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Review

Review of the Policy, Social, Operational, and Technological Factors Affecting Cigarette Butt Recycling Potential in Extended Producer Responsibility Programs

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Abstract: Cigarette butts (CBs) are the most diffuse waste in the world, often abandoned into the environment without proper disposal. They are dangerous because of the numerous harmful chemicals potentially released by them into the environment. In the literature, there are several technological options for CB recycling, but some critical concerns could affect their effectiveness due to the quality and quantity of CB litter that is collected in the proper way. The extended producer responsibility scheme for CBs is proposed at the Europe level as an action to tackle CB litter and encourage sustainable product development. The present paper focuses on analyzing the existing literature to identify critical issues within the policy framework, social behavior, waste collection and transport, and technological processes. The collection and transport of CB waste is a major issue, being a key step for bringing CB to the recycling process. The main concern is the small quantity of CBs collected: 0.06% of the municipal waste and 0.18% of the unsorted waste in the case study's administrative area of Perugia. Another crucial issue is the need for behavioral interventions to increase education and awareness of citizens that are smokers, addressing the discrepancy between smokers' behaviors and beliefs. The main results, along with the critical issues related to the topics, are highlighted.

Keywords: waste management; cigarette butts; tobacco products; waste collection; cigarette recycling

Citation: Pazzaglia, A.; Castellani, B. Review of the Policy, Social, Operational, and Technological Factors Affecting Cigarette Butt Recycling Potential in Extended Producer Responsibility Programs. *Recycling* **2023**, *8*, 95. https://doi.org/10.3390/recycling8060095

Academic Editor: Huijuan Dong

Received: 18 September 2023
Revised: 13 November 2023
Accepted: 30 November 2023
Published: 1 December 2023

1. Introduction

Cigarette butts (CBs) are considered one of the major sources of litter in public areas and pose a serious environmental threat [1–3]. The challenge of recycling CBs is to be taken up on a global scale because, although the cultivation, harvesting, and processing of tobacco are limited to specific areas, consumption and the resulting waste afflict the entire world population and the entire planet. Globally, approximately 5.2 trillion cigarettes were consumed yearly in the period 2021–2022 [4]. According to a WHO study, two-thirds of the used CBs are dispersed into the environment [5].

The literature data show an estimated increase of 9 trillion cigarettes by 2025 due to population growth [6]. Global cigarette consumption can produce 340–680 million kg of butts annually, with over two million tons of waste related to cigarette packaging [7,8].

Focusing on the Italian scenario, even though there are no studies on the abandonment of CBs in Italy, statistical data show that smokers make up 24.2% of the population, and their average daily consumption is about 12 cigarettes, while a quarter of smokers consume more than a packet [9]. By making a preliminary calculation (calculating only 12 cigarettes per person) and considering the 5.9×10^6 inhabitants of Italy, the number of CBs produced exceeds 6.2×10^{10} per year.

The calculation of the number of CBs potentially present in a specific area is crucial to design the proper collection options, since waste management is a sector strictly dependent on the local scenario. In addition, the literature shows that CB collection is currently inefficient because of the high dispersion of CBs in the environment and their small size [10]. The present paper intends to make a contribution on this topic, discussing the CB collection and transport issues and analyzing the urban scenario in the city center of Perugia, Central Italy, with the aim of providing some numerical results.

Another issue with CBs is the presence of numerous harmful chemicals that can have a significant impact on the environment, including rivers and other aquatic ecosystems, and organisms [11]. According to the WHO, tobacco products contain over 7000 toxic chemicals, including human carcinogens, which enter and accumulate in the environment [5]. Research has shown that harmful chemicals released from discarded butts, which include nicotine, arsenic, and heavy metals, can be highly toxic to aquatic organisms. In addition to tobacco product waste, there are other waste products associated with tobacco use such as the two million tons of paper, ink, cellophane, film, and glue used in tobacco product packaging.

Toxicity research shows that cellulose acetate cigarette filters do not biodegrade in most cases due to the presence of acetyl molecules. However, under specific environmental circumstances, with sunlight and humidity, cigarette filters can break into smaller plastic pieces, releasing some of the chemicals contained in a cigarette. Many of these chemicals are harmful to the environment, and at least 50 are known human carcinogens [5].

The dispersion of CBs in the environment is just the last step of the tobacco product industry that impacts the environment. However, an increasing number of studies have demonstrated that each stage of the tobacco supply chain produces serious environmental impacts, including deforestation, chemicals contaminating soil and water, and resource depletion, in addition to the above-described litter with the consequent leaking of harmful substances into the natural environment, causing wildlife harm [12].

As in the case of any type of waste, the reference tool for choosing priority actions and processes to reduce the impacts of waste is the waste hierarchy. It suggests that prevention is the most preferred action, in order to protect the environment, to reduce resource consumption, and also to be sustainable from an economic and social point of view [13].

Preventive actions can be taken against smoking, such as the WHO MPOWER measures, which provide a package of technical measures aimed at reducing the demand for tobacco products [14]. The MPOWER measures include monitoring tobacco use, protecting people from tobacco use, providing assistance to quit tobacco use, raising awareness about health and environmental issues, enforcing bans on tobacco advertising, promotion, and sponsorship, and increasing taxes on tobacco. Published studies show the effectiveness of the MPOWER measures, in particular raising taxes on tobacco [15]. In addition to the EU-specific directives addressing CB littering, the WHO MPOWER technical package must be considered as a tool for countries to implement tobacco demand-reduction measures and public health policies.

