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Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations

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HIGHLIGHTS

- Plastic policy was adapted due to COVID-19 pandemic.
- COVID-19 pandemic is contributing to worldwide plastic pollution.
- COVID-19 precautionary measures challenged environmental sustainability.
- Sustainability calls for straightened links between policy-industry-research.

GRAPHICAL ABSTRACT

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ABSTRACT

Plastics have become a severe transboundary threat to natural ecosystems and human health, with studies predicting a twofold increase in the number of plastic debris (including micro and nano-sized plastics) by 2030. However, such predictions will likely be aggravated by the excessive use and consumption of single-use plastics (including personal protective equipment such as masks and gloves) due to COVID-19 pandemic. This review aimed to provide a comprehensive overview on the effects of COVID-19 on macroplastic pollution and its potential implications on the environment and human health considering short- and long-term scenarios; addressing the main challenges and discussing potential strategies to overcome them. It emphasises that future measures, involved in an emergent health crisis or not, should reflect a balance between public health and environmental safety as they are both undoubtedly connected. Although the use and consumption of plastics significantly improved our quality of life, it is crucial to shift towards sustainable alternatives, such as bio-based plastics. Plastics should remain in the top of the political agenda in Europe and across the world, not only to minimise plastic leakage and pollution, but to promote sustainable growth and to stimulate both green and blue- economies. Discussions on this topic, particularly considering the excessive use of plastic, should start soon with the involvement of the scientific community, plastic producers and politicians in order to be prepared for the near future.

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1. Introduction

Since December 2019, the world was affected by a pandemic originated by a novel coronavirus (SARS-CoV-2) responsible for a severe respiratory syndrome known as COVID-19 [1]. The severity of COVID-19 disease, allied with its high contagiousness (e.g., direct human contact or contact with contaminated surfaces/waste, airborne/respiratory droplets and oral-faecal transmission [2-4]) and the absence of a safe and effective vaccine, has raised attention and fear from governments, medical staff, the scientific community, and the general public towards prevention and control of its transmission.

As an attend to flatten the epidemic curve ($R_0 \leq 1$), governments worldwide have implemented several precautionary measures. Some include partial or total lockdown of cities/regions/municipalities (e.g., Italy and Spain on 10th and 16th March, respectively), restrictions on social contact and social distance, reduced mobility of goods and passengers, reduced economic activities and businesses to essential supply chains only [5]. Alongside, the creation of provisory treatment facilities for COVID-19 patients with moderate to severe symptoms, the limited access to hospitals and healthcare facilities by family/visitors, the mandatory quarantine (self-isolation) of COVID-19 patients with minor symptoms, and the mandatory use of personal protective equipment (PPE) by frontline workers (which use dramatically increased in the infectious disease units), have been implemented to protect the Hospitals and other Healthcare system of breaking down [6,7].

However, what started as a health crisis promptly evolved into an economic, social and environmental threat. With public health now being of utmost priority, along with close monitoring of economic and social impacts, the implications of COVID-19 in the environment remains largely undervalued [8]. Unmanaged plastics waste is particularly concerning due to its implications to natural ecosystems and public health and safety. Nonetheless, environmental health problems have received less and less attention from governmental agencies, the scientific community and general public. This can be perceived by the withdrawal of several national and state-wide agreements on the use and consumption of plastics [9], and the numerous publications in international peer-review journals (Fig. 1). Even though publications on COVID-19 pandemic have increased in the last 3 months, the number of studies in environmental sciences (< 3%) is considerably lower than other fields, such as medicine and health (65%). From those on environmental sciences, only approximately 20% addressed the effect of COVID-19 disease on waste and plastic pollution (Fig. 1A and B).

This paper provides a comprehensive review on the potential impact of COVID-19 pandemic precautionary measures in the environment while considering the shift on public behaviour and policies towards single-use items and waste management. It provides an in-depth discussion on both short- and long-term environmental effects of COVID-19 pandemic – particularly considering plastics use, consumption and waste mismanagement - that remained poorly covered by the recently published critical reviews on similar topics [8,10-12]. It also identifies the main challenges and discusses mitigation measures to overcome them, with particular emphasis on the reduction of plastic production and waste generation.

2. Impacts of COVID-19 preventive measures on the environment in a short-term scenario

At first glance COVID-19 pandemic seems to be indirectly contributing towards the UN 2030 Sustainable Development Goals (namely 11, 12, 13, 15 SGDs) by increasing overall health and safety of cities by reducing the greenhouse gas emissions (GHG), outdoor air pollution, environmental noise level (including underwater noise due to reduced marine transportation activities), land and wildlife pressure. However, it is failing considering the poor indoor air quality, increased use-consumption patterns of single-use-plastics (including PPE) and a shifted priority on waste management, behavioural that is contrary to environmental sustainability (including the green and circular economies) (Table 1).

