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Review

Pros and Cons of Plastic during the COVID-19 Pandemic

Fabiula Danielli Bastos de Sousa [1,2]

[1] Technology Development Center, Universidade Federal de Pelotas, Rua Gomes Carneiro, 1, Pelotas, RS 96010-610, Brazil; fabiuladesousa@gmail.com

[2] Center of Engineering, Modeling and Applied Social Science, Universidade Federal do ABC, Avenida dos Estados, 5001, Santo André, SP 09210-580, Brazil

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Abstract: Since the beginning of the first cases of the new coronavirus, opinions and laws on the use of plastic materials have been questioned around the world. Their importance in the manufacture of hospital devices and personal protective equipment (PPE) is unquestionable, as they contribute largely to the reduction of the virus spread, helping health systems from all edges of the world and, most importantly, saving lives. However, the same material that is a protector, becomes a polluter when inadequately disposed of in the environment, generating or worsening socio-environmental problems, such as pollution of water bodies by plastic. A critical overview of the role of plastic during the COVID-19 pandemic is provided in this paper. A future panorama is attempted to be outlined. The real possibility of the virus spread from the use of plastic is discussed, as well as the recycling of plastic during the pandemic, correlating its use with problems that it may cause.

Keywords: COVID-19; plastic; virus spread; recycling; public health; environmental problems

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1. Introduction

Since the beginning of the first cases of the new coronavirus, our society has been completely changed. Some materials, such as plastic, have gained media attention.

Plastic is a polymeric material, formed basically by long carbon chains, resulting in a material that presents, in general, high molar mass. It can be natural or synthetic and, according to the mechanical properties, can be classified as thermoplastic, thermoset, and rubber. Thermoplastic is also known as plastic, which, in general, can flow when heated in the molten state and becomes solid when cooled; thermoset becomes rigid (cannot flow) after cure reaction; and rubber has elasticity due to the cross-linkings formed during vulcanization/cure reaction. Some characteristics of plastic such as the low cost [1], low density, flexibility, strength, user-friendly design, durability [2], and fabrication capabilities [1] make it ideal to be used as packaging.

During the COVID-19 pandemic, the role of plastic is on evidence, being considered a protector for saving lives, while as polluters when inappropriately disposed of causing environmental problems. As an example, masks can be mentioned. They are of mandatory use in the vast majority of countries, important to avoid the contamination and transmission of the disease, and that can become a socio-environmental problem when post-used masks are disposed of in inappropriate places.

Even before the crisis, the use of plastic, especially the one for single-use, was rethought, and a solution widely used in several places is the creation of laws prohibiting its use. With the pandemic, due to the importance of this material, opinions and laws on the use of plastic materials have been questioned around the world, and some existing laws were suspended.

Hence, in the past, considered a polluter and being banned around the world; suddenly, considered a protector. In a short period of time, too much information and abrupt habit changes make people confused. So, the main aim of this work is to propose a reflection on the true role of plastic in our modern society, especially in the coping with the COVID-19 pandemic, addressing topics such as the recycling of plastic during the pandemic, the socio-environmental problems concerning the inappropriate disposal of plastic, and a discussion about the role of plastic in the post-pandemic scenario.

2. COVID-19

Pneumonia cases have been reported in Wuhan, China, since December 2019, officially named as coronavirus disease (COVID-19) by the World Health Organization (WHO) [3,4]. COVID-19 was considered a Public Health Emergency of International Concern [5], and a pandemic [6].

COVID-19 is caused by a coronavirus called SARS-CoV-2. Coronaviruses are a large family of viruses that are common in people and different species of animals. Rarely can animal coronaviruses infect and spread among people, as occurred with SARS-CoV-2 [7].

Before discussing the role of plastic in the pandemic scenario, it is important to be clear about the main forms of COVID-19 virus transmission. The main form of transmission is from person to person (direct transmission), requiring no physical contact between infected and susceptible individuals. "Droplet sprays" of virus-laden respiratory tract fluid are released during a sneeze, a cough, or a speak. These droplets are typically greater than 5 μm in diameter [8,9], and can carry a variety of respiratory pathogens [10], impacting directly on a susceptible individual. The virus can be spread even when a person simply breathes [11]. Alternatively, microscopic aerosol particles (airborne transmission) consisting of the residual solid components of evaporated respiratory droplets can be inhaled, as they are tiny enough (<5 μm) to remain airborne for hours [12–14]. Another kind of transmission is known as indirect, which occurs via fomite, i.e., an object that has been contaminated with the infectious virus [13]. Figure 1 schematically shows the main ways of transmission. Transmission via the fecal-oral route is also possible [15–17].

