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Policy, Social, Operational and Technological Factors Affecting Cigarette Butt Recycling

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Abstract: Cigarette butts (CBs) are the most diffuse waste in the world, often abandoned in the environment without proper disposal. They are dangerous because of the numerous harmful chemicals potentially released in the environment. There are, in literature, several technological options for CB recycling, but some critical concerns could affect their effectiveness due to the quality and quantity of CB litter collected in the proper way. The present paper focuses on policy framework social behavior, waste collection and transport and technological processes. The Extended Producer Responsibility scheme for CBs is proposed at European level as an action to tackle CB litter and encourage sustainable product development. The CB waste collection and transport is 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 administrative area of Perugia. Another crucial issue is the need for behavioral interventions to increase education and awareness of smoker citizens, addressing the discrepancy between smokers' behaviors and beliefs.

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

1. Introduction

Cigarette butts (CBs) are considered one of the major sources of litter on public areas and pose a serious environmental threat [1-3]. The challenge to be taken up is 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. Worldwide, approximately 967 million smokers consumed approximately 6.25 trillion cigarettes in 2012 [4].

According to the Tobacco Atlas, a project of the American Cancer Society, in 2016 the number of smoked cigarettes dropped to 5.7 trillion; 76% of them discarded as litter in urban areas instead of being properly disposed of in designated containers. This is in line with the WHO study, which stated that two-thirds of used CBs are dispersed into the environment [5].

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, over two million tons of waste related to packaging [7,8].

There are no studies on the abandonment of CBs in Italy, but the number of smokers and the number of cigarettes smoked are known. In Italy, smokers make up 24.2% of the population and the 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), considering the $5.9 \cdot 10^6$ inhabitants, in Italy the number of CBs exceeds $6.2 \cdot 10^{10}$ per year.

The WHO study analyzed also the impacts of the tobacco supply chain, showing how this product and related industry create waste and environmental damage throughout their life cycle.

CBs represent a significant environmental hazard due to the presence of numerous harmful chemicals that can have a significant impact on environment and organisms [10].

According to the WHO, tobacco product waste contains over 7000 toxic chemicals, including human carcinogens, which enter and accumulate in the environment. 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 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.

This waste ends up everywhere, including rivers and other aquatic environments. In fact, the major criticalities associated with this type of waste are the high percentage of dispersion in the environment, with ineffective collection systems, and the lack of an "End-of-waste" regulatory framework that regulates its recovery in accordance with the principles of circular economy. The responsibility for the management of tobacco product waste lies with citizens' associations and groups, local communities and governments which use public funds for this management. To solve CBs problem policy implement the extended producer responsibility (EPR) through Single-Use Plastics Directive that impose tobacco producers cover the cost of collecting, transporting and treating CBs, and informing consumers about responsible behavior [11]. In addition, numerous researchers are investigating processes to recycle and repurpose CBs in various industries. Some of these studies focus on the building materials sector, while others explore their potential in the chemical industry.

The present paper intends to give an overview of the main issues related to the recycling of CBs, discussing in particular the policy framework, the social aspects of consumers, collection and transport issues. These aspects are crucial to make effective the recycling pathways, discussed in literature and here briefly presented.

2. Methodology

The objective of the paper is to discuss the main issues influencing the recycling of CBs. CBs recycling is the last step of a very complex pathway, which involves political, social, operational and technological aspects. Each of such aspects is related to a key actor: policy makers, local government entities, smoker citizens, waste management companies and operators, industry and research institutions.

Therefore, the paper focuses on four topics: policy framework, consumers' behavior and social aspects, sorted collection and transport, recycling technologies, highlighting critical issues for the full development of the CB recycling pathway.

3. European policy framework

The directives from the European Union to be considered as reference for cigarette waste are three: Directive 2008/98/EC and Directive 2018/851/EU, which include tobacco products with plastic-free filters as waste, and the special one for the reduction of plastic which includes tobacco products with plastic filters with specific obligations and costs (Directive 2019/904/EU) [11-13].

As a matter of fact, waste from smoking products, although not specifically indicated, falls within the scope of the directive 2008/98/EC relating to waste, since they are not included in the list of those excluded in the Article 2. Separate collection is not foreseen for such type of waste and they are therefore disposed as unsorted waste.