Table 1: Positive and negative consequences of COVID-19 pandemic and lockdown measures on the environment.

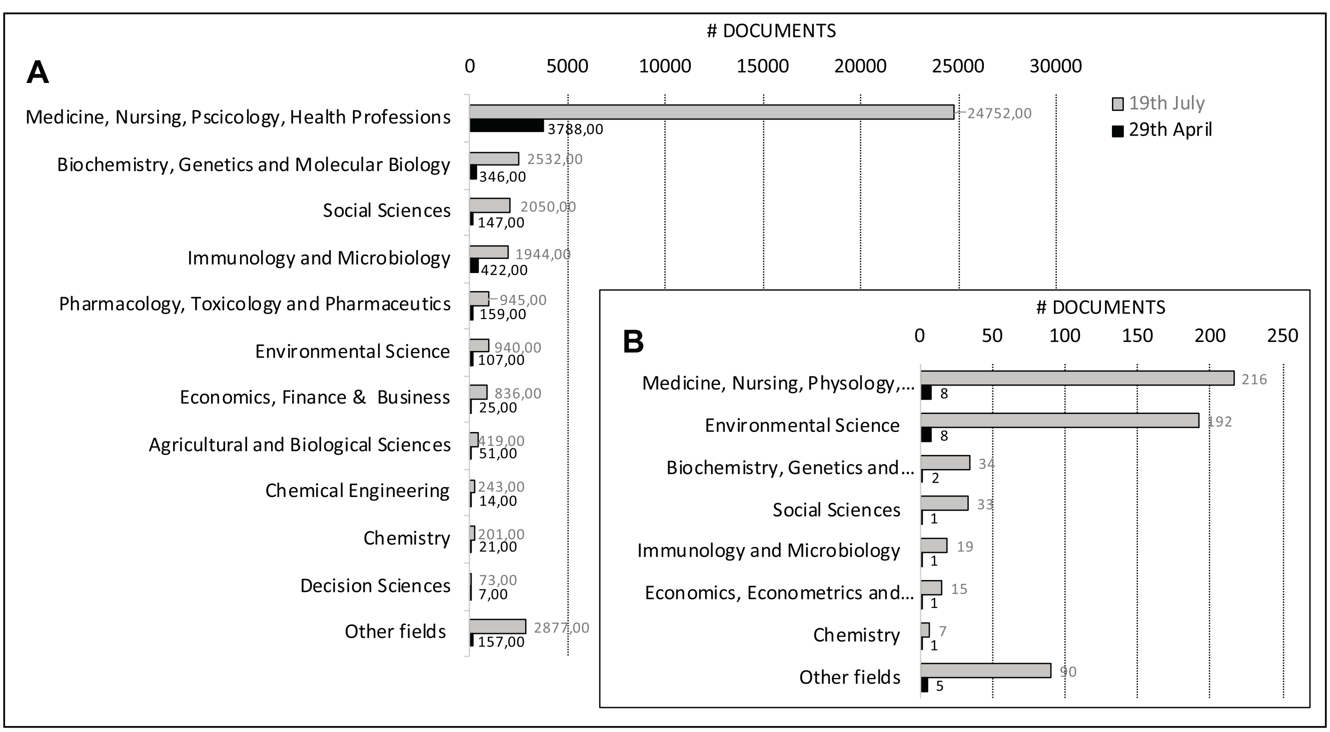

Fig. 1. Number of scientific documents published in 2020 by subject area by searching for keywords COVID-19 or SARS-CoV2 (A); the number of scientific documents published in 2020 by searching the previous keywords in addition to the keyword “Plastics” or “Pollution” or “Waste” (B). Data retrieved from Scopus on 29th of April and 19th July 2020. Scientific documents include scientific article, letter, editorial, note, review, short survey, conference paper, data paper.

While the positive impacts of COVID-19 in the environment are resulting from a "postponed" anthropogenic activity that soon will entail after the pandemic scenario; the negative short-term effects (that are mostly related with plastic use, consumption and waste mismanagement as discussed below) will shortly add-up to the current environmental issues, aggravating their impact in the natural ecosystems and compromising potential mitigation/remediation measures.