Figure 1. Schema showing the main ways of COVID-19 contamination, in which the person (1) is infected (even being asymptomatic), and person (2) is not yet infected (susceptible individual): (a) Person-to-person and (b) via airborne or aerosol, which are direct ways of transmission. (c) Via fomite, an indirect way of transmission. (d) Contaminated objects, such as the table, are the result of the droplets fall containing active virus present in the airborne/aerosol and/or by the contact of the infected person. (e) By touching a contaminated object and touching the eyes, mouth, or nose, a healthy person can get infected. (f) Magnification of the active virus, present in the droplets excreted from the mouth and nose when the infected person sneezes, coughs, speaks, and breathes. Modified from [18].

In general, coughing produces the largest droplet concentrations and nose breathing the least [9]. The louder one speaks, the more aerosol particles are produced, regardless of the language spoken [10]. A 10-min conversation (normal volume) with an asymptomatic infected person exposes others to approximately 6000 aerosols, which can be inhaled [13]. Thus, it is demonstrated the importance of keeping away more than 1 m from an infected person [12], and wearing a protective face mask providing protection, since it is a kind of aerosol filter [19].

From this point on, the role of plastic during the COVID-19 pandemic will be addressed.

3. The Role of Plastic in the Pandemic Scenario

The role of plastic in coping with the COVID-19 pandemic will be divided into two sections: At home and in the hospitals.

3.1. The Role of Plastic at Home

As the transmission of the virus occurs incredibly fast, and aiming at the non-overload of hospitals, protective measures have been taken by most countries, with social distancing being the main one [13]. In many locations, only essential establishments have been kept open, some of them only for delivery. Online and app orders have been encouraged.

When going out shopping, protective measures such as improving personal hygiene, and wearing face masks can prevent the infection. When getting home, it is necessary to follow a whole hygiene protocol to avoid contamination. In this sense, the literature will be briefly discussed in the sequence, presenting some possibilities of hygiene protocols of plastic packaging as a great advantage, and correlated aspects.

Van Doremalen et al. [20] analyzed the stability of SARS-CoV-2 on surfaces and in aerosols. According to the results, SARS-CoV-2 was more stable on plastic (polypropylene) and stainless steel, and the viable virus was detected up to 72 h after application to these surfaces. SARS-CoV-2 remained viable in aerosols for 3 h, 4 h in copper, and 24 h in cardboard. Correspondingly, Chin et al. [21] demonstrated the stability of SARS-CoV-2 on different surfaces. No infectious virus could be detected on day 7 in plastic.

As aforementioned, the virus remains active for a longer time on different materials. Depending on the nature of the bonding force between the droplet/surface interfaces, even droplets invisible to the naked eye, it is defined that [22]: When $\theta > 90°$, there is no wetting of the solid by the liquid, that is, there is no scattering of the liquid (Figure 2a); when $\theta < 90°$, there is a wetting and the liquid spreads spontaneously (Figure 2b), θ being the contact angle.

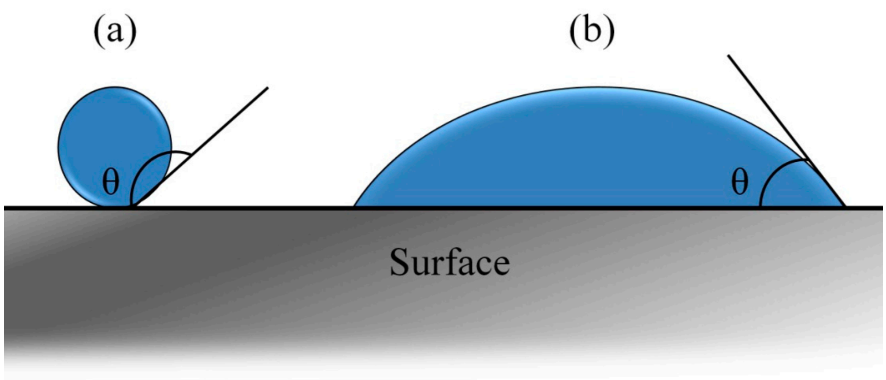

Figure 2. Nature of the bonding force between the droplet/surface interfaces: (**a**) droplet does not wet the surface, and (**b**) droplet wets the surface.

The droplets consist mainly of mucus, saliva, and active virus [23]. They have different sizes and compositions (which directly influence their viscosity), forming a kind of protective cover on the virus.

So, it is believed that the greater the intimate contact between them (Figure 2b), the greater the droplet tendency to remain on the surface. In other words, the higher the θ value (Figure 2a), the higher the probability/facility of the droplet to be removed from a given surface by the action of a sanitizer, for instance.

