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What is the environmental impact of different strategies for the use of medical and community masks?

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1 What is the environmental impact of different strategies for the use 2 of medical and community masks?

3
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Abstract**Introduction**

The use of protective masks, especially medical masks, increased dramatically during the COVID-19 crisis. Medical masks are made of synthetic materials, mainly polypropylene, and a majority of them are produced in China and imported to the European market. The urgency of the need has so far prevailed over environmental considerations.

Objective

Assess the environmental impact of different strategies for the use of facemask

Method

Different strategies for the use of medical and community masks are being investigated for their environmental impact in this study. 8 scenarios, differentiating the typologies of masks and the modes of reuse are compared using several environmental impact indicators, mainly the Global Warming Potential (GWP100), and the plastic leakage (PL). This study attempts to provide clear recommendations that consider both the environmental impact and the protective effectiveness of face masks used in the community.

Results

The environmental impact of single-use masks is the most unfavorable, with a GWP of 0.4 -1.3 kgCO₂ eq., depending on the transport scenario, and a PL of 1.8 g, for a one month protection against COVID-19. The use of home-made cotton masks and prolonged use of medical masks through wait-and-reuse are the scenarios with the lowest impact.

Conclusion

The use of medical masks with a wait and reuse strategy seems to be the most appropriate when considering both environmental impact and effectiveness. Our results also highlight the need to develop procedures and the legal/operational framework to extend the use of protective equipment during a pandemic.

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3 55 **Strengths and limitations of this study**
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- 8 57 - This study provides an environmental assessment (GWP 100, plastic leakage) for different
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10 58 mask type and use strategies.
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13 59 - It recommends use or reuse strategies based on both performance and environmental
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15 60 impacts.
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18 61 - The transportation and end-of-life assumptions are representative of an EU context.
19
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21 62 - As littering rates are poorly documented, plastic leakage in other geographic regions may
22
23 63 significantly differ.
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26 64 - Masks weight and composition used in this study are taken from regular European masks
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28 65 disregarding the variability from one manufacturer to another.
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68 Introduction

69 The COVID-19 crisis has led to dramatic changes in our daily habits. The consequences of these
70 changes on the environment are still poorly understood. The decrease in industrial activity
71 during confinement and the decline in intra- and inter-national mobility has led to a significant
72 drop in CO₂ emissions¹. An average decrease of 6.4% % in yearly CO₂ emissions was observed
73 worldwide for 2020². Positive effects have also been observed on other air pollutants, such
74 as PM, NO_x, SO₂ and on river pollution. However, some observations made in China, near
75 Hubei's epicenter, show an unclear environmental picture, with a lower decrease in air
76 pollutants than expected. This suggests that other effects, such as increased energy demand
77 for household needs, must also be considered ³. Due to the temporary nature of the
78 confinement measures, some authors argue that the longer-term effects of the COVID-19
79 crisis on the environmental footprint of human activities remain highly uncertain and may
80 offset the observed short-term environmental benefits ⁴. In the United States, a sharp drop
81 in jet fuel and gasoline consumption has been observed during the crisis, leading to a decrease
82 in CO₂ emissions of around 15%. However, it has been estimated that in a scenario of
83 sustainable impact on the economy, the consequences of delayed investment in green energy
84 and traffic-related emission reduction programs alone could outweigh the short-term effects
85 ⁵. The evolution of some activities or consumption patterns during the COVID-19 crisis are
86 also likely to worsen the environmental balance: development of e-commerce (increase of
87 transport distances and packaging), high consumption of disinfection products, massive
88 COVID-19 screening in populations (increase in medical consumables).

89 The consumption of protective equipment and most particularly facemasks has also
90 experienced a sharp increase during the crisis. To meet the growing demand, the production

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3 91 of disposable masks has dramatically increased since the first pandemic wave ⁶. By June 2020,
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6 92 China was producing 200 million facemasks per day, 20 times more than in February of the
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8 93 same year ⁷. With the second pandemic wave, the wearing of facemasks was mandatory in
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10 94 closed spaces and densely populated areas in many countries. Medical masks and community
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13 95 masks have become essential tools in the fight against the spread of the virus.