However, as stated in Article 8, the rules on the extended responsibility of the producer are also applied to the producers of smoking products, with particular reference to the design and production of cigarettes or similar products to 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 scheme" to ensure that producers bear financial and operational responsibility for the management

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of the product's life cycle, including separate collection, sorting and treatment operations. This obligation may also include the responsibility related to the a contribution to waste prevention and recyclability of products.

The "extended producer responsibility scheme" can be defined as a group of measures adopted by The Member States to ensure that producers' responsibility covers also the stage of the life cycle in which the product becomes 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 provides, among other things, that producers must cover the following costs: i) 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 own products and from unclaimed deposit bonds; ii) costs of adequate information to waste holders; iii) 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 filtered tobacco products.

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

At point 22, then, 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 containing plastic 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 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 the points where dispersion into the environment most frequently occurs.

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

Article 7 regulates the marking requirements and provides that Member States 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; ii) the presence of plastic in the product and the consequent negative environmental impact due to dispersion or other forms of improper waste disposal.

Article 8 regulates the extended producer responsibility and provides that Member States ensure that the extended producer responsibility schemes are established also for single-use plastic tobacco products. The producers should cover at least the following costs: i) costs of awareness-raising measures; ii) costs for removing waste from such dispersed products, waste transport and treatment; iii) 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, waste transport and treatment. Such costs may include the creation of specific waste collection infrastructure for such products, for example special containers in the places where waste is usually disposed.

Such services should be carried out in a cost-effective manner and the costs of waste removal are limited to activities undertaken by or on behalf of public authorities. The calculation methodology is

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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 set financial contributions to the costs of waste removal by setting appropriate fixed amounts on a multiannual basis.

Article 10 regulates the awareness-raising measures and provides 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 deriving from the products covered by this directive, as well as measures aimed at communicate to consumers of single-use plastic products: i) the availability of reusable alternatives, reuse schemes and waste management options; ii) the impact on the environment, in particular the marine environment, of the dispersion or other unsuitable waste disposal of single-use plastic products; iii) the impact of improper waste disposal methods of single-use plastic products on the sewer system.

4. Social aspects and consumer behavior

People behavior 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, availability of ashtrays and CB collection containers, social norms, local regulations, personal beliefs and habits of smokers. People might not know how much throwing cigarette butts on the ground affects society and the environment. That is why some people might do it more often than other types of littering [***Error! Reference source not found.***]. Some smokers may think that CBs are biodegradable, resulting in more littering [14]. Furthermore, smokers' perception of increased littering is also influenced by the presence of a larger number of CBs already on the ground [16].

In [17], 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 litter, but 75 % of them reported disposing CBs on the ground at least one time. This result suggests that more education is needed to face the discrepancy.

Additionally, the act of littering CBs was found to be more common in places where people socialize frequently and where smokers experience a feeling of comfort and relaxation [18]. 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 [19]. 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 associate with as their own [20].

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.

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 receptacles for CBs outside businesses, smoking prohibitions in outdoor public places, dedicated smoking areas, and replicating return and deposit schemes adopted in collection of other types of waste, such as glass, plastic.

5. Sorted collection and transport of CBs

The collection and transportation of any waste is the most impactful step of 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 fuel consumption of the involved sheet, and expensive also due to the significant involvement of human labor. In accordance with literature, it represents more than half of the waste management costs (50-90%) [21] and it can be optimized through a combination of proper equipment sizing and effective routing [22].

The main factors affecting the efficiency of waste collection systems include quantity and quality of waste for each stop; number and type of the used containers, distance between stops, collection route topography [23].

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These factors are quite challenging if applied to cigarettes butts for more than one reason. First of all, the actual amount in 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 the disposal. In fact, CBs are easily dispersed in the environment mainly because of lack of public awareness and absence of designated smoking areas and public spaces with cigarette disposal infrastructure. To better comprehend these aspects, an analysis of a case study was carried out: the cigarette waste production in the historical city center of Perugia, Central Italy (Figure 1).

Figure 1. The historical city center in Perugia.