After prevention, the subsequent priority action is recycling. Through recycling, the recovery of CBs from disposal or dispersion, to create secondary materials, is in accordance with the principles of the circular economy [16]. An increasing number of publications in the last three or four years, focused on the investigation of several recycling methods for the collected CBs, attest the interest of the scientific community in the CB recycling pathway [17]. The products obtained from the recycling processes presented in the literature are mainly solid materials for the building and construction sector, for energy storage devices, and for the agriculture and environmental engineering sectors [17].

In the scientific community, there are also opposing views on the viability of CB recycling. There are studies affirming that CB recycling is ineffective and costly and highlighting the necessity of stronger restrictions, such as cigarette filter banning. This position is based on two main aspects. The first one is the waste hierarchy, where prevention is a priority action with respect to recycling [3]. The second one is based on the marketing role of the cigarette filters, which is misunderstood and wrongly considered a protective device against smocking harms, reducing in actual willing to quit smoking [18].

For restricting filters, a stronger action is required from the policy makers with respect to the current lenient measures based on the implementation of the extended producer responsibility (EPR), as provided in the European Single-Use Plastics Directive [19].

The EPR scheme imposes tobacco producers to cover the cost of collecting, transporting, and treating CBs, and informing consumers about responsible behavior. Thus, the EPR concept assigns tobacco industries the responsibility for the management of tobacco product waste, relieving citizens' associations and groups, local communities, and governments. A more inclusive approach is the Product Stewardship (PS) principle, which is based on the idea of sharing responsibility by all parties involved in the product life cycle. In [20], EPR and PS are considered complementary in order to prevent, reduce, and mitigate the environmental effects of CB waste.

Another viable approach is Design for Environment (DfE), which integrates environmental considerations into product creation, incorporating both engineering and industrial designs. This approach aims to systematically mitigate the environmental impacts associated with product life cycles, encompassing stages from raw material extraction to end-of-life disposal or recycling. For illustrating the application of DfE principles within the cigarette industry, OCB serves as an exemplary case [21]. OCB has undertaken the production of biodegradable filters designed to meet the stringent EN 14995 standard for biodegradability. Another notable initiative is undertaken by Terracycle, a waste management company specializing in the recycling of various materials, including cigarette butts. Terracycle employs diverse collection methods, acknowledging the cost-effectiveness and complexity inherent in gathering cigarette butts due to their low weight and wide dispersion in the environment. This method entails a collaborative effort between the company and individuals or enterprises, who collect and ship the cigarette waste to Terracycle at no cost [22].

Other measures have been also developed worldwide to address the environmental issues associated with CBs. The most common measures used to address these issues are as follows: (i) the definition of the designated smoking areas, equipped with ashtrays or cigarette disposal units to encourage smokers to dispose of their cigarette butts properly; (ii) the installation of dedicated CB bins in areas with high smoking activity; (iii) the imposition of fines for the littering of CBs; and (iv) public awareness campaigns [23]. These actions are devoted to guide consumers towards proper behavior pertaining to CB disposal.

As is evident from the literature, the CB waste management is a complex and open topic. There are several aspects to be analyzed in order to firstly prevent and then recycle CB waste. Prevention is mainly related to the prevention and reduction of smoking and is based on proper ad hoc policy framework but also is related to consumers' behavior. Once produced, CB waste must be collected and transported, in order to be recycled. The present paper intends to provide a review of the main issues related to CB management, discussing in particular the policy framework, the social aspects of consumers, collection, and transport issues. These aspects are crucial to design effective recycling pathways, as discussed in the literature and presented here in brief.

2. Methodology

The objective of the paper is to discuss the main issues influencing the management and recycling of CBs.

The analysis proposed in this paper is based on the assumption that the waste management structure varies considerably from country to country, also at the local level, but, on the other hand, the waste management sector has certain functions and actors that are shared globally.

In the waste management sector, the following are the main actors: policy makers, local government entities, consumers and waste producers, waste management companies and operators, industry, and research institutions.

As far as policy framework is concerned, all countries have a legislative entity responsible for creating environmental policies and laws. Beyond national levels, there are international agreements or directives that provide directions for national legislative work. Policies vary from country to country; thus, in the present paper, the analysis is focused on the European Union and, at a national level, on Italy.

At the local level, the roles and responsibilities of local governments also vary greatly among countries. In some countries, the responsibility for municipal solid waste management lies entirely with the local governments. Alternatively, this responsibility may be shared between central/federal government and local governments.

Local governments often organize the collection and recycling of waste, are responsible for collecting tax, and approve waste management plans. In other cases, the waste management activities are entrusted to waste companies, which handle waste from collection to disposal. The waste management structure at a local—mainly urban—level is strictly site dependent. For this reason, the present paper focuses on a specific case study, in the urban area of Perugia, Central Italy, with the aim of providing some numerical results for the concerns associated with the collection and transport of CBs. Data on the number of CBs produced are provided by the local waste management company, GESENU SpA, using ministerial public statistic data.

Then, there are waste generators/producers, and in the case of CBs, they are both tobacco industries and citizens that are smokers. The effective prevention and recycling of CBs depends on their actions and practices. Finally, CB recycling is the last step of such a complex pathway, involving both the circular design of the products by the industry and the research of novel recycling processes by the research institutions.

Considering the general organizational structure and the actors of the waste management sector, this paper will discuss four main topics, i.e., policy aspects (focusing on the European Policy Framework), social aspects (focusing on consumer behavior), operational aspects (focusing on the sorted collection and transport stages), and technological aspects (focusing on the recycling technologies available on literature), highlighting the critical issues for the full development of the CB management pathway, as shown in Table 1.

