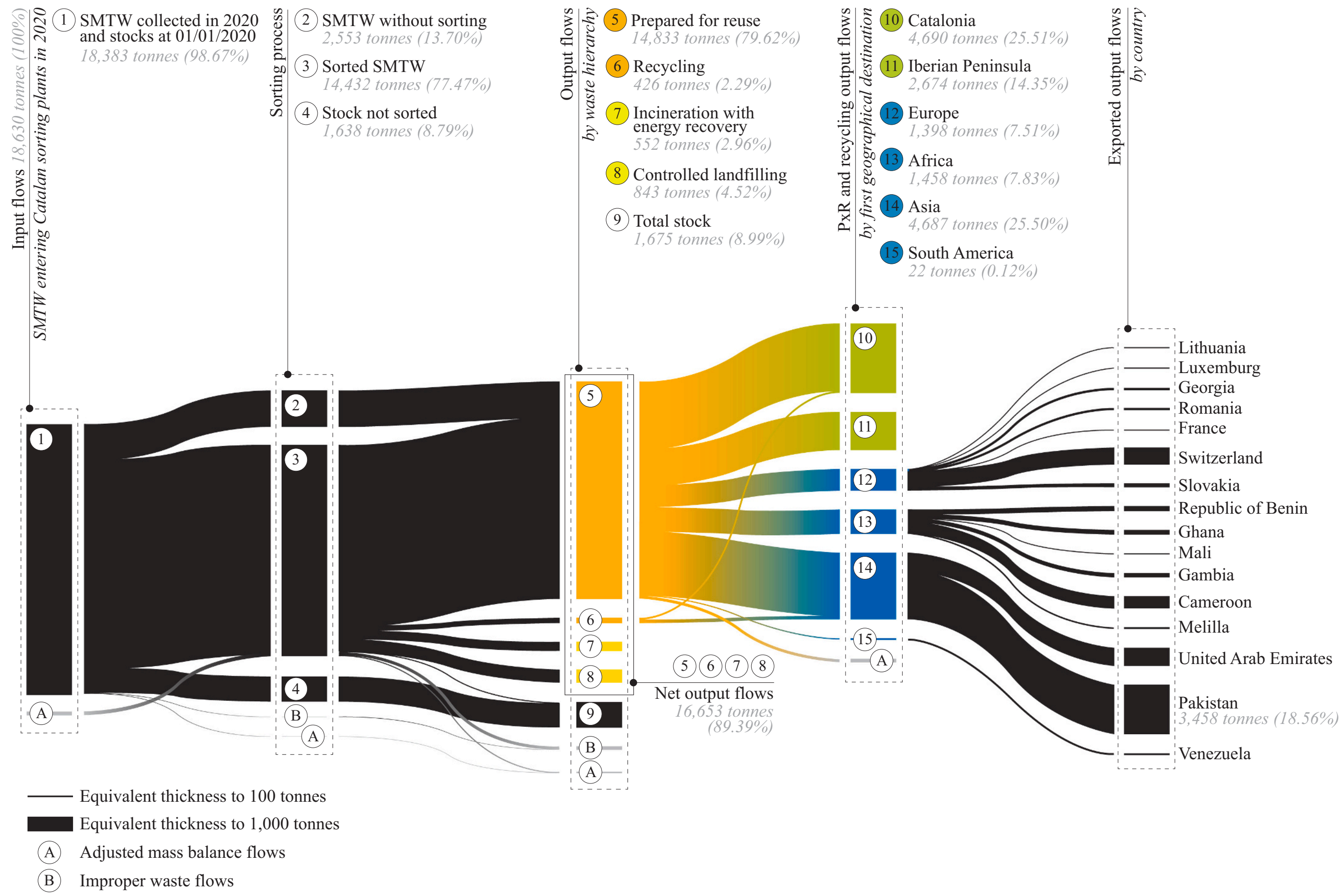

Fig. 3. SMTW flows for Catalonia in 2020.

Table 2
Amount of MTW and its potential global warming potential (CO_2 eq emissions) generated by its EoL management in Catalonia.

Waste hierarchy levels	Textile waste (t)	Textile waste (%)	Carbon footprint (t CO_2 eq)	Carbon footprint (%)
Prepared for reuse	14,833	9.24	2814	5.19
- Transport			*2814*	*5.19*
- Treatment[*]			*n/a*	
Recycling	426	0.27	146	0.27
- Transport			*114*	*0.21*
- Treatment			*32*	*0.06*
Incineration with energy recovery	52,397	32.63	6183	11.41
- Transport			*52*	*0.10*
- Treatment			*6131*	*11.31*
Controlled landfilling	92,897	57.86	45,047	83.13
- Transport			*85*	*0.16*
- Treatment			*44,962*	*82.97*
Total	160,553	100.00	54,190	100.00

[*] Note that an important quantity of textile prepared for reuse is exported to low-middle income countries, and the treatment processes performed in these countries are unknown. Thus, environmental impacts could arise in the preparation for reuse treatment, as the quantity of textiles for reuse that will end up being sold as second-hand or discarded is not known. Neither how these discarded flows will be managed.

energy recovery and landfill contributed the most to the carbon footprint.