The wettability degree is influenced by the characteristics of the droplets, surface, and environment. Thus, the chemical structure of the surface/droplet (type and composition of plastic, processing used in the packaging production, etc), surface roughness, droplet viscosity, room temperature, humidity, air speed, among others. Some of them will be briefly discussed.

Regarding the temperature, the active virus is highly stable at 4 °C. However, its stability decreases with the temperature increase [21,24,25]. Concerning the surface roughness, Chin et al. [21] depicted that the smaller stability of the COVID-19 observed in papers, wood, and cloth (type A) is due to the higher roughness, since the stability was much higher in glass, banknotes, stainless steel, and plastic (type B), i.e., smoother surfaces (non-porous surfaces [26]). So, it is supposed that type A surfaces are represented by Figure 2a, whereas type B by Figure 2b. The transmission of the COVID-19 can be reduced by high relative humidity [25]. Besides, low wind contributes to the COVID-19 survival [26]. Some results [27] showed that, in Turkey, the higher the average wind speed, the higher the number of COVID-19 cases; the lower the temperature on a day, the higher the number of COVID-19 cases on that day.

Based on the aspects discussed until this point, doubts can be raised about the real protection resulting from a package as the virus can remain active on it. Some recognized organizations such as the WHO [12], US Department of Agriculture [14], US Food & Drug Administration [28], and Centers for Disease Control and Prevention [7] say that, until now, there is no evidence of fomite-to-human transmission, making it important to follow hygienic protocols.

Viral particles excreted from the mouth and nose are often found on hands, which can be spread to commonly touched items (abiotic built environment) (Figure 1). Other people then may catch COVID-19 by touching these contaminated objects or surfaces [29], then touching their eyes, nose, or mouth [12], making it important to sanitize surfaces. So, person-to-person transmission of droplets is the main way the virus spreads, followed by aerosol and fomite transmission. Thus, fomite-to-human, or indirect transmission, cannot be completely ruled out.

The great advantage of plastic packaging during outbreaks is the possibility of being cleaned or washed, creating a protective barrier in food, in addition to increasing shelf time (prevent food spoilage [30]), and security. Sanitization/cleaning of plastic packaging and its importance will be briefly discussed.

After purchasing, the packaging must be sanitized when arriving at home. Plastic packages can be washed with soap and water, or cleaned with simple disinfectant [12]. They can be cleaned with solutions containing 62% to 71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite for one minute [24]. It is important to wash the hands with soap and water for at least 20 s after handling food packaging, after removing food from the packaging, before preparing food for eating, and before eating; and frequent cleaning and disinfecting of surfaces [28], avoiding touching eyes, mouth, and nose [12].

Chin et al. [21] tested the virucidal effects of disinfectants (Table 1). No infectious virus could be detected after a 5-min incubation at 22 °C, except for a 5-min incubation with hand soap. These results demonstrate the importance of using these agents in the hygiene of hands and surfaces in the spread control of COVID-19. The effect of pH was also tested (pH 3–10), showing that SARS-CoV-2 is extremely stable in all of them at room temperature.

Besides, fruits and vegetables should be kept for at least 5 min in a container with water and sodium hypochlorite, and then washed in running water to avoid contamination. However, such a practice, depending on the food, can decrease its resistance when stored in refrigerators, for example. Thus, buying packaged foods can become an advantage, since they can be washed or cleaned by using one of the options described above, without damaging the food.

Table 1. Virucidal effects of different disinfectants on SARS-CoV-2, modified from Chin et al. [21].

Disinfectant (Working Concentration)	Virus Titre (Log $TCID_{50}$/mL)
	5 min
Household bleach (1:49)	Undetectable
Household bleach (1:99)	Undetectable
Hand soap solution (1:49)	3.6 *
Ethanol (70%)	Undetectable
Povidone-iodine (7.5%)	Undetectable
Chloroxylenol (0.05%)	Undetectable
Chlorhexidine (0.05%)	Undetectable
Benzalkonium chloride (0.1%)	Undetectable

* Only one of the triplicate reactions was positive in the $TCID_{50}$ assay.

3.2. The Role of Plastic in Hospitals

Most of the devices used to save lives are made totally or partially of plastic, such as respirators, thermometers, and COVID-19 tests, in addition to other more common and no less important items such as syringes, tubes, oropharyngeal cannulas, suction probes, catheters, packaging of saline solutions and medicines, among many others. There is also the case of expanded polystyrene, which acts as a thermal insulator and protector against mechanical stresses, protecting sensitive pharmacological products. Moreover, the use of single-use such as glasses and cutlery are important in hospitals to avoid the virus spread.