2.1. Increased medical waste during the pandemic

Cities facing high COVID-19 incidence rates are struggling to manage the dramatic increase in medical waste production by healthcare facilities. For instance, the King Abdullah University Hospital in Jordan produced tenfold higher medical waste (~650 kg per day, when considering an occupation of 95 COVID-19 patients) than the average generation rate during the regular operational day of the hospital [25]. A drastic increase in medical waste was also reported in other parts of the world, such as in Catalonia, Spain, and in China, with an increment of 350% and 370%, respectively [30]. The dramatic increase in medical waste is overloading the capacity of each country or municipality, to manage/treat it adequately. Due to the persistence and high contagiousness of SARS-CoV-2 virus, many countries are classifying all hospital waste as infectious, which require to be incinerated under high temperatures, allowing sterilisation, followed by landfilling of residual ash. While some countries or municipalities will manage alternatives to treat medical waste properly, others (with less economic and waste management resources) might be forced to apply inappropriate management strategies, which will likely entail adverse effects to the environment, human health and safety, while raising the potential for a second wave of epidemy. As examples, Wuhan inhabitants in China (~11 M) produced 200 tons of medical waste on a single day (on February 24, 2020), which is four times higher than can be incinerated by the city's only dedicated facility, forcing authorities to deploy mobile treatment facilities [8]. Conversely, some Indian municipalities are following a flawed system of medical waste disposal and management, which mostly rely on landfilling and local burning strategies [31]. Uncontrolled incineration of medical waste, which is mostly made of plastic, is not recommended, as it contributes to the release of GHG, as well as other potentially dangerous compounds, such heavy metals, dioxins, PCBs and furans [32].

2.2. Need for a proper use and disposal of personal protective equipment

To prevent virus transmission, the use of PPE, such as medical masks and gloves, by medical staff and health workers, and later on by ordinary citizens became essential. The demand for PPE increased significantly worldwide. For instance, an estimated monthly use of 129 billion face masks and 65 billion gloves would be necessary to protect citizens worldwide [33]. The use of PPE, especially of face masks, has been incentivised in some highly impacted areas (regions/municipalities), but quickly spread to the worldwide population driven by anxiety and the perceived feeling of safety. The increased demand and indiscriminate use of PPE by ordinary citizens quickly became controversial due to the lack of correct handling and disposal, and the shortage of this material in Healthcare facilities, where such material is mandatory and of utmost importance [34]. Surgical masks and gloves should not be worn longer than a few hours and should be adequately discarded to avoid cross-contamination. In this sense, several countries have tried to implement safety measures considering the disposal of potentially infected PPE. As an example, the Portuguese Environmental Agency recommended that all potentially contaminated PPE used by ordinary citizens should be disposed of as mixed wastes (not recyclables) in sealed and leak-proof garbage bags, that will likely follow to incineration facilities (preferable), or daily landfilling [35]. Several states in the U.S. have also stopped recycling programs, as authorities have been concerned about the risk of COVID-19 spreading in recycling centres [26], thus prioritising both incineration and landfilling. Such a reduction in waste recycling is divergent from the goals of circular economy [36] and sustainable development, and even contributing to plastic waste pollution. In most cases, PPE will likely end up discarded without precautionary measures along with empty bottles of hand sanitiser and organic solid wastes in regular municipal solid waste, or worse, littered in the environment. Incorrect disposal of disposable gloves and masks, along with other plastic items, have been found littering in several public places. For instance, a considerable amount (compared with only one or two items observed per month) of disposable masks was observed in a 100 m stretch in Soko's islands beach, Hong Kong, during an environmental survey carried out by the NGO Oceans Asia (http://oceansasia.org/beach-mask-coronavirus/).

2.3. Increased use and demand of single-use-plastics

The increased waste production related to PPE soon became accompanied by the increased use and disposal of other single-used-plastics (SUP). For instance, demand on plastics is expected to increase by 40% in packaging and 17% in other applications, including medical uses [33]. Safety concerns related to shopping in supermarkets during COVID-19 led to a preference of consumers and providers for fresh-food packaged in plastic containers (to avoid food contamination and to extend shelf-life), and for the use of single-use food packaging and plastic bags to carry groceries. In order to address customers concerns and assure their safety, supermarkets implemented additional health safety measures such as social distance, cleanliness, hygiene, and, in some cases, by providing home delivery and/or a pick-up service. Taking advantage of these preferences, plastic industry lobbyists have raised doubts with governmental leaders concerning food safety, hygiene and cross-contamination when using reusable containers and bags during the COVID-19 pandemic. Although lobbyists from the plastics industry have capitalised on these concerns before (e.g., [30]), recent concerns over COVID-19 safety have then resulted in a reversal of policies to ban or reduce SUP and fee payments in some jurisdictions. For example, in New York and Maine, SUP ban was delayed to 15th of May 2020 and 15th January 2021, respectively; while Massachusetts and New Hampshire reintroduced SUPs and even banned the use of reusable shopping bags due to potential health threats to workers and customers [9]. Viable SARS-CoV-2 virus persists longer on plastic surfaces than other materials, such as cardboard [as reviewed by 9, 32]; thus it could be argued that rescinding SUP bans could be premature, as many

Table 1
Positive and negative consequences of COVID-19 pandemic and lockdown measures on the environment.