4. Discussion

This section discusses the current practices of MTW by citizens and waste managers with the objective of identifying current limitations. Then, we provided further insight into how the current MTW could be improved in the near future for a smooth implementation of the mandatory separate collection of TW in 2025.

4.1. Improving current citizen MTW management practices

According to the outcomes of this study, a low percentage of citizens are aware that they incorrectly dispose of their TW in the mixed-fraction container (ARC, personal communication, June 11, 2022; Llorens, 2020). The collected responses explain the high share of MTW found in the mixed-fraction container, as almost 50 % of respondents disposed of TW in the mixed-waste fraction (Table C2 in the SI, questions 02 and 03). Although these seem to be two different disposal practices, the results are the same: A considerable fraction of TW ends up in the mixed-waste fraction. According to survey results, an awareness campaign about the need to improve the collection of MTW should focus on the share of citizens who are less concerned about TW, namely, citizens aged under 35. This study detected major opinion deviance depending on the condition of the clothing and thus the understanding of TW by citizens. A harmonized definition of TW together with correct disposal practices should be better communicated to citizens.

A portion of MTW in good condition has usually been collected by NGOs for charity (Manshoven et al., 2019; Mistra Future Fashion, 2019). In Catalonia, SMTW is currently collected by eight social organizations (Agència de Residus de Catalunya, 2020a). Thus, SMTW containers are still perceived as an installation for a social service (Generalitat de Catalunya, 2022). Fig. 2 suggests this statement, as SMTW containers are primarily used for MTW assumed to be in good condition and thus likely to be reused. However, clothes in worse condition are collected via SMTW containers in civic amenity sites and mixed-fraction containers. This fact also confirms the low collection rate of net SMTW (10.37 %) compared to higher percentages of UMTW (89.63 %). As far as the objective of other MSW fraction containers focuses on *recycling*—rather than *reuse*—and these present higher collection rates (Agència de Residus de Catalunya, 2022; Barcelona Regional, 2020), a clarification on whether SMTW is collected for reuse but also recycling is in order. Currently, citizens separate MTW based on their own judgement, as information is unclear. Indeed, it was detected that even the information displayed by an ARC website (Generalitat de Catalunya Departament d'Acció Climàtica Alimentació i Agenda Rural and Agència de Residus de Catalunya, n.d.) about the correct disposal practice of MSW is ambiguous on communicating the most adequate path for MTW.

Enhancing the existing SMTW collection system is a key factor in improving the SMTW collection rate. Alternative methods for the collection of SMTWs should be further investigated, as public space occupation is critical and limited in cities (Circular Fashion Pact, personal communication, January 2022). On the one hand, according to Hole and Hole (2020), existing recycling policies for MSW fractions can be applied to MTW. Struk (2017) showed that curbside collection of waste improved paper and plastic separation compared to drop-off sites. Thus, increasing the number of SMTW containers per inhabitants and improving their accessibility (seven days a week at any hour) are necessary. According to survey results, 25 % of respondents lived >10 min away from the closest SMTW collection container, and 8.2 % did not know the location of the closest SMTW collection container (Table C2 in the SI, question 05). Collection rates could also be improved by the coexistence of different systems. For example, the Circular Fashion Pact aims to collect MTW at points of sale (Generalitat de Catalunya, 2022), although according to survey results, this is not a common disposal practice (Table C2 in the SI, question 05). For successfully implementing these new collection systems, communication and education campaigns are also key (Hole and Hole, 2020). Other potential points of MTW collection are public infrastructures such as schools, universities, supermarkets, and industrial sites, among others. The latter could prevent containers from being vandalized and therefore ensure a better condition of SMTW when reaching MTW sorting plants. Other studies have successfully used reward schemes and a weight-based tax system to increase the collection rates of MSW (Hole and Hole, 2020).

4.2. EoL management of MTW flows by waste managers

Catalonia must intensely pursue improving SMTW collection, as UMTW is estimated to cost up to 30 million euros to local authorities (Agència de Residus de Catalunya, 2020b; Nohales, 2021). The results from this study also show higher GHG emissions per tonne of UMTW (353 kg CO_2 eq) than the emissions per tonne of SMTW (207 kg CO_2 eq). However, if the amount of SMTW in dedicated containers suddenly increased, the existing MTW collection enterprises would not be able to manage it due to capacity limitations. For example, in 2020, the COVID-19 situation made citizens discard more clothes (ARC, personal communication, April 26, 2022). As a result, the amount of MTW collected in 2020 (8.99 %) tripled when compared to 2019 figures. Due to limitations in terms of physical space, logistics and financial problems, a significant amount of SMTW was directly sold without any prior sorting (13.70 %), although this practice was not preferred by MTW companies (Engrunes, personal communication, March 22, 2022; Humana, personal communication, June 15, 2022; Solidança, personal communication, June 17, 2022) or for the traceability of the MTW. Investments to increase the current collection and treatment capacities of existing MTW sorting plants shall be made, as MTW is predicted to increase considerably in the coming years.