Additionally, indispensable during the pandemic, the personal protective equipment (PPE) used by hospital workers, composed of face masks, gloves, clothing, aprons, caps, covers, glasses/goggles, the vast majority of which are made of plastic. Surgical gloves are made of natural rubber, which is also a type of polymer. The literature highlights the importance of using these PPEs [19,31–35].

As explained by Czigány and Ronkay [36], all masks and particle filters are made of plastic (reusable masks). The face masks have typically several layers, mainly polypropylene, as its microfibers are hydrophobic, skin-friendly, and non-allergenic. Among the advantages, by using PPEs, the possibility of an epidemic or pandemic is decreased, stretching the virus spread in time, which means that the health care system does not have to treat a higher number of patients at the same time.

In the document published by the Brazilian Ministry of Health for the management of bodies in the context of the new coronavirus COVID-19, it warned about the importance of the use of PPEs by professionals responsible for preparing the bodies of COVID-19 victims in morgues and hospitals: it is necessary to use appropriate PPEs such as a beanie; goggles or facial protector; long-sleeved waterproof apron; surgical mask; waterproof gloves; and boots [37]. It is important to emphasize the importance of using waterproof materials to avoid contact with infected blood, fluids, and body secretions. Plastic materials are ideal for such applications because they are waterproof.

In the case of the hospital death, after recognition by a family member, the body receives three layers of protection: A sheet, a waterproof bag suitable to prevent leakage of liquids and secretions, and a second external bag, which should, at the end of the process, be cleaned and disinfected, and later identified with the data and the reason of death, after being placed in a sealed coffin. If death occurs at home, the removal of the body must be done by the health team, and the body is wrapped in sheets and plastic bag, which should prevent the leakage of bodily fluids during the transport to the morgue, following the same steps for preparation described for death in the hospital [37]. Such procedures vary according to the standards of each country, highlighting the importance of the use of plastic materials in the fight against the spread of the virus.

In the case of interim guidance of 24 March 2020 from WHO, called Infection prevention and control for the safe management of a body in the context of COVID-19 [38], it described the need not to use body bags (made of plastic), although they may be used for other reasons (e.g., excessive body fluid leakage).

Another important application of plastic during the pandemic is as a thickening agent in alcohol in gel, widely used for hand hygiene. It has advantages such as convenience and ease of application, and avoids waste due to its high viscosity. Being composed of ethanol 70%, it becomes more flammable, and the higher viscosity of alcohol in gel brings greater safety, besides having proven action in combating the virus.

So far, the importance of plastic has been evidenced, especially as a protector during the current pandemic. However, the same protector can easily become a polluter when inappropriately disposed of in the environment. Some socio-environmental problems caused by plastic will be discussed in the next section.

4. Socio-Environmental Problems Caused by Plastic

During the pandemic, the production of plastic waste has increased worldwide, either by the increase in packaging or use of PPEs by the population in general, such as masks. It is important to keep in mind that each citizen is responsible for the waste they produce as well as its disposal, and this improper disposal can cause or aggravate environmental problems, such as in Figure 3a, which shows a post-used glove that was inadequately disposed of on the sidewalk.

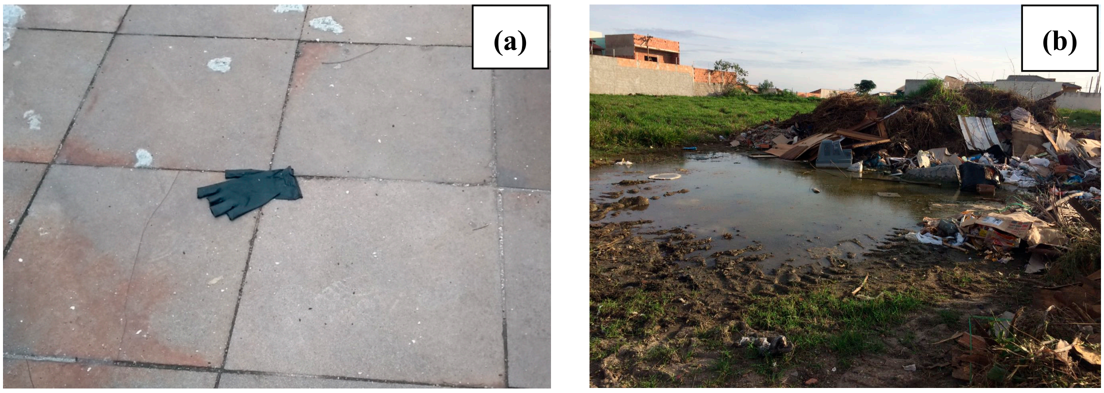

Figure 3. (**a**) Post-used glove inappropriately disposed of on the sidewalk, and (**b**) irregular disposal of waste in a wasteland.