Table 1. Topics addressed in this study.

Topics	Actors Involved	Actions in the Waste Hierarchy	Level
Policy aspects	Policy makers	Prevention Recycling	International (Europe) National (Italy)
Social aspects	Consumers Waste producers Research institutions	Prevention Recycling	Local
Operational aspects	Waste management companies Local governments	Recycling	Local
Technological aspects	Waste management companies Industry Research institutions	Recycling	National Local

The policy framework section analyzes the content of three European directives (Directive 2008/98/EC, Directive 2018/851/EU, and Directive 2019/904/EU) that can be considered as references for cigarette waste. The section on social aspects and consumer behavior discusses the behavior of cigarette consumers. The references were obtained from the Scopus database using the search terms 'social AND cigarette AND butt'. The records were screened for relevance. The utilization of recycled CBs section provides a partial review of current technologies related to CBs. For the purpose of identifying relevant papers, the Scopus database was searched using the following terms: 'cigarette AND butts AND valorization', 'cigarette AND butts AND recycling', and 'cigarette AND butts AND reuse'. The records retrieved were then screened for relevance. Figure 1 summarizes the methodology used in the paper.

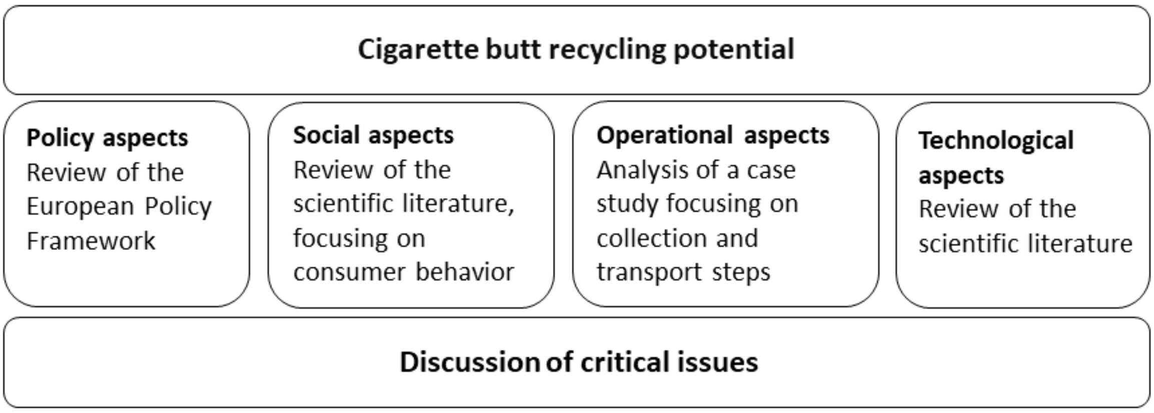

Figure 1. Flowchart of the methodology.

3. Policy Aspects: European Policy Framework

There are three directives from the European Union that should be considered as references for cigarette waste: Directive 2008/98/EC and Directive 2018/851/EU, which include tobacco products with plastic-free filters as waste, and Directive 2019/904/EU, a special directive for the reduction of plastic that includes tobacco products with plastic filters with specific obligations and costs [19,24,25]. The key concepts of the three EU directives are summarized in Table 2.

Table 2. Key concepts of the three main EU directives concerning cigarette waste.

European Directive	Key Concepts
2008/98/EC	Waste hierarchy (Article 4) Extended producer responsibility (Article 8)
2018/851/EU	General minimum requirements for extended producer responsibility schemes (Article 8a)
2019/904/EU	Need for waste of tobacco products reduction (Point 16) Separate collection not mandatory for waste of tobacco products (Point 22) Marking requirements (Article 7) Extended producer responsibility for all single-use plastic products (Article 8) Awareness raising measures (Article 10)

The waste of tobacco products, although not specifically indicated, falls within the scope of the directive 2008/98/EC related to waste, since they are not included in the list of those excluded in the Article 2. Separate collection is not mandatory for such a type of waste, and therefore, they are disposed as unsorted waste.

However, as stated in Article 8, the rules on EPR are also applied to the producers of tobacco products, with a particular reference to the design and production of cigarettes or similar products for the efficient use of resources throughout their life cycle, disassembly, and recycling.

A second directive, 2018/851/EU, introduced the definition of 'extended producer responsibility (EPR) scheme' to ensure that producers bear the financial and operational responsibility for the management of the product's life cycle, including separate collection, sorting, and treatment operations. This obligation may also include the responsibility related to their contribution to the waste prevention and recyclability of products.

The EPR scheme can be defined as a group of measures adopted by The Member States to ensure that producers' responsibility also covers the stage of the life cycle in which the product becomes a waste.

The same directive also introduced the Article 8 bis in the directive 2008/98/EC, entitled 'Minimum general requirements regarding extended producer responsibility', which states, among other things, that producers must cover the following costs: (i) the costs of the separate collection and transport, including the treatment necessary to achieve the Union's waste management objectives, taking into account the revenues from re-use, the sale of secondary raw materials obtained from their products, and unclaimed deposit bonds; (ii) the costs of adequate information to waste holders; and (iii) the costs of data collection and communication. As already mentioned, there is no separate collection for smoking product waste.

The Directive 904/2019/EU, on the reduction of the impact of certain plastic products on the environment, regulates only tobacco products that contain plastic in their filters and not all filter-containing tobacco products.

Point 16 of the directive deals with the butts or filters of tobacco products and begins with the consideration that it is crucial to reduce the environmental impact of the post-consumer waste of tobacco products with filters containing plastic that mainly are thrown directly into the environment.