Positive impacts	Negative impacts
• Increased outdoor air quality [13-16] • Decreased pollution noise [17,18] • Decreased household food waste [19] • Decrease energy consumption and GHG emissions [20,21] • Global decrease on wildlife trade [22] • Decrease on deforestation [22] • Increase in surface water quality [23]	• Decreased indoor air quality [14,24] • Increased medical waste [25] • Decline in waste recycling with increase in incineration and landfilling [26] • Increased disinfection routines with hazardous chemical substances in household and outdoor environments [27,28] • Increased ecological risk to natural ecosystems due to the use of disinfectants [29]

consumers have already adjusted to using non-plastic alternatives following the implementation of these policies these policies in many jurisdictions worldwide [37,38]. Besides, it is unclear how reusable grocery bags could contribute to higher risk compared to clothes or shoes, a potential risk that could also be mitigated with proper hand hygiene and decontamination bath (i.e., soaked in liquid soap and water temperature > 40 °C). The end-of-life waste management for many SUP during COVID-19 is likely as mixed municipal solid waste, as recycling streams are being restricted worldwide. Thus, as COVID-19 disease continues to spread across the world, the indiscriminate use and incorrect disposal of medical and plastic waste by billions of citizens (most of them with low biodegradation rates in open environments) is rapidly becoming a global and emerging issue.

2.4. Disinfection of common public places

As COVID-19 is transmitted by contaminated surfaces, several disinfection campaigns have been applied to several facilities such as hospitals, offices, clinics, universities, airports; and public places such streets, public gardens and even beaches. Yet, the choice of the chemical disinfectants and the places for disinfection have been highly questionable. For instance, the majority of products used to disinfect against COVID-19 that meets the Environmental protection Agency (EPA) criteria contain quaternary ammonium and sodium hypochlorite (bleach) [17]. But other mixtures of hydrogen peroxide, isopropanol, among others, have also been applied. According to several studies, the regular use of ammonium and bleach have been leading to a negative impact on human health. For instance, several studies report a link between the use of disinfectants and chronic obstructive pulmonary disease among healthcare workers, and between asthma and exposure to cleaning products and disinfectants in household settings [39,40]. Furthermore, foetuses and very young children are sensitive to the effects of such toxic chemicals, which had been also related with childhood cancer and asthma [41]. Moreover, most disinfectants used, such as quaternary ammonium and sodium hypochlorite, are rapidly exhausted in the presence of organic matter, reducing their activity and efficacy when simply sprayed over surfaces where organic matter can be found (e.g. streets) [42].

Likewise, the disinfection of a natural environment brought negative impacts on local fauna and flora. As an example, the regional government in Andaluzia, Spain, even sprayed a 1.9 km beach in Zahara de los Atunes with a diluted bleach solution as an overwhelming attempt to stop COVI-19 spread. Nevertheless, such a measure was quickly questioned by biologists and conservationists, as it might bring severe negative consequences to local nidificant avifauna, crab species and beach flora. The application of disinfectants in farms has also a high probability of occurring, and previous studies already highlighted the connection of the application of disinfectants with increased health risk factor in farm animals (e.g., pigs) and farm workers [43,44].

3. Impacts of COVID-19 preventive measures on the environment in a long-term scenario

Although the plastic demand and waste generation are yet to be assessed for the first semester of 2020, it can be predicted a generalised increment on packaging and on medical sectors due to the demand for SUP (also boosted by the shift in ban policies) and PPE due to COVID-19 [9,30]. SUP was already one of the major contributors to marine litter [37]. And, considering the mandatory use of PPE (particularly masks of single usage) will soon contribute with a great share. For instance, in United Kingdom (66.7 million inhabitants), it is predicted that if every citizen used one masks per day would generate at least 60 000 tonnes of contaminated plastic waste [66].