This plastic improperly disposed of ends up, in one way or another, having different water bodies (rivers, seas, and oceans) as its destination [39], increasing the serious environmental problem of plastic in the waters [40]. Pollution in general and other environmental problems may negatively impact the population health, with COVID-19 possibly having been influenced as well [41–45]. “Rampant deforestation, uncontrolled expansion of agriculture, intensive farming, mining and infrastructure development, as well as the exploitation of wild species have created a ‘perfect storm’ for the spillover of diseases from wildlife to people” [46]. According to WHO [47], 23% of premature deaths worldwide could be attributed to environmental factors.

Unfortunately, news about the presence of masks and gloves in oceans, seas, and rivers, which were used to prevent the spread of COVID-19, has been increasingly common around the world [48]. Not that people throw their masks and gloves in the waters, but because they are thrown in inappropriate places (as in Figure 3a) and they are advected by wind, stormwater, drainage systems, and wastewater [49], ending up in the waters. Around 8–13 million tons of plastic reaches the water bodies per year [50,51], being that inappropriately disposed of PPEs is worsening the problem. Thus, at the same time that the crisis has brought improvements to the environment as a reduction in air pollution levels [44,52], referred to as positive indirect effects of COVID-19 on the environment [53], it seems to aggravated marine pollution, the negative indirect effect of COVID-19 on the environment [53], with the lack of awareness of the population as a great ally. These post-used PPEs, called 'pandemic plastics', are worse than a simple bottle of water incorrectly disposed of, since they are hazardous in terms of being pathogen contaminated.

The United Nations Environment Program launched, in early 2017, the global campaign #CleanSeas to end up the marine litter accumulation [51]. This pollution damages marine wildlife, the fishing industry, and tourism, costing at least $8 billion in damage to marine ecosystems. Estimates indicate that, if the inappropriate disposal continues, by 2050 the oceans will have more plastic than fish (in mass). Waste plastic makes up 80% of all the marine litter from surface waters to deep-sea sediments [54]. It has been predicted that 155–265 million tons of plastic accumulation in the natural environment by 2060 [55].

The problem is extremely serious, as many seabirds and animals die from plastic consumption. They are attracted by the movement and colors of these residues in the waters, confusing them with their prey and, consequently, the vast majority of these animals die of starvation. Their stomach is full of residues, not digested, giving the satiety sensation and reducing the animal's food instinct, leading to malnutrition. Still, sharp or pointed objects may cause internal injury to animals, causing them to die in the same way, or they are asphyxiated by plastic residues. Also, species that return to the surface to breathe can become attached to fishing nets and other residues, causing death by drowning [56]. For instance, last year a sperm whale became stuck on a beach on the Isle of Harris in Scotland and died, with 220 lb of debris found in its stomach including bundles of rope, plastic gloves, bags, and cups [57]. Very recently, a Magellanic Penguin was found dead on a beach in the city of São Sebastião, north coast of São Paulo, Brazil. During the necropsy, a mask was found in its stomach, the cause of its death [58].

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [59], marine plastic pollution has increased tenfold since 1980, affecting at least 267 species, including 86% of marine turtles, 44% of seabirds, and 43% of marine mammals, affecting humans through food chains.

Macroplastics from packaging in general, post-used gloves and masks, when present in water (i.e., when inappropriately disposed of), due to the action of the weather and the inherent degradation of the material, turns into microplastics over the years (pieces smaller than 5 mm) [60,61]. Water pollution by microplastics is considered a socio-environmental problem, which may damage human health, aquatic fauna, and flora [62–64]. Human exposure to microplastics could be through the food chain (ingestion) or due to air inhalation [65], with their presence confirmed in seafood, sea salt, sugar, honey, tap water, and beer [66–69].

The same glove shown in Figure 3a and its future destination is schematically shown in Figure 4. Someone inappropriately disposed of it on the sidewalk, while a strong storm was coming. The glove ended up in the sea, and through the action of the environment, its degradation started. The time went out, and its pieces got smaller and smaller, being transformed into microplastics, and ending its destination in various foods and beverages previously mentioned, which will be consumed by the population.

Waste disposed of in inappropriate places can also contaminate the soil and groundwater due to slurry produced from the decomposition and percolation of water through waste (such as in Figure 3b), in addition to the risk of fire, both by self-combustion (spontaneous ignition) and by intentional/criminal ignition. Slurry usually contains toxic metals and other harmful waste stemming from improper disposal of materials such as solvents, paints, cleaning products in general, and oils, among many others [70]. The waste pile begins with the inadequate disposal of any waste, such as a glove (Figure 3a) or a mask that was used to save lives. Besides, it can assist in urban waterproofing, aggravating the problem of floods in cities through the clogging of manholes caused by the accumulation of waste carried by rainwater or winds (Figure 3). Furthermore, clogged manholes and waste disposed of in inappropriate places (Figure 3b) can become ideal environments for the reproduction of disease-transmitting insects, such as *Aedes aegypti* mosquito, the vector of diseases such as dengue, chikungunya, yellow fever, and zika [71].