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15 96 Given the wide use of facemasks, there is an urgent need to consider the environmental
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18 97 impact of this practice and ways to extend the life of this equipment. Several arguments can
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20 98 be put forward: (1) the bulk of production comes from Asia, resulting in significant use of
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23 99 transportation to supply regions such as Europe and the United States, (2) medical masks are
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25 100 intended for single use, resulting in additional waste and possible littering of used masks, and
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28 101 (3) medical masks and some community masks are made of plastic. Poor management of this
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30 102 waste can therefore contribute to the presence of macroplastics and microplastics in the
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33 103 environment, particularly in the Ocean ⁸. Considering that 3% of masks could enter the
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35 104 environment (overall loss rate), it is estimated that up to 1.56 billions disposable masks could
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37
38 105 have entered the Ocean in 2020, which represents between 4680 and 6240 tons of plastic pollution
39
40 106 to the marine environment ⁹. Life cycle assessment (LCA) conducted on facemasks in United
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42 107 Kingdom also shows that the environmental impact of disposable masks are generally higher
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45 108 than recycled masks. In the absence of recycling, the production of waste in this country, as
46
47 109 a consequence of the use of one mask each day for a year by the entire British population,
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49
50 110 was estimated at $1,24 \cdot 10^5$ tons, including $0,66 \cdot 10^5$ tons of non-recyclable contaminated plastic
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52 111 ¹⁰. Many countries are attempting to restrict the use of single-use plastics, including
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55 112 restricting the use of plastic bags. The increase in plastic waste is putting pressure on the
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57 113 waste management system to find new strategies to deal with this change ¹¹. On the other

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3 114 hand, there is good evidence that face masks used in the community provide protection
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6 115 against Covid-19 infections ¹², even though effectiveness can be very different according to
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8 116 the type of masks, the wearing adherence or the environmental parameters (humidity,
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11 117 heat,..).

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13 118 In this study, we aim to explore and compare the environmental impact of the different masks
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15 119 used in the community and attempt to provide clear recommendations on the best
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18 120 compromise between protection effectiveness and environmental impact.
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125 **Method**

126 The environmental impact assessment proposed in this study is based on: (1) the construction of
127 scenarios of mask use in the general population, distinguishing their typology and modalities of reuse,
128 and (2) the analysis of these scenarios using three impact indicators, reflecting global warming, plastic
129 littering and ecological scarcity (UBP method).

130 **Mask typology**

131 Three types of masks, intended for general public use, were considered: medical masks, community
132 masks and labelled community masks.

133 Medical masks (or surgical masks) are originally intended for single use and designed to protect
134 patients from possible pathogens exhaled by the medical personnel. In the context of the COVID-19
135 pandemic, these masks have been widely used outside of healthcare settings to protect the public by
136 preventing pathogens from leaving the wearer and thus from being transmitted to others in the
137 vicinity of the wearer. In Europe, medical masks must meet the requirements of EN 14683 and must
138 comply with the Medical Products Directive (Directive 93/42/EEC). Medical masks are constituted of
139 3 different layers of nonwoven fabric, generally in polypropylene (referred here below as PP masks)
140 ¹³. A majority of them are produced in China and imported by ship in large quantities on the European
141 market. However, during the first pandemic wave in spring 2020, due to the lack of Filtering Facepiece
142 Respirators and medical masks, emergency shipments were made by air.

143 The term community mask encompasses all non-professional masks that are intended to protect the
144 general public from infection, essentially in reducing the emissions from the wearer (source control).
145 Community masks range from homemade cotton masks (referred here below as COT masks) to more
146 or less sophisticated textile masks. Community masks have the advantage that they can be produced
147 locally, either centrally in the case of commercial masks, or at home for personal use. The performance
148 of community masks is not subject to legal requirements, so their quality can vary greatly. In some
149 countries, quality labels have been proposed, allowing minimum performance requirements to be

1
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3 150 defined on a voluntary basis. This is the case, for instance, of the French AFNOR label and of the Swiss
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5 151 TESTEX label (referred here below as PES masks). Currently, labelled masks represent only a minority
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8 152 of production, probably due to higher manufacturing costs. While "common" community masks are
9
10 153 generally made of cotton or other textiles of natural origin, labelled masks, which require greater
11
12 154 technicality, are made of polymers, such as elastane or polyester. Community trade masks without
13
14 155 labels were considered to come from the wider European market. For the labelled masks, the origin
15
16 156 is more specific, since the AFNOR and TESTEX labelled masks are, to our knowledge, only produced in
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18
19 157 France and Switzerland respectively.