Plastic pollution before COVID-19 pandemic was already scaling in terrestrial, aquatic, and atmospheric environments [37]. An estimated 4.8–12.7 million metric tons (Mt) of mismanaged plastic waste generated on land entered the marine environment in 2010 alone [46], with much of this (1.2–2.4 million Mt) delivered by rivers [47]. A study by Eriksen et al. [48] reported that over 5 trillion plastic debris was estimated floating in the world's oceans. However, even this staggering statistic is dwarfed on a planetary scale when compared to the 7 trillion plastic debris estimated to enter San Francisco Bay each year [49]. The recommended N95 masks are made of plastics such as polypropylene (PP) and polyethylene terephthalate (PET). Similarly, surgical gloves and masks are made of nonwoven materials (e.g., spunbond meltblown spunbond) that often incorporate other polymers such as polyethylene (PE), PP and PET [50,51]. Such masks will likely degrade into smaller microplastic pieces [33]. In the Magdalena River, Columbia, the degradation of nonwoven synthetic textiles was the predominant origin of microplastic microfibres found in both water and sediment samples [33]. Thus, the disposal of such items in open fields will endure the "never-ending-story" of plastics in the environment.

Once littered in open environments (terrestrial or aquatics), both PPE and plastic litter will likely induce sewage system blockage in towns and cities (particularly in developing countries) and will also negatively affect water percolation and normal agricultural soils aeration, with repercussions on land productivity (as reviewed by [33]). Moreover, plastic pollution in the environment will deteriorate and fragment, originating plastic particles of micro- and nano-size [33]. The persistence and ubiquity of plastic debris, allied with polymer type, shape and size, are known to impose serious threats to biodiversity as they can be easily ingested and cause physical effects, such as internal abrasions and blockages [52-54]. Although plastic pollution is typically considered as biochemically inert [55], plastic additives are being incorporated during manufacturing processes to improve their properties [56,57]. Furthermore, plastic pollution can also act as a vector of different contaminants, invasive species, and pathogens such as SARS-CoV2 [56-59]. Plastic additives and/or absorbed contaminants that can leach out and eventually percolate into various environmental compartments, decreasing soil and water quality and inducing adverse effects on terrestrial and aquatic biota, at different levels of biological organisation [62,63]. Also, plastic littered in open environments, particularly in aquatic environments such as lakes, ponds and puddles, may provide breeding grounds for vectors of zoonotic diseases, such as mosquito *Aedes* spp. which is the vector of dengue and Zika [64], which may also threaten general public health and safety [8].

3.1. The implications of COVID-19 on environmental footprint

Life cycle assessment (LCA) standards is providing the best framework for the evaluation of the environmental footprint (i.e., environmental damage - such as emission of GHG and hazardous chemicals, energy consumed from its production to disposal) of a specific product available in the market [65,74]. Although the absence of data on the demand/use of PPE and SUP, and subsequent increment of plastics waste and changes in waste management strategies, during the first semester of COVID-19 evolution, several reports tried to estimate their environmental footprint considering different scenarios. For instance, and considering the use of masks, the UCL Plastic Waste Innovation report [66] carried out an LCA on UK-wide face mask-adoption scenarios (single use mask/day, reusable mask with no filter with manual or machine wash, reusable masks without filters with manual or machine wash). Such study showed that the use of reusable masks significantly reduces the amount of waste by 95%, followed by reusable masks with disposable filters (60%). Reusable masks without filters (washing method: washing machine) had the general lowest contribution to climate change (< 2.00E + 008 Kg CO_2 eq), when considering manufacturing, transport, and use. Conversely, single use masks and reusable masks with disposable filters had the highest contribution to climate change (~1.47E + 009 and 1.50E + 009; respectively Kg CO_2 eq). Thus, the use of single use masks would aggravate climate change by 10 times than using reusable masks.

Even though there is no such assessment for gloves, previous research has shown their production and use may be detrimental to the environment [67]. For synthetic rubber gloves produced in Malaysia, the production of each kilogram of product consumes up to 10.0413 MJ of energy, with impacts highly dependent on energy production [66]. In Thailand, the total carbon footprint emission of 200 pieces of rubber glove was about 42 kg CO_2-eq [68]. Considering the estimated recommended monthly consumption of 65 billion gloves globally [33], and the previously estimated carbon footprint emission (by [68]), it would result in the emission of 1.44 × 10E + 010 Kg CO2 eq kg (14 Mt CO_2 eq). The use and preference of SUP, particularly plastic bags, over paper and cotton bags has also been questioned during COVID-19. However, in such cases, LCA studies remains not conclusive. As examples, a previous study carried out by Lewis et al. [69] based on LCAs on those options, reported that paper has higher environmental impacts in most categories when compared to single-use plastic bags. However, Mattila et al. [70] could not discern differences between plastic, paper, and cotton bags when they took different end of life scenarios into account. LCAs provide important insights on their environmental footprint during production and usage, but such studies have been widely criticised for not considering waste mismanaged (i.e., leakage) and therefore not accounting for all impacts in the environment. Boucher and Billard [71] argue that LCAs neglect plastic pollution. Schweitzer et al. [72] criticise LCAs for not considering environmental leakage in waste management scenarios. Fortunately, there have been some recent studies which have started to develop effect factor approaches for risks associated with littering of plastic bags and entanglement of biota with plastic [73]. Notwithstanding, the reusable alternatives should be the road ahead to reduce the global warming potential below that of single-use plastic and PPE.