Figure 4. Schema showing the degradation process in the sea of the glove inadequately disposed of as previously showed, its transformation into microplastics, and its destination to foods and beverages, which will be consumed by the population. Modified from [18].

Last, but not least, maybe the most important aspect to be considered about the irregular disposition of post-used EPPs is the possibility of contamination, since they are hazardous residues pathogen-contaminated. Even knowing that the survival time of the virus is tiny [24], it could be enough to reach other organisms, to mutate and change characteristics, among others [72], in addition to endangering the safety of people, especially those who work in the cleaning sector of cities.

It is essential to bear in mind that post-used gloves and masks are non-recyclable items. As a general rule, all the items containing the global symbol of recycling are subject to recycling, such as packaging in general. Subsequently, to minimize the aforementioned socio-environmental problems, one of the possibilities is the continuity of recycling, even during the pandemic. Aspects related to plastic recycling will be addressed in the sequence.

5. Recycling of Plastic during the Pandemic

Some important points were depicted previously, such as the importance of sanitizing the packages, the possible products to be used for this, and the survival time of the virus in different surfaces. All this information must be pointed out when thinking about recycling during the COVID-19 pandemic.

Concerning the recycling, the source of danger and cross-contamination is in the interface between the generator—considered to be an individual discharging or depositing their recyclables and waste into a public system—and the handler—the professional who is doing something with the recyclable materials or the residual waste. In other words, the risk of infection concerning the recycling is usually when the worker takes any material from the generator (has physical contact with the material), which can be contaminated [73]. So, healthy people should continue to help with recycling, by cleaning the packages after using, separating, and sending them to the selective collection. After using the packages, they must be cleaned to remove organic residues, and stored in clean closed plastic bags or in boxes for a period of seven days before selective collection [74]. By doing so, the survival time of the virus is exceeded [21], and the handling of the packaging will be safe in the recycling sector.

According to the International Solid Waste Association (ISWA) [75], masks, gloves, and fabric, as well as contaminated residues are not recyclable, even knowing that they are made of plastic. In the case of an infected person, their residues (contaminated residues) must be put into two closed bags, not filling them up (around three-quarters of the total capacity of the bag), and put in the mixed waste (trash) with a label "COVID-19", not in the selective collection. During the crisis, people must be collaborative and protect themselves and others, especially the professionals working in the collection and treatment of waste, which are essential to our society and considered front-line workers.

At this point, it is important to reflect on the importance of the waste workers in our society. They expose their lives to protect ours. During this crisis, these workers are more exposed because they are on the streets to work despite isolation, since the waste itself is not considered an effective vector for transmission [74]. As mentioned before, there is no evidence of COVID-19 transmission via fomite-to-human [7]. To ensure their health, hygiene norms must be enhanced, such as frequent change and cleaning of PPEs and professional clothing, use of professional gloves and masks, and frequent hand-washing [73]. However, many workers of the recycling sector work in precarious conditions, especially self-employed or informal waste pickers, very common in developing or underdeveloped countries [76].

Contaminated residues such as single-use PPEs are considered infectious waste and, in this case, thermal treatments are safer. In the case of absence, sanitary landfills can provide an alternative disposal route [75]. Reusable PPEs should be cleaned under the manufacturer's instructions [38]. According to Czigány and Ronkay [36], reusable face masks have typically several layers, mainly polypropylene. As they may be considered hazardous residues, they are still recyclable, and mechanical recycling (which typically means extrusion in the melt state at about 180 °C) could be a safe way of disposal. In this case, to recycle them, the same pieces of advice depicted above should be followed.

Hospital and medical waste, hazardous residues, must be properly collected, treated, and disposed of to avoid pollution and health risks [75]. If the contaminated waste was not properly treated, it can be a source of infection. According to some authors [77], the biggest challenge concerning waste management during pandemics is to ensure the destruction of residual pathogens in household and medical waste. The literature warns about the risks from the improper management of contaminated residues, including post-used PPEs, which may increase the spread of viral disease [78].

Even having clear in mind the magnitude of recycling, it should be pointed out that recycling during the outbreak of COVID-19 became a huge challenge, since recycling facilities and programs have been shut due to the pandemic [79]. Some cities of the US have suspended recycling programs because authorities have been concerned about the risk of spreading the virus in recycling centers, and in some countries of the EU, the waste management was restricted [53]. In some cities, such as São Paulo, Brazil, only mechanized separation has been performed to avoid possible contamination of workers. Besides, unfortunately, many cities from developing or underdeveloped countries, such as Brazil, run the risk of completely stopping the selective collection service due to lack of funds during the pandemic crisis [80].