Attention should also be paid to enhancing local market demand for reuse and recycling and investing in sorting and recycling technologies. Major exports for reuse detected in this study partially occur because of the lack of a strong secondhand market. The tiny recycling flows (2.29 %) are due to the lack of automatic sorting technologies that can detect material compositions and the use of human-based criteria. Additionally, textile exports for recycling are high because of the limited availability of local recycling technologies (Solidança, personal communication, June 14, 2022). Moreover, textile manufacturers currently prefer TW from preconsumption rather than from post-consumption (i.e., Ferre Yarns, Iaios, Hilaturas Arnau). Therefore, export of these materials for recycling is emerging as the only alternative to avoid finalist treatments.

Regarding textile exports for reuse and recycling, current available data refers to first geographical destinations where these flows are exported. During the present research, we found that companies located in Catalonia and the Iberian Peninsula buy textiles for reuse and recycling from Catalan-based companies to later sell them to international markets (Engrunes, personal communication, March 22, 2022). This might also be frequent in companies located in Europe, which in fact are already importing textiles for reuse from Catalonia. An educated guess suggests that exported flows could increase up to 75 % if exported textiles for reuse and recycling moved across two locations before being really reused or recycled. These journeys of the flows between more than one destination would result in higher environmental impacts associated with the SMTW EoL stage: exporting transport already contributed 70.72 % to SMTW assuming that SMTW was treated in the locations that MTW managers declared to the ARC in 2020.

Therefore, working on local business models aimed at reuse and recycling at the level of the Iberian Peninsula is one core issue. On the one hand, because operating at this scale generates lower environmental impact: as already discussed, exporting textiles for reuse and recycling generates emissions associated to transport. On the other hand, as exported flows are currently not tracked, there is still a high uncertainty about their real carbon footprint once they reach importing countries. This study assumes that textiles for reuse and for recycling are effectively fully reused and fully recycled. However, further analysis exploring how the carbon footprint varies depending on the final treatment of exported flows would be advisable. It has been similarly done in works from other fields, which are based on various scenarios (Reinert et al., 2021; Wernet et al., 2016). Analysis shall also be further promoted when improved traceability and more data on SMTW becomes available. Additionally, although the focus of this study is on environmental impacts, social impacts regarding the labour rights of those who will receive textile output for reuse and recycling (Brink et al., 2021) arise from flows being exported.

5. Conclusions

This study examined the EoL management of MTW in Catalonia in 2020. To do so, a novel methodological framework combining the social analysis of citizens' practices relating to MTW disposal and the environmental assessment of MTW flows was proposed. This methodological framework is applicable to other EU territories and will allow replicability of this work in these contexts.

On the one hand, outcomes from the survey of 1469 citizens showed that, significantly, young citizens and citizens less concerned about TW and the environment had worse disposal practices. Furthermore, MTW disposal practices suggestively differed depending on clothing condition. Also, surveying resulted a useful method to learn about citizen practices when disposing textile waste. A further study identifying textile disposal practices once the re-casted EU directive on waste (EU/2018/851) is in place would be useful to understand possible limitations of collection processes and identify potential improvements.

On the other hand, the results from the combined MFA-LCA showed a low net SMTW collection rate (10.38 %) compared to UMTW, which was mainly disposed of in the mixed-fraction container (89.62 %). SMTW contributed 207 kg CO_2 eq per tonne, and UMTW contributed 353 kg CO_2 eq per tonne, while the total GHG emissions associated with the Catalan MTW EoL stage were 54,190 t CO_2 eq. <10 % of MTW was classified for reuse and recycling, and >90 % of MTW ended up incinerating with energy recovery or landfilling. From SMTW, the major output was textiles for reuse, and half of the textile flows for reuse and recycling were exported outside the Iberian Peninsula. Pakistan was the country that received the most exports from Catalonia. If more export transactions were considered, the total amount of textile exported could increase up to 75 %, added the fact that an unknown percentage of exported flows for reuse and recycling might end up landfilled. Data availability for a more detailed assessment of the environmental impacts associated with exports is currently nonexistent. Further research shall shed light on the quantities of exported textiles considering real trade and their respective treatment. Additionally, a complete LCA could be relevant, as well as a dynamic analysis over a period of various years.

In the specific context of Catalonia, where the increase in the SMTW collection rate is a must, environmental education through clear communication campaigns supporting citizens' decision at the time of disposing of TW is one of the main priorities. Even more urgent is the establishment of a more desirable SMTW management system that can be locally sustained by itself. Export flows could be minimized by actions to promote secondhand markets, instilling new buying habits in citizens, and enhancing the development of local recycling industries. Investment in citizen awareness campaigns, MTW managers and technologies for sorting and recycling are key aspects to improve the current MTW management in Catalonia. SMTW is the least environmentally harmful way to treat MTW. However, only when the abovementioned actions are accomplished will the increase in the SMTW collection rate generate environmental benefits and become more environmentally and socially sustainable.

CRediT authorship contribution statement

Gemma Morell-Delgado: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Laura Talens Peiró:** Conceptualization, Writing - Review & Editing, Supervision and Funding. **Susana Toboso-Chavero**: Conceptualization, Writing - Review & Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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