With medical and municipal solid waste (MSW) generated being considered as potentially infectious during COVID-19 pandemic, incineration and landfilling are being prioritised over recycling, which will result in a deterioration on air quality in a medium- to long-term [33]. Production of GHG, such as CO_2 and CH_4, is released in significant amounts during plastic waste decomposition in landfills, or during the burning of plastics waste [33]. For instance, in United Kingdom, the carbon footprint of MSW incineration is − 0.179 t CO_2 eq./t MSW while that from landfilling is 0.395 t CO_2 eq./t MSW [103]. Open burning of plastics waste can also release other hazardous chemicals such as heavy metals, dioxins, PCBs, dioxins and furans, which are linked to health risks allied to respiratory disorders. Air pollution is one of the major environmental threats to public health, and it is responsible for > 6 million deaths worldwide [75].

4. Plastic waste during and after pandemic scenarios: Challenges and recommendations

Numerous international agreements on plastics and plastic pollution have been established to address and reduce their impact on global economies, societies and natural environments. Among them, the Basel Convention and its amendment in 2019, UNCLOS (United Nations Convention on the Law of the Sea), MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships), GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), UN Global Partnership on Marine Litter, G7 Ocean Plastics Charter, and the European Union Plastics Strategy [38].

However, the COVID-19 pandemic has clearly outgrown the perceived threat of plastic pollution, leading to a sudden shift in the hierarchisation of values, i.e., where health is considered as a value in spite of environmental care, which shows a clear decrease in its perceived importance [76]. The withdrawal in several national and statewide agreements that set environmental sustainability as the steppingstone, followed by change in waste production and management to ensure health needs. A long-term shift in such value hierarchisation will likely cause “damage” to already considerably high environmental threats, compromising the Earth’s supporting ecosystems and future generations to meet their own needs. Thus, it is imperative to re-think the undertaken measures during COVID-19 to minimise the negative consequences in a future outbreak scenario. Some strategies to better manage medical and plastic waste may include:

4.1. Improvement of municipal waste-management

During epidemic and pandemic events, it is of utmost importance to gather reliable information about quantity and type of waste (i.e., accurate characterisation data), and how much material can be reused or recycled (stimulated by proper decontamination) to then determine what indeed goes for incineration or landfill. It is also crucial to determine valid goals, such as complying with regulations and follow the hierarchy of waste management (reduce, reuse, recycle, and recover) to conserve resources [45]. Waste management is especially important during the pandemic due to the increased risk of pathogen transmission and increased domestic waste production. Likewise, it should be mandatory and reinforced the use of PPE for workers related to waste management. Therefore, municipalities responsible for waste collection and treatment should create guidelines and procedures to apply during pandemics regarding waste reduction recommendations, protective measures, collection frequency, and end-of-life.

4.2. Disinfection of medical wastes and PPE allowing for safe recycling

During pandemic events, all medical waste and PPE should be carefully monitored by specialised personnel to guarantee health safety. Disinfection technology, including UV, ozone or bioengineering approaches, can offer a sustainable strategy to treat waste and wastewaters [77-81]. The choice of an appropriate disinfection technology should rely on the amount of waste, type of waste, costs and maintenance. For high volumes of infectious medical waste (> 10 t/day) the incineration continues to be the best option as it completely kills pathogens due to the high-temperature applied (over 800 °C). If the amount of medical waste is not too high (< 10 t/day), chemical disinfection (i.e., use of chemical disinfectants) or physical disinfection (microwave or high temperature steam) might be an option [79]. Alongside, decontamination of PPE, including face shields, surgical masks and N95 respirators, could be useful to maintain adequate supplies, and to promote its extended, reuse and recyclability options. Moreover, recycling technologies of non-woven textiles, from which most PPE is made, is still very limited due to the lack of technology and their composition (e.g. combination of materials as composites) [82]. The use of UV-C light, ozone gas, ionised hydrogen peroxide, and microwave- and heat-based seem to be valid decontamination approaches to apply to PPE and N95 masks, improving their reusability and reducing the production of waste [77-81,83,84].