Considering the increase in deliveries due to isolation, the amount of packaging produced per household tends to increase significantly. Accordingly, a recent survey reveals that the producers of packaging for food, pharmaceutical, and medical products are, in some cases, reaching the limits of their capacity [81,82]. Hence, a recent balance from the Brazilian Association of Public Cleaning and Special Waste Companies (Abrelpe) showed the variation in the amount and composition of the waste generated in Brazil in April 2020: Waste generation was 7.25% lower compared to the same month of 2019, with an increase in the volume of recyclable materials between 25 and 30% [80]. Consequently, the continuity of recycling is essential during the pandemics, name it "if households and businesses massively stop with separating recyclables and delivering them separated to separation containers, the overall waste system will be saddled with between 30 and 50% more materials and there is a risk of system failure" [73].

6. Discussion

Due to the socio-environmental problems generated (or aggravated) by the improper disposal, there has been great effort around the world to reduce the use of single-use plastic materials such as straws and bags, until the COVID-19 emerged. Regarding bags, their use had been banned in several countries, and the adoption of reusable bags had been widely encouraged.

Conversely, even before the pandemic state was decreed, the use of reusable bags was controversial in terms of food safety since consumers transport many different foods, which could contaminate their bags and pose a risk to their health due to cross-contamination [83]. Recently, the level and variety of microbial contamination of some used reusable plastic bags was demonstrated [83]. Several genera of *Enterobacteriaceae*, coagulase-negative staphylococci, and *Listeria monocytogenes* were found including, in general, high percentages of antibiotics resistance. Many members of the *Enterobacteriaceae* family are responsible for the spoilage of a great variety of foods.

Williams et al. [84] also analyzed the contamination of some used reusable bags. Bacteria were found in 99% and coliform bacteria were detected in 51% of the bags tested, with generic *Escherichia coli* in 8%.

Reusable bags, if not regularly washed, create the potential for cross-contamination of foods, especially when raw meat products and uncooked foods (fruits and vegetables) are carried in the same bags, either together or in different uses.

Washing reduces the bacteria in bags by >99.9%. However, interviewers indicated that only 3% regularly clean their bags [84]. Another option to reduce the problem is to use separate bags for different classes of products, such as fruits and vegetables, meats, and ready-to-eat foods [83].

In contrast, single-use plastic bags [85], first-use reusable bags [84,85], and new cloth reusable bags [84] showed no evidence of bacteria, depicting that the first option is more hygienic than reusable bags.

Furthermore, the Danish Ministry of Environment compared the life-cycle assessment (LCA) of alternative grocery shopping bags [86]. Overall, single-use bags (plastic, paper, and biopolymer) provided the lowest environmental impacts, concerning climate change impacts. On the other hand, reusable bags made of composite and cotton obtained the highest environmental impacts (climate change impacts, human toxicity, cancer effects, and resource depletion), making it necessary to reuse them 20,000 times to lower the environmental impacts related to their production to values comparable to single-use bags. Reuse is encouraged for all types of bags as it helps reduce the impacts generated.

Due to public health during the COVID-19 pandemic, nowadays many places do not allow, or no longer encourage, the use of reusable bags [87–89]. "Just weeks ago, cities and even states across the US were busy banning straws, limiting takeout containers and mandating that shoppers bring reusable bags or pay a small fee as a movement to eliminate single-use plastics took hold in mainstream America. What difference a pandemic makes. In a matter of days, hard-on bans to reduce de use of plastics—and particularly plastic shopping sacks—across the US have come under fire amid worries about the virus clinging to reusable bags, cups, and straw" [87]. The COVID-19 pandemic brought with it the opportunity to rethink plastic bag bans [88]. In São Paulo, a law prohibiting the use of single-use glasses, cutlery, and plates was recently suspended due to the pandemic [90].

At this point, it is important to reflect on the post-pandemic scenario. New laws to preserve the environment are always welcome, and even the change people mindset is not an easy task. People who were changing habits, becoming more aware consumers, were unexpectedly interrupted by the pandemic. After the crisis, the world will slowly return to its normality, and known environmental problems will be aggravated.

Bearing in mind the benefits of using plastic to avoid the virus spread, and based on the discussion about the use of reusable bags and the results of the LCA study, maybe it is time to rethink the use of single-use bags. However, rethinking does not necessarily mean encouraging its use or even use it indiscriminately. It is necessary, whenever possible, to reduce the quantity at source.