Then, in point 22, the directive highlights that separate collection is not necessary to ensure proper treatment in line with the waste hierarchy for tobacco products with plastic-containing filters, and therefore, the introduction of separate collection for these products should not be mandatory. This directive also establishes extended producer responsibility requirements in addition to those stated in Directive 2008/98/EC, such as the one requiring producers of certain single-use plastic products to cover the costs of waste removal. It should also be possible to include the costs for the creation of specific infrastructures for the collection of post-consumer waste of tobacco products, such as special containers at points where tobacco product dispersion into the environment most frequently occurs.

The directive includes tobacco products with filters among the single-use plastic products for which are stated marking requirements (art. 7), extended producer responsibility (art. 8), and awareness measures (art. 10).

Article 7 regulates the marking requirements and mentions that Member States should ensure that each single-use plastic product (listed in part D of the annex) and placed on the market has, on the packaging or on the product itself, a marking in large characters, clearly legible and indelible for communicating to consumers the following information: (i) the correct methods of waste management and the forms of waste disposal to be avoided, in line with the waste hierarchy and (ii) the presence of plastic in the product and the consequent negative environmental impact due to their dispersion or other forms of improper waste disposal.

Article 8 regulates the EPR and mentions that Member States should ensure that the EPR schemes are also established for single-use plastic tobacco products. The producers should cover at least the following costs: (i) the costs of awareness-raising measures; (ii) the costs for removing waste from such dispersed products and their waste transport and treatment; and (iii) the costs of data collection and communication, as in the Directive 2008/98/EC.

Furthermore, Member States are required to ensure that manufacturers cover the costs of waste collection for single-use plastic tobacco products placed in public collection systems, including the infrastructure, its operation, and waste transport and treatment. Such costs may include the creation of specific waste collection infrastructure for such products, for example, special containers in places where waste is usually disposed.

Such services should be carried out in a cost-effective manner, and the costs of waste removal should be limited to activities undertaken by or on behalf of public authorities. The calculation methodology is designed in a way that allows the costs of waste removal to be fixed in a proportionate way. In order to minimize administrative costs, Member States may assign financial contributions to the costs of waste removal by setting appropriate fixed contributions on a multiannual basis.

Article 10 regulates the awareness-raising measures and mentions that the Member States adopt measures aimed at informing consumers and encouraging them to adopt responsible behavior in order to reduce the dispersion of waste derived from the products covered by this directive, as well as measures aimed at communicating to the consumers of single-use plastic products the following: (i) the availability of reusable alternatives, reuse schemes, and waste management options; (ii) the impact on the environment, in particular the marine environment, due to the dispersion or other unsuitable waste disposal of single-use plastic products; and (iii) the impact of improper waste disposal methods of single-use plastic products on the sewer system.

4. Social Aspects: Consumer Behavior

Human demeanor is the key aspect that contributes to environmental pollution due to cigarette litter. This behavior is predominantly shaped by factors such as the location where smoking occurs, the availability of ashtrays and CB collection containers, social norms, local regulations, personal beliefs, and the habits of smokers. People might not know the degree to which throwing cigarette butts on the ground affects society and the environment. Therefore, some people may be involved in this type of littering more often than other types [26]. Some smokers may think that CBs are biodegradable, resulting in more littering [27]. Furthermore, smokers' perception of increased littering is also influenced by the presence of a larger number of CBs already present on the ground [28].

In [29], the authors interviewed 1000 smokers, aged 18 and older, and found that there is a strong disconnection between behaviors and beliefs: 86% of smokers consider CBs to be a litter, but 75% of them reported disposing CBs on the ground at least one time. This result suggests that more education is needed to tackle this discrepancy.

Previous research has linked the problem of CB littering to structural concerns, specifically the absence of readily available receptacles (like ashtrays) in convenient areas where smokers can properly dispose of their cigarette butts [30]. Finally, it is important to mention that individuals are inclined to place a higher importance on the environmental condition of the public areas they frequently utilize. As a result, they often engage in littering practices in locations that they do not personally consider as their own [31].

Another issue concerns the beliefs regarding filters. Indeed, they lack a positive impact on health. Filters misleadingly reassure smokers that they reduce product harmfulness, potentially rendering them even more hazardous than non-filtered cigarettes [32].

To tackle the issue of CB pollution, a comprehensive approach is needed, which involves creating awareness, encouraging responsible disposal practices, and implementing efficient waste management strategies. As a prevention strategy, banning filters, as the scientific literature suggests, surely addresses the root of the problem. Nevertheless, the policy framework currently seems to be quite lenient with respect to this solution. Therefore, in the current scenario, alternative and synergic strategies need to be explored to effectively tackle the issue of CBs.

Public awareness campaigns can inform smokers about the environmental impact of CB litter and encourage responsible disposal habits. Different collection strategies could improve the collection of CBs. These measurements include smoking prohibitions in outdoor public places, dedicated smoking areas, and replicating return and deposit schemes adopted in the collection of other types of waste, such as glass and plastic.

5. Operational Aspects: Sorted Collection and Transport of CBs

The collection and transportation of any waste is the most impactful step of a waste management cycle from several points of view. It is a crucial municipal and public service, with large operational costs and environmental impact. Municipal waste collection is polluting, because of the involved fuel consumption, and also expensive, due to the significant involvement of human labor. In accordance with the literature, it represents more than half of the waste management costs (50–90%) [33], and it can be optimized through a combination of proper equipment sizing and effective routing [34].

The main factors affecting the efficiency of waste collection systems include the quantity and quality of waste for each stop, the number and type of the used containers, the distance between stops, and the collection route topography.