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21 158

22 23 159 **Reuse strategy**

24
25 160 The lack of protective means and the need to extend the life cycle of masks during the first COVID-19
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28 161 wave generated numerous studies on their reuse. Although medical masks are normally intended for
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30 162 single use, it has been shown that certain physical treatments such as UVC, microwaves or dry heat
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32 163 can effectively decontaminate them without significantly altering their barrier capacity. The latter
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34 164 method is of particular interest for the treatment of medical masks, as it is accessible in all households.
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36 165 It has been shown exposure to at least 70°C for 30 min is sufficient to effectively decontaminate
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38
39 166 surgical masks or respirators¹⁴⁻¹⁶.

40
41 167 Another alternative, which has yet to be validated, is the wait & reuse strategy. The viability of the
42
43 168 virus deposited on a surface decreases significantly after a few hours. Tests on surgical masks have
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45 169 shown that under ambient temperature and humidity conditions (22°C, 65% RH), a 3-log reduction in
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48 170 **virus load** was achieved after 4 to 7 days¹⁷. In a similar way to what has been proposed by the
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50 171 N95Decon scientific group for respirators, surgical masks could therefore be stored at room
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52 172 temperature for 7 days before being reused (by the same user).

53
54 173 The situation with community masks is more straightforward since they are designed with the intent
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56
57 174 of cleaning and reusing by the general public. The issue of maintaining performance is also less critical

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3 175 since there are no legal requirements for this type of mask. The strategy considered here is therefore
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5 176 that of a reuse after a decontamination at home in a washing machine at 60°C. Labelled community
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7 177 mask are a special situation, since maintaining their performances is conditioned by the limitation of
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9 178 the number of washing cycles, to 20 and 5 washes for the AFNOR and TESTEX labels, respectively^{18,19}.

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13 14 15 180 **Environmental Impact assessment**

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17 181 This study follows the methodology of life cycle assessment (LCA) and considers all the life cycle stages
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19 182 of the different masks including production, transport, use (decontamination) and end of life. The
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21 183 primary data sources used and hypothesis are referenced throughout this article. The secondary data
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23 184 used for impact characterization used to perform the LCA analysis are based on the Ecoinvent
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25 185 database (<https://www.ecoinvent.org/database/database.html>) unless otherwise mentioned; the
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27 186 functional unit (FU) chosen for the comparison of the masks is “to equip one person with a mask during
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29 187 a month”. Several environmental impact indicators were considered:

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34 189 - The Global Warming Potential (GWP100) index, which expresses the impact of manufacturing,
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36 190 transporting and recycling masks in terms of greenhouse gases. GWP100 expresses the time-
37
38 191 integrated warming effect, over a 100 year period, due to the release of a given greenhouse gas
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40 192 in today's atmosphere, relative to that of carbon dioxide (in mass unit kg)²⁰.
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43 193 - The UBP method relies on the methodological concept of ecological scarcity and expresses the
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45 194 environmental impact in terms of eco-points. It encompasses for instance the water footprint of
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47 195 cotton production as well as the biodiversity impact of energy production during the use phase.
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49 196 However. Calculation using the UBP method has been performed and is available in Appendix
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51 197 S1.
- 52
53
54 198 - The plastic leakage (PL), which expresses the amount of plastic leaving the technosphere and
55
56 199 cumulating in the natural environment. PL measures the quantity of plastic ultimately released

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3 200 into the ocean or into the other compartments (freshwater, soils, other terrestrial
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5 201 environments) including both microplastics and macroplastics²¹ The littering rate used by
6
7 202 default for on-the-go plastic is generally ranging between 2%^{22,23} and 12%²⁴. A recent study
8
9 203 focusing on masks articulates a littering rate of 3% worldwide. In this study, we used a 2%
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11
12 204 littering rate²¹.