In the post-pandemic scenario, among the priority issues to be addressed, will be paradigm shifts in waste management.

The changing habits of the population increased the production of recyclable waste, thus requiring recycling companies to increase the production capacity, by implementing systems for collecting and selecting recyclable materials more effectively, including new process improvements [91,92], which will reduce unnecessary losses and expenses. So, a modernization in the process is necessary to make it more efficient (with automation and digitalization as examples [93]), so investments in the sector will be required.

However, the global economic crisis could damage the recycling industry, and a reduction in investments may damage the development of the sector. The implementation of new technologies requires investments, which will be probably postponed. To avoid this, financial aids from governments could be necessary.

New targets will be imposed by the circular economy. New laws will be created aiming at greater responsibility of the producing companies, mainly packaging, as a way to implement reverse logistics. Some countries, such as Spain, are trying to reduce the production of plastic waste by creating new taxes, called green tax [94]. The use of plastic microparticles in hygiene and beauty products will also be prohibited. In Canada, the extended producer responsibility was implemented, supporting Canadian commitments to move towards zero plastic waste [95].

The recycling process will have a greater emphasis on society, encouraging the use of recycled materials. For instance, packaging companies could synchronize new product designs with recyclers before launching them to market [93]. Besides, government regulations including new long-term targets will be created in favor of the population, in line with academic results. As mentioned by Dente and Hashimoto [96], “the combination of analytical tools such as material flow analysis, LCA, network analysis and input-output analysis appear necessary to fully comprehend the consequences of the COVID-19 epidemics”.

One interesting example is the one by Singkran [97], who analyzed the assessment of urban product consumption and the relevant waste management of Bangkok. The worst result was obtained for plastic, with the plastic waste left in the environment. According to the author, to increase the city’s consumption efficiency, minimization of product consumption and waste for disposal should be considered simultaneously with the improvement of relevant practices and regulations on waste minimization. A similar study was performed in Austria, Germany, and Serbia, about polyethylene terephthalate (PET) bottle recycling by using material flow analysis and LCA [98].

Last, but not least, the recycling sector can be a major ally in job creation, strengthening economies during the post-crisis period.

From this point on, some people’s points of view who are engaged in different sectors involved in the plastic issue will be addressed in their own words:

- “The industry is also noticing that consumers’ view of plastic packaging has changed during the crisis. The function of the packaging, i.e., the hygiene and protection of the product, is being perceived more strongly again. We hope that this contributes to a more objective discussion about plastic packaging in the future”, said the IK (Industrievereinigung Kunststoffverpackungen) General Director Dr. Martin Engelmann to the survey [82].
- “We have been reminded of the value these materials bring. After we have recovered, we should focus our efforts on truly fixing our broken waste management system instead of banning valuable products in a futile attempt to adapt to it”, said Ineos [88].
- As said by Antonis Mavropoulos, president of ISWA:”I think the first thing we have to conclude is that single-use and easy disposability has become a massive trend again in this period, probably in a way, canceling efforts of many years to reduce single-use packaging” [79].

- According to The International Union for Conservation of Nature (IUCN) [54], recycling and reuse of plastic products, and support for research and innovation to develop new products to replace single-use plastics are necessary to prevent and reduce plastic pollution.
- According to Zambrano-Monserrate [53], "the virus crisis brings other environmental problems that may last longer and maybe more challenging to manage if countries neglect the impact of the epidemic on the environment".
- "We can build back better and emerge from the current crisis stronger and more resilient than ever—but to do so means choosing policies and actions that protect the nature—so that nature can help to protect us", according to IPBES [46].
- "People's safety should come before profits", said Greenpeace [99].

It seems that the outbreak crisis made the different views of the sectors enrolled even more visible, and not only the fight against COVID-19 is on course nowadays. Consumers, government, and companies, acting in an integrated manner, are the fundamental elements for a paradigm shift [76]. Each sector is co-responsible for the environmental problems generated by plastic.

There is no doubt of the importance of the use of plastic in the development of today's society. After analyzing all the highlighted issues, there is no hesitation about the role of plastic during an outbreak pandemic such as the COVID-19, especially in the fight against the virus, safety, and population health. By using it, the virus spread is avoided, and millions of lives around the globe are saved. However, and after finishing this global crisis, will plastic continue playing the same role?

7. Conclusions

This work proposed a critical overview of the role of plastic during the COVID-19 pandemic. The real possibility of the virus spread from the use of plastic, the recycling of plastic during the pandemic, and the problems that it may cause when inappropriately disposed of were discussed, trying to propose a future panorama. This is undoubtedly a life-saving protector, but can become a polluter if not properly used and disposed of.

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