These factors are quite challenging if applied to CBs for more than one reason. First of all, the actual weight of CBs that can be potentially collected is much lower than any other sorted waste type, affecting the economic sustainability of a dedicated collection route. It is also difficult to evaluate and identify the urban areas where CBs are largely produced to optimize the installation of disposal infrastructure and the consequent collection route. Probably, public spaces like historical city centers, parks, and sidewalks could be considered as strategic areas for the production of smoke product waste. In such areas, cigarette bins should be located to encourage its disposal. In fact, CBs are easily dispersed in the environment mainly because of the lack of public awareness and the absence of designated smoking areas and public spaces with cigarette disposal infrastructure. To better comprehend these aspects, an analysis of a specific case study was carried out: the cigarette waste production in the historical city center of Perugia, Central Italy (Figure 2).

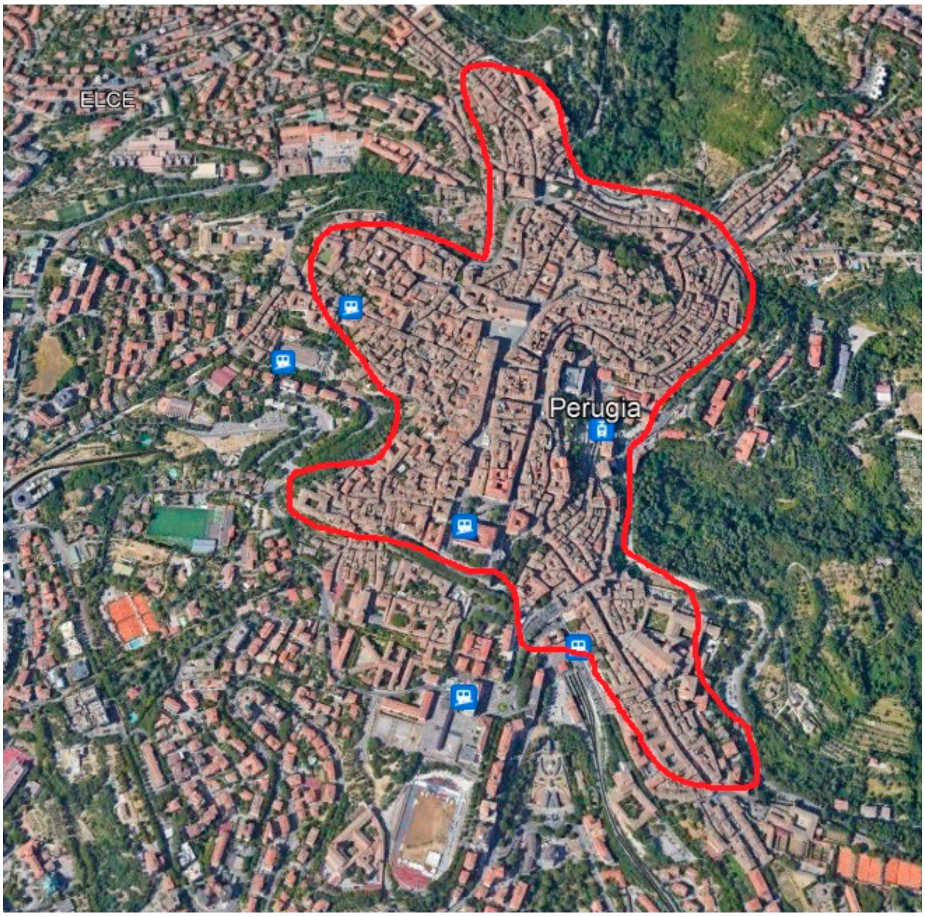

Figure 2. The historical city center of Perugia.

The resident inhabitants in the historical city center of Perugia are 12,500, corresponding to an equivalent annual population of 4,562,500 people. In addition, visitors per year are 622,542. The total amount of attendances is 5,185,042 people. Furthermore, the annual CB production in the historical city center of Perugia is about 1130 kg per year by considering the following aspects: (i) the percentage of smokers is 24.20%; (ii) the estimated average number of smoked cigarettes is equal to three during the residence time; and (iii) the average weight of CB is equal to 0.0003 kg. Currently, the CBs are collected together with the unsorted waste, at each of the 75 bins located in the historical city center (Figure 3).

Figure 3. Bins located in the historical city center of Perugia.

Waste from the historical city center's bins is collected every day manually by personnel of the waste management company that are also devoted to other activities such as street sweeping. The operators cover the collection route with three-wheelers. The unsorted waste is then treated in a mechanical treatment (MT) plant for landfill disposal. In order to recycle CBs, a study should be conducted to assess the feasibility of establishing dedicated infrastructure for sorted collection and transportation to recycling plants, considering both environmental and economic perspectives. These data are provided by the local waste management company, GESENU SpA.

In this sense, it is interesting to estimate the actual portion of CBs with respect to both the total produced waste and the unsorted waste. The evaluation was carried out considering data presented by Istituto superiore per la protezione e la ricerca ambientale (ISPRA) and calculated for the administrative area of Perugia [35]. The population is equal to 641,318 inhabitants with a total production of municipal waste equal to 345,639 tons per year. The amount of unsorted waste is equal to 114,516 tons per year. Considering that, in Italy, the smokers comprise 24.2% of the population and the average number of cigarettes smoked per day is 12 [9], the total amount of cigarette waste per year is equal to 204 tons per year. It represents 0.06% of the municipal waste and 0.18% of the unsorted waste. This very low share of the waste sets the need for some considerations about economic and management aspects of the sorted collection and recycling of CBs to be sustainable and effective. This finding supports and enriches the results of similar studies in the literature. In [36], the authors highlighted that just few papers in the literature have focused on the CB collection step, since lab investigations on CB utilization processes require small quantities of samples. Nevertheless, the authors also concluded that the logistical aspect related to the CB collection is an extremely critical step of the process, from an operational and economic point of view. The ineffectiveness of the CB handling and recycling is also suggested in [17].