4.3. Implementation of a sustainable/rational use of personal protective equipment in healthcare and non-healthcare facilities, particularly in pandemic hotspots areas

Several recommendations for optimising the available PPE have been proposed by WHO (Interim guidance, 27 Feb. 2020), such as: the use of physical barriers on trials, registrations, general attendance to reduce exposure to infectious viruses, such as a glass or plastic windows; the stimulation of telemedicine (in case of healthcare facilities to evaluate suspected cases of infected patients and to avoid overcrowded emergency rooms), telemarketing and online/tele-shopping; mandatory PPE for front-line workers involved in the direct care of infected patients, or involved in the management of infected medical wastes (and such PPE might be reused after a proper disinfection [84]. It is also important to choose PPE of high quality (i.e., with high potential for disinfection and reuse purposes). This rational use and reuse of materials could lead to reductions in the production of medical waste, also lifting pressure on the overwhelming of medical waste treatment facilities.

4.4. Implementation of sustainable safety measures to guarantee the delivery goods and ensure services provisioning

Reusable grocery bags (preferable plastic or fabric) should be encouraged but highlighting the need for implementing mitigation strategies to ensure the complete elimination of the pathogenic agent. Such mitigations strategies could involve proper hand hygiene and decontamination bath of the reusable bags (i.e., soaked in liquid soap and water temperature > 40 °C). Online shopping with food delivery or drive-through windows could also be implemented. Home-delivery should, however, be delivered in paper bags or cardboard boxes, and service workers should be wearing protective equipment, and frequently sanitising their hands. It is worth recalling that the phasing of single-use plastics in Europe prevented the emission of 3.4 million tonnes of CO_2, environmental damages with predicted of €22 billion by 2030, and consumer costs of €6.5 billion [85]. Moreover, in some European countries, consumption of single-use plastic carrier bags was estimated as high as 466 per capita, with up to 10% being littered in the case of HDPE plastic bags [86]. Therefore, the reversal of measures such as the ones implemented by the EU could lead to great economic losses as well as environmental damages while motivated by unproven benefits in the prevention of the SARS-CoV-2 transmission.

4.5. Promote sustainable and safer consumption and production patterns for plastics

Confinement measures leaded to a dramatic increase in the use and consumption of disposable plastics, but such patterns seem to remain after deconfinement. As an example, beauty salons and hairdressers are implementing precautionary measures to ensure customers safety against COVID-19, among them the mandatory use of masks by workers and customers and the distribution of individual kits with disposable plastic items (feet protection and coats) (e.g., [87]). Such items are partially or completely based on polymers such as PE, PA, PP and PET. Such polymers are derived from fossil fuel (non-renewable) resources and present low degradability in open environments. Besides, they are among the most commonly found polymers found in terrestrial and marine debris and, in the micro-size (1 μm − 5 mm, [88]), are known to induce deleterious effects on several aquatic species [89]. The preference for use of single-use-plastics over reusable alternatives is actually not sustained by the scientific literature, when considering proper hygiene and sterilisation procedures to eliminate SARS-CoV2 viability. Thus, the preference for reusable alternatives should be encouraged.

In a circular economy, bio-based plastics (polymers partially or totally derived from biomass) have been emerging as a sustainable but short-term alternative to conventional plastics, by replacing fossil fuel with renewable resources. Besides, biobased plastics have the potential to decrease carbon footprint and increase recycling targets (such as home composting) and waste management efficiency, therefore lowering the economic and environmental pressure caused by conventional plastic litter [90,91]. Bio-based biodegradable options offer additional benefits as they break down by enzymatic or biological activity in open environments [92]. Aliphatic polyesters (e.g., polylactic acid, PLA and polyhydroxyalkanoates, PHA) and furanic-aliphatic polyesters (e.g., Polyethylene 2,5-furandicarboxylate, PEF and Polyethylene 2,5-furandicarboxylate –co-polylactic acid, PEF-co-PLA) are of particular interest as building-blocks for PPE and other single-use plastics due to their sustainable thermophysical properties and adjustable degradation rates [93].

However, the transition from fuel-based to biobased plastics must be considered after overcoming the current production limitations and lack of scientific support towards the environmental safety of the greener solution. Current biobased plastics still represents a minor percentage on the global plastic production (~7.4 of 348 million Mt in 2017) [94]. This is mainly due to the intense requirement for land use and related financial investment, the undeveloped recycling and/or disposal routes, unknown toxicological effects of their biodegradation in open environments [9]. Some biobased plastics are also designed to be durable and mechanically resistant, which compared to the fossil-fuel counterpart, the only benefit might rely on the feedstock and lower carbon footprint during their production and usage. Biobased solutions might be an option, but there is still a need to scale up in innovation and technology to move towards a sustainable solution. Worldwide plastic economies must adapt plastic production to variety feedstocks with lower land-use impacts, along with the use of renewable electricity in the production process, and to integrate plastic production in biorefineries that can make multiple products from the available feedstocks [9]. Likewise, bioplastics must be safe-by-design and should be environmentally friendly and free of hazardous chemicals/additives [95]. Nevertheless, policies should prioritise plastic prevention and overall reduction [96].