The resident inhabitants in the historical city center of Perugia are 12500, corresponding to an equivalent annual population of 4562500 persons. In addition, visitors per year are 622542. The total amount of attendances is 5185042 persons. Considering that: i) the percentage of smokers is 24.20 %; ii) the estimated average number of smoked cigarettes is equal to 3 during the residence time; iii) the average weight of CB is equal to 0.0003 kg, the annual CB production in the historical city center of Perugia is about 1130 kg per year. Currently, the CBs are collected together with the unsorted waste, at each of the 75 bins located in the historical city centers (Figure 2).

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Figure 2. Bins located in the historical city center of Perugia.

Waste in the historical city center bins is collected every day manually by personnel of the waste management company devoted also 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. To recycle CBs, a specific infrastructure for the sorted collection and transport to recycling plant should be planned and developed.

In this sense, it is interesting to estimate the actual portion of CBs with respect both to the total produced waste and the unsorted waste. The evaluation was carried out considering data presented by ISPRA and calculated for the administrative area of Perugia [24]. The population is equal to 641318 inhabitants with a total production of municipal waste equal to 345639 t per year. The amount of unsorted waste is equal to 114516 t per year. Considering that in Italy the smokers are 24.2 % of the population and the average value of cigarette smoked per day is 12 [9], the total amount of cigarette waste per year is equal to 204 t per year. It represents 0.06 % of the municipal waste and 0.18 % of the unsorted waste. This very low share sets the need for some considerations about economic and management aspects of the sorted collection and recycling of CBs to be sustainable and effective.

6. Technologies for CB recycling

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 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 (Figure 3).

The tipping paper hold the filter and stabilize the mouthpiece while the cigarette paper contains 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 have been added additives like glycerol (used as humectans) and flavorings. The filter is made of cellulose acetate, which is resistant to biodegradation while tipping paper protect filter from UV radiation. Cellulose acetate hydrolysis is a slow process, taking up to several months under anaerobic conditions to degrade [25].

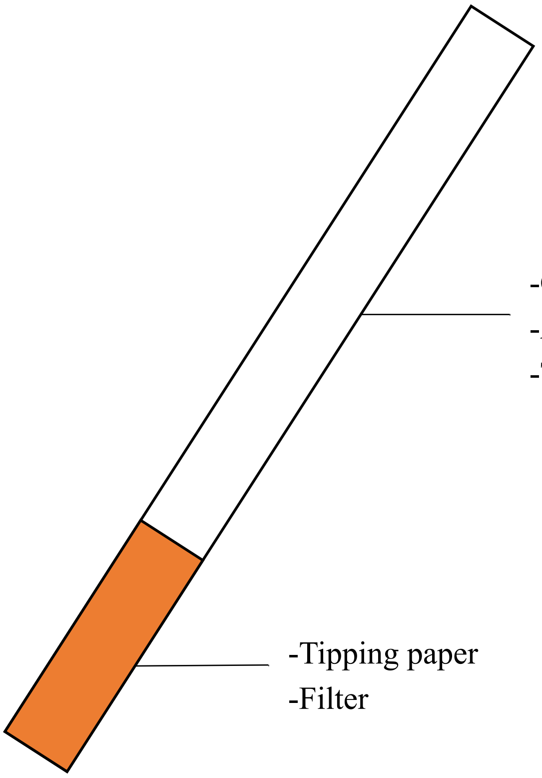

Figure 3. Simplified cigarette structure with the main components

6.1. Asphalts

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 [26,27]. 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 lacking CBs [28].

6.2. Clay brick

As a possible alternative use, many authors have studied the addition of CBs to fired clay bricks [29-33]. In this study, CBs were incorporated at different percentages, up to 10%, to assess their impact on clay bricks 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% [33]. A significant decrease in thermal conductivity was estimated with an increase in CB content, showing a 58% reduction when 10% CBs were added [31-32]. Heavy metal leachability was not significant, likely due to the high firing temperature, about 1050 °C, converting metals to their oxides [30]. Despite an increase in polycyclic aromatic hydrocarbon residues with an increase in CB content, they remained below legal limits [29].

6.3. Gypsum

The integration of gypsum composites presents a promising solution for the management of problematic waste. The initial research [34] in this domain indicated that the incorporation of shredded CBs in 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 to gypsum. Moreover, [35] 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 [36-37].