Some start-up companies in the market propose CB management services, integrating the installation of the dedicated ashtrays, the collection of the CBs with a frequency defined in accordance with the needs of the client (mainly municipalities), and the recycling process of CBs [37]. To the best of our knowledge, there are no data available on the techno-economic performance of the proposed service. Further investigation in this domian is needed.

6. Technological Aspects: Recycling and Utilization of CBs

This section describes various scientific approaches and emerging technologies for recycling CBs. It provides an overview of mechanical, thermal, and chemical recycling methods, highlighting the state-of-the-art methods and discussing their potential for transforming CB waste into valuable resources.

The proper recycling pathway depends on the starting composition of a cigarette, which includes a filter, cigarette paper, tobacco, tipping paper, and additives.

The tipping paper holds the filter and stabilizes the mouthpiece, while the cigarette paper contains the tobacco blend. It consists of different types of tobacco grown and processed in various ways. Nicotiana Rustica and Nicotiana Tabacum are the most commercialized tobacco species. Furthermore, in tobacco, additives like glycerol (used as a humectant) and flavorings are added. The filter is made of cellulose acetate, which is resistant to biodegradation, while tipping paper protects the filter from UV radiation. Cellulose acetate hydrolysis is a slow process, taking up to several months under anaerobic conditions to complete [38]. Tataranni and Rahman have examined the potential of implementing shredded cigarette filters as an eco-friendly substitute for the addition of fibers in Stone Mastic Asphalts [39,40]. The incorporation of CBs acts as a stabilizer and boosts the mechanical efficiency of the bituminous blends. The research undertaken by Rahman et al. demonstrated that the amalgamation of CBs and bitumen led to considerably better physical and rheological characteristics of the mixture in comparison to the standard mixture that lacked CBs [41].

As a possible alternative use, many authors have studied the addition of CBs to fired clay bricks [42–46]. In these studies, CBs were incorporated in different percentages, up to 10%, to assess their impact on clay brick properties. The results showed that both compressive strength and density decreased with an increase in CB percentage. However, incorporating up to 5% CBs did not result in a significant decrease in flexural strength. As the embedded CB percentage increased up to 10%, water absorption also increased from 5% to 18% [46]. A significant decrease in thermal conductivity was estimated with an increase in CB content, showing a 58% reduction when 10% CBs were added [44,45]. Heavy metal leachability was not significant, likely due to the high firing temperature, about 1050 °C, converting metals to their oxides [43]. Despite an increase in polycyclic aromatic hydrocarbon residues with an increase in CB content, they remained below legal limits [42].

The integration of gypsum composites presents a promising solution for the management of problematic waste. The initial research [47] in this domain indicated that the incorporation of shredded CBs into gypsum has the potential to enhance its mechanical properties significantly. This includes an increase in superficial hardness, mechanical strength, and density. Optimal results were achieved when using a ratio of 2.5% w/w of CBs in gypsum. Moreover, [48] demonstrated that the addition of up to 3.5% w/w of CBs in gypsum resulted in notable improvements in flexural and compressive strengths. This, in turn, led to a reduction in thermal conductivity coefficient when compared to the control sample. It is worth noting that all test cases satisfied the minimum requirements prescribed by relevant standards [49,50].

Yuan et al. [51] produced unglazed fired ceramic tiles, incorporating shredded CBs at a rate of 1.5% by dry weight, and studied characteristics such as density, shrinkage, water absorption, and modulus of rupture. The increase in the percentage of CBs caused an increase in shrinkage and water absorption, whereas the density and modulus of rupture decreased.

Researchers in Brazil developed a technology to produce cellulose pulp from recycled CBs, which showed promising results for use in the paper industry [52]. Cellulose acetate has been hydrolyzed with a strong alkali to obtain cellulose pulp and a dark, toxic effluent that could not be successfully treated with standard methods. The researchers proposed clarifying the effluent and reusing it in a new pulping process, but this solution may not be sustainable due to the constant production of this effluent.

CBs are also utilized as insecticides. Some authors have used CB waste to control mosquito-borne diseases [53]. Especially, the effect against Aedes albopictus and Aedes aegypti has been assessed. These two mosquitos are the vectors of virus that cause dengue fever. Studies have shown that CB waste can increase mortality and disrupt larval development, making it a promising vector control strategy [54,55]. However, further research is needed to fully understand its potential and limitations.

Two research studies by Ifelebuegu et al. (2018) and Xiong et al. (2018) explored a process for converting waste cigarette filters into a sorbent with oleophilic and superhydrophobic properties. The process involved ultrasonic cleaning followed by surface modification using chemical vapor deposition with methyltrichlorosilane. Ifelebuegu et al. [56] observed that the modified filters demonstrated superhydrophobicity and could absorb oils up to 16–26 times their weight with up to 20 cycles of reuse capacity. On the other hand, Xiong et al. [57] found that the modified filters had an absorption capacity of 80% and 82% for pump and silicone oil, respectively, after 10 cycles.