4.6. Remediation measures to mitigate the potential adverse effects of plastic pollution due to pandemic scenarios

The increasing danger of plastic waste (particularly SUP and PPE) due to COVID-19 is already an unquestionable reality, which calls for remediation/mitigation strategies. However, such knowledge is based on in-situ visual census. There is a need to develop new technological approaches to improve monitoring and mapping of plastic pollution (e.g., drones). Along with the plastic prevention and reduction (e.g., SUP and microbeads) and the concept of responsibility against plastic pollution, it is important to develop and/or optimise remediation approaches.

There are already strategies and approaches that proved their efficiency and should be prioritised and implemented in the next coming years. For instance, clean-up technologies such as automated waste collection boats/ floaters proved to be efficient for plastics removal from surface waters (e.g., the Interceptor, launched by The Ocean Cleanup; the Bubble barrier and the Waternet). Wastewater treatments seem to eliminate a considerable percentage of plastic debris, but there is still a need of complementary treatments when considering particles of smaller size such as microplastics [97]. With this purpose, and in addition to the membrane treatments and filtrations already applied, the application of cleaner technologies, such as the application of membrane processes, regenerative filters systems or precipitation with magnetic nanoparticles, and application of inorganic–organic hybrid silica gels – organosilanes, have been developed and proved to be successful [97-100]. There are other experimental techniques that are being devolved for this purpose, such as dynamic membranes, photocatalysis, elimination with fats and constructed wetlands (a horizontal subsurface-flow that uses vegetation, soil and organisms to treat wastewater) [97]. For drinking water, there are few advance techniques that proved efficiency on plastic debris removal, such as electrocoagulation, magnetic extraction and membrane separation [97]. In soil systems, the application of synthetic, or improved natural microbial community for plastic bioremediation processes seems to be a low-cost, highly efficient and green approach [101].

4.7. Create synergisms between academia and government to increase public awareness (including stakeholders) towards a sustainable production, use and disposal of plastics

It is imperative to rethink our attitudes towards plastic usage, by promoting sustainable behaviours, breaking old habits and adopting new ones. To achieve this, it is important to stimulate scientific research and solutions for an effective communicative strategy as decision-makers struggle to find relevant communication channels and tonalities to increase environmental awareness of the public and persuade people to change their lifestyle, consumption patterns and behaviour. In addition, knowledge communication forums using science communication and citizen science through public participatory approaches should be stimulated [9]. Raising awareness over plastic waste and contamination should not be interrupted nor reversed, as it required long-term efforts to results in behavioural changes, which may be loss due to disruption or contradictory information.

5. Final considerations

Given the concerning trend, it must be acknowledged the urgent need for a reassessment of the world's fundamental goals and priorities without neglecting consequences on economies, societies but mostly to the environment. Enormous amounts of plastic waste (including medical waste) are being generated at a global scale, with the majority being landfilled or incinerated (which are less favourable with higher negative environmental impacts) and minor fraction being recycled. This will aggravate current estimations (4–12 million tonnes/year of plastics go into the seas and oceans) [102]. Plastic waste will not be the only that need to be addressed when health-related issues are overcome, but all the consequences (indirect effects) that will arise from our shift in priorities without thinking in a long-run. It is of utmost importance to recognise that Human Health is connected and dependent on the health of our environment and ecosystems, and if humanity does not respect such connection, and continuing thinking on "today" instead of "today in prole of a sustainable future", there will not exist a future. In this matter, the scientists should embrace (more tightly) their ethical obligation to become active as knowledge brokers enabling a common goal-oriented debate among politicians, producers, and the general public [76]. Likewise, governors should seek to implement a more efficient plastic waste management system for plastic waste recovery; accompanied by restrict laws and regulation for production, use, and consumption of plastic products (including incentives for recycling and redesigning). Plastics indeed offers a panoply of characteristics and properties that greatly improved our quality of life, thus being difficult to imagine a plastic-free economy and life. Yet, we must seek sustainable options. Biobased plastics might be a solution at an early stage, but it is important to scale up in innovation to ensure their environmental friendliness and their integration in the circular economy. Likewise, such process must be accompanied by extended producer responsibility, with the producer (distributors and sellers) internalising the cost of management of waste (recycling and disposal) of their products. Plastics should, therefore, remain in the top of the political agenda in Europe and across the world, not only to minimise plastic leakage and pollution but to promote a circular economy, and to ensure sustainable growth, underlining both green and blue- economies.

Declaration of Competing Interest

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

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