6.4. Ceramic tiles

Yuan et al. [38] 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 escalation in shrinkage and water absorption, whereas the density and modulus of rupture decreased.

6.5. Cellulose pulp

Researchers in Brazil developed a technology to produce cellulose pulp from recycled CBs, which showed promising results for use in the paper industry [39]. Cellulose acetate has been hydrolyzed with a strong alkali obtaining 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 effluent.

6.6. Insecticide

Another utilization of CBs is as insecticide. Some authors have use CBs waste as a control against mosquito-borne diseases [40]. Especially the effect against Aedes albopictus and Aedes aegypti are 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 [41-42]. However, further research is needed to fully understand its potential and limitations.

6.7. Superhydrophobic sorbent

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. [43] 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. [44] found that the modified filters had an absorption capacity of 80% and 82% for pump and silicone oil, respectively, after 10 cycles.

6.8. Biofilm carrier

The effectiveness and feasibility of using waste CBs as a biofilm carrier in the integrated fixed film activated sludge process and an anaerobic moving bed biofilm reactor was evaluated by researchers. The study showed that CBs can remove organic matter and nutrients from wastewater in the first process, and in the second, it can effectively remove phosphate and organic matter. Moreover, the modified materials' properties such as high porosity, roughness, and high surface area can increase effective mixed liquor suspended solids in an anaerobic reaction basin. The use of CBs was also found to be a cost-effective and durable option for wastewater treatment [45-46].

6.9. Sound absorption

Escobar et al. [47] 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 [48]. They suggested a chemical purification method for CBs to eliminate harmful substances while also enhancing their acoustic properties [49].

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 perform circular economy.

The European directives address tobacco waste 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 of the tobacco product litter. This can be achieved affecting positively the behavior 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 tobacco companies are considered responsible also for the collection and disposal of cigarette butts.

In accordance with Vanapalli et al. [14], the EPR scheme is considered a rights-based regulatory instrument and is one of the four different policy instruments to tackle the issue of CBs littering, together with price-based instruments, regulation and behavioural instruments. The first one aims to deter cigarette consumption by altering the relative cost through the implementation of taxes, charges, fees, and fines.

At the Italian level, an example of policy instrument is the ministerial decree 15 Febraury 2017 [50] published in Italy by the Ministry of the Environment. According to this, 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 deriving from CB litter. Such campaigns can be implemented by producers, even in collaboration with other stakeholders. The Ministry of the Environment allocates the 50% of the sums deriving from the pecuniary administrative sanctions for abandonment of tobacco waste to the implementation of information and awareness campaigns [50]. In the same Ministerial Decree, the municipalities are invited to install a network of bins for the CB in the streets, in parks as well as in places of high social aggregation, indicating their location and correct use.

So, the policy framework suggests and fixes actions to the key actors in the field; what seems to be weak is the EU position towards 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 CB are mixed with unsorted waste and consequently sent to disposal or energy recovery.

On the other hand, as analyzed in the present paper, the amount 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 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) [51]. Studies with LCA approach could be added to determine the sustainability and effectiveness of the chosen collection and recycling scheme, taking also into account issues related to the small CB waste fluxes and the size of the recycling plant [52].

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 photo oxidation [53]. 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 [54]. The use of biodegradable alternatives for producing smoke products can surely contribute to reducing the persistence of CB litter and therefore their environmental impact.

Finally, social behaviour should be monitored and positively changed: shifting societal attitudes towards responsible disposal 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.

8. Conclusions

CBs recycling requires a multi-faceted approach, involving political, social, operational and technological aspects. This paper analyzed them highlighting the challenges to reduce litter and improve the CBs recycling.

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

Starting from the policy framework, the Extended producer responsibility scheme for tobacco products is proposed at European level as an action to tackle CB litter and encourage sustainable product development.

The collection and transport phase is considered by the authors a key step to 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.

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

There is also need for behavioral interventions to increase education and awareness of smoker citizens, integrated with improvement of proper disposal infrastructure.

The literature overview on CBs recycling technologies show a wide range of investigated options. Together with recycling, also the design of smoking products with biodegradable and green materials is advisable.

Future work is needed on the development of full-scale recycling processes and evaluation of optimized CB waste management solutions with the engagement of all the stakeholders, research institutions, local entities, companies and communities.

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