Escobar et al. [58] investigated the acoustic properties of both smoked and unsmoked CBs. All types of CBs exhibited excellent sound absorption characteristics, with a coefficient greater than 0.8 for frequencies above 2000 Hz [59]. They suggested a chemical purification method for CBs to eliminate harmful substances while also enhancing their acoustic properties [60]. Table 3 summarizes the aforementioned recycling technologies.

Table 3. Summary of the main findings regarding recycling technologies.

Recycling Technologies	Main Findings
Asphalts	Incorporating shredded CB waste into asphalts to achieve a better physical and rheological characteristic of the mixture in comparison to the standard mixture without CBs.
Clay brick	Incorporating shredded CB waste into clay brick. Heavy metal leachability was not significant, likely due to the high firing temperature, about 1050 °C, converting metals to their oxides.
Gypsum	Incorporation of shredded CB waste into gypsum, improving the mechanical properties of gypsum. Best result was achieved by incorporating 2.5% w/w of CBs into gypsum.
Ceramic tiles	Incorporation of shredded CB waste into ceramic tiles.
Cellulose pulp	Cellulose pulp, obtained from CB waste, has potential use in the paper industry. The production of toxic effluent is the main issue of this process.
Insecticide	Use of CB waste as a control strategy against the vectors of dengue fever.
Superhydrophobic sorbent	Superhydrophobic and oleophilic sorbents from waste cigarette filters absorb 16–26 times their weight with up to 20 cycles of reuse capacity.
Sound absorption	Investigation of the sound absorption characteristics of smoked CBs. Coefficient of absorption was greater than 0.8 for frequencies above 2000 Hz.

7. Critical Issues

Cigarette litter management faces several critical issues that need to be addressed to effectively reduce the CB environmental impact and pollution and achieve a circular economy.

The European directives address the waste of tobacco products and cigarettes in multiple aspects. The first one is related to the restrictions and requirements to reduce tobacco consumption; this represents the priority action in the waste hierarchy together with the reduction in the tobacco product litter. This can be achieved and can positively affect the behaviors of the key actors. Measures are established and recommended to improve smokers' behavior, such as awareness campaigns and communication actions.

To affect the behavior of industrial producers, the concept of extended producer responsibility (EPR) was introduced. It means that tobacco companies are considered responsible for the collection and disposal of CBs.

In accordance with Vanapalli et al. [26], the EPR scheme is considered a rights-based regulatory instrument and is one of the four different policy instruments to tackle the issue of CB littering, together with price-based instruments, regulation, and behavioral instruments. The first one aims to deter cigarette consumption by altering the relative cost through the implementation of taxes, charges, fees, and fines. Conversely, the World

Health Organization (WHO) asserts that the tobacco industry should not be regarded as a stakeholder in any EPR initiatives. This is because EPR involves holding producers responsible for making product modifications to improve them, while the tobacco industry continues to sell tobacco products regardless of their adverse outcomes [61]. Furthermore, Article 5.3 of the Framework Convention on Tobacco Control, which was signed by Italy and more than 160 other countries, explicitly states that the parties to this international treaty are obligated to protect policies aimed at reducing cigarette consumption from interference by commercial and other vested interests of the tobacco industry. This definition ensures that the tobacco industry is not considered a stakeholder in any EPR policies [61].

Because there are no relevant European Commission guidelines available, the Member States have directly entrusted the tobacco industry with managing the waste of cigarette butts (CBs) and developing awareness campaigns. This partnership has allowed the tobacco industry to collaborate with governments and portray itself as a socially responsible entity. This is the case in France, where the tobacco industry controls the management and communication around the pollution of cigarette butts [62]. As suggested in [23], the EPR scheme could be complemented by the PS principle, and tobacco industries still have responsibilities, in terms of liability, economics, product life cycle, and information, but there are also other stakeholders, with no conflicts of interest, such as government agencies, citizen groups, and academic researchers, which take on complementary responsibilities. The objective is to create significant public health outcomes, such as the denormalization of the tobacco use and an increase in the anti-industry sentiments together with the commercialization of less marketable tobacco products [63].

At the national level in Italy, an example of policy instrument is the ministerial decree of 15 February 2017 [64] published in Italy by the Ministry of the Environment. According to this decree, tobacco producers may implement, in collaboration with the Ministry of the Environment, communication campaigns in order to make consumers aware of the harmful consequences for the environment derived from CB litter. The Ministry of the Environment allocates 50% of the sums derived from the pecuniary administrative sanctions for the abandonment of tobacco waste to the implementation of information and awareness campaigns [64]. In the same ministerial decree, the municipalities are invited to install a network of bins for the CB in the streets, in parks, and in places of high social aggregation, indicating their location and correct use. However, it is noteworthy that receptacles designed for cigarette butts might inadvertently encourage smoking behavior. Despite their proximity to smokers, cigarette butts frequently find their way to the ground [65–67].

Another important aspect is the EU position's on the need for a separate collection scheme for tobacco products, which is not mandatory (point 22 of the Directive 904/2019/EU). Such a decision does not help the proper and massive recovery of CB for the application of specific recycling processes, thus resulting in a scenario where it is still possible that CBs are mixed with unsorted waste and consequently sent to disposal or energy recovery.

On the other hand, as analyzed in the present paper, the number of CBs collected in a sorted scheme would be very low with respect to the other waste fluxes. This fact could discourage the waste management companies for economic and operational reasons. In fact, a sorted collection of CBs means the definition of specific collection routes, with higher costs related to the dedicated labor and fleet. This could be overcome by the cooperation between waste management companies and local administrative entities.

The collection of small quantities of CBs with a capillary distribution in the urban spaces requires an additional optimization of the dedicated routes with the objective of minimizing costs. There are several optimization approaches, which can be considered, such as vehicle routing problem (VRP) [68]. GPS technology could be also used to increase waste collection efficiency, thanks to the real-time tracking and monitoring of waste bin locations and fleets [69]. The urban areas, in which the CB collection should be active, could be determined using GIS-based methods. In [70], the authors estimated the density of CBs in several areas of Madrid, Spain, by performing GIS analyses based on Kernel

Density Estimations. The methodology was successfully validated by in-field measures and observations.

Studies using the LCA approach could also be added to determine the sustainability and effectiveness of the chosen collection and recycling scheme, also taking into account issues related to the small CB waste fluxes and the size of the recycling plant [71].

Generally, to perform CB recycling, firstly, a sorted collection and transport should be designed considering the following criteria, i.e., the definition of the area, the estimation of the number of produced CBs, the definition of the numbers of ashtrays, the definition of the frequency and route of the collection, the assessment of the overall performance, integrating all the previously discussed methodologies.

Another prominent technological point is encouraging the development and use of innovative technologies, such as the use of biodegradable materials. An example of this is when titanium dioxide (TiO_2) is added to the cigarette filters to make them whiter. This addition accelerates the degradation process by serving as a catalyst for photooxidation [72]. Another method involves employing different materials instead of cellulose acetate. For instance, a UK company produces filters made from food starch-based carbohydrate polymers derived from potato or rice [73]. The use of biodegradable alternatives for producing smoke products can surely contribute to reducing the persistence of CB litter, but probably, these filters will still leach out the toxic chemicals, maintaining the environmental problem. However, all types of CBs do not yield positive health effects. Despite their initial design for aesthetics and subsequent promotion as harm-reduction tools, studies indicate that cigarette filters lack any health advantages. In reality, filters falsely instill a sense of safety among smokers regarding the products' harmfulness, potentially rendering them riskier than non-filtered cigarettes. Consequently, as suggested by the scientific literature, the ban on cigarette filters would be justified [19,30]. Although the scientific literature highlights that banning cigarette filters is a priority both for public health and the environment, there is no evidence of such a position in the current EU directives. Surely, the banning of cigarette filters is a preventive action, and thus, the most preferred one in accordance with the waste hierarchy. More efforts are needed to reach this result. Meanwhile, a proper disposal, recovery, and recycling of CBs is useful to prevent environmental pollution and landfill disposal.

To reach this goal, social behavior should be monitored and positively changed, i.e., shifting societal attitudes towards responsible disposal, and mostly, quitting smoking is crucial, but at the same time, it is a complex task. The main issues are smokers' beliefs and habits, to be addressed by effective behavioral interventions, such as targeted awareness-raising campaigns. Several challenges hinder the collection and recycling of CB, arising from both political and social issues that limit the public awareness of CB littering problems. The lack of specific laws regarding CB collection and recycling contributes to a lack of public awareness. Also, cultural norms could favor discarding cigarette butts as common litter, discouraging participation in recycling programs. This cultural attitude may be linked to a general lack of awareness about the environmental impact of CB, emphasizing the need for awareness campaigns. Moreover, the absence of designated smoking area and collection points for CB recycling can discourage individuals from participating. If there are no convenient and accessible bins or collection systems, people may resort to littering. Additionally, the absence of recycling programs sponsored by manufacturers, except for cases like Terracycle (see introduction section), makes CB recycling more challenging. Introducing such programs could improve and expand CB recycling efforts.

Tackling these obstacles necessitates a holistic strategy, encompassing awareness-raising educational initiatives, the establishment of user-friendly collection systems from smoking areas, and the formulation of conducive policies and regulations to promote the responsible disposal and recycling of cigarette butts.

8. Conclusions

CBs management requires a multi-faceted approach, involving political, social, operational, and technological aspects. This paper analyzed these aspects, highlighting the challenges in reducing litter and improving CB recycling. Banning cigarette filters would eliminate the issue at its core, but since it is not currently within the agenda of European institutions, it is important to explore alternative strategies for managing the cigarette filter problem.

To do so, some progress should be made in terms of public education, collaboration among various stakeholders, waste collection and transport, and infrastructure improvements.

Starting from the policy framework, the extended producer responsibility scheme for tobacco products is proposed at the European level as an action to tackle CB litter and encourage sustainable product development. Banning filters is suggested by the literature as the definitive action to tackle CB pollution, but at the moment, the European directives does not recommend this approach.

The collection and transport phase is considered by the authors a key step in the final recycling, involving concerns related to the small quantities of CBs collected, which could make investments less attractive for waste management companies or local entities. These issues necessitate additional research to gain a deeper understanding of their environmental and economic implications.

In addition, the EU directive does not consider the sorted collection of tobacco products mandatory, and this could negatively affect the quality and quantity of CBs sent for recycling.

There is also need for behavioral interventions to increase education and awareness among citizens that are smokers, along with the improvement in proper disposal infrastructure.

This literature overview on CB recycling technologies shows a wide range of investigated recycling options. However, CB collection is likely to be the bottleneck in the recycling process. Hence, future work should focus on studying an effective collection system to evaluate if recycling is an effective strategy in CB waste management.

Author Contributions: Conceptualization, B.C.; methodology, B.C.; investigation, B.C. and A.P.; resources, B.C. and A.P.; data curation, B.C. and A.P.; writing—original draft preparation, B.C. and A.P.; writing—review and editing, B.C.; visualization, B.C. and A.P.; supervision, B.C.; project administration, B.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to acknowledge GESENU Spa for their support in the waste collection data analysis.

Conflicts of Interest: The authors declare no conflict of interest.

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