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14 205 The destination chosen for masks transport is Switzerland. However, shipping origin and method
15
16 206 vary as masks can come from Switzerland, France or China, and be transported either by truck, boat
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18 207 or plane. Different assumptions are made for additional environmental burdens during the use
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20 208 phase of the mask life cycle according to the decontamination method. For the decontamination in
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22 209 a washing machine, we consider a household washing machine cycle running at 60°C during 1h40
23
24 210 with a dry load of 6 kg of clothes with an energy use of 1.8 kWh/cycle, a water use of 67.6 L/cycle
25
26 211 and a soap consumption of 65 g/cycle²⁵. For the oven sterilization we assume that, based on
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28 212 personal measurement, an oven running at 70°C during 30 min consumes 0.345 kWh of electricity.
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30 213 In the end of life stage, we assumed that all masks were incinerated after disposal. Heat and
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32 214 electricity recovery efficiencies in Europe vary quite significantly between different plants, at
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34 215 average values of 31% for heat and 12% for electricity²⁶. The strategies for using the masks and the
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36 216 corresponding assessment parameters are summarized in Table 1.
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Scenario	Mask type	Material	Weight [g]	Origin	Transport (main)	Re-use	Consumption mask/month ^a
PP_1	Medical mask	Polypropylene (PP) / Nylon /Aluminium ^b	3.2 (2.5/0.5/0.2)	China	Boat	No	30
PP_2		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Plane	No	30
PP_3		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Boat	Hot drying, 30 min. 70°C	3
PP_4		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Boat	Wait and reuse	3 ^c
COT_1	Unlabelled community mask	Cotton (COT)	5	China	Boat	Washing machine 60°C	2
COT_2		Cotton (COT)	5	Homemade ^d	-	Washing machine 60°C	2
PES_1	Labelled community mask ^e	Elastane / polyester (PES)	6.3 (0.13/6.17)	France	Truck	Washing machine 60°	2
PES_2		Elastane / polyester (PES)	6.3 (0.13/6.17)	Switzerland	Truck	Washing machine 60°	6

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222 ^a Number of worn-out masks disposed of and then replaced by a user during a month (consumption = 30/nb. of expected reuses)223 ^a Aluminium nose strip224 ^c One mask is used each weekday, for 10 reuses225 ^d made from old cloth/fabric226 ^e Considering the French quality label AFNOR (scenario PES_1) and the Swiss quality label Testex (scenario PES_2)

227

228 *Table 1. Summary of Mask typology and uses scenarios*

229 Results

230 Global warming potential

231 The CO₂- equivalent impact of the different scenarios of mask use is presented in Figure 1. The use of
232 disposable masks brought by plane (scenario PP_2), as experienced during the Personal Protective
233 Equipment (PPE) shortage of the first pandemic wave, is by far the most detrimental with 1.3 kg/CO₂
234 eq./FU. Without taking this extreme situation into account, a strong variability is observed between
235 the different scenarios of mask use. There is a factor of 30 between the most unfavourable scenario
236 (PP_1 - disposable medical mask brought by boat) and the most favourable scenario (COT_2 – Home-
237 made washable cotton mask). The differences observed are largely due to the absence of
238 manufacturing impact from the second-hand fabric as well as a very low contribution from the usage
239 phase in scenario COT_2. The decontamination of medical masks by heating (PP_3) is not very
240 advantageous, as well as the use of community masks made of polymers, as long as the number of
241 reuse cycles remains limited. Taking into account the discounted emissions from incineration after
242 disposal leads to a negative contribution of the end of life stage to the total CO₂-equivalent emissions
243 in all scenarios except COT_1 and COT_2. Overall, the most advantageous scenarios are home-made
244 cotton masks (COT_2) and the extended use of medical masks through a wait and reuse strategy
245 (PP_4).

246
247 Figure 1 about here

248
249 Results similar to those of the carbon footprint are obtained by considering a broader impact indicator,
250 such as UBP, which integrates water consumption (see Supplementary file S1). The impact related to
251 use increases for all masks when recycled multiple times. The most advantageous scenarios remain
252 however the home-made cotton masks (COT_2) and the extended use of medical masks through a
253 wait and reuse strategy (PP_4). Notably, the impact of decontamination of medical masks by heating

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3 254 (PP_3) is more than doubled, making it less advantageous than the single-use scenario of medical
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5 255 masks shipped from China by boat (PP_1).
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10 257 **Plastic leakage (PL)**
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12 258 The impact of the different scenarios of mask use from the point of view of plastic leakage is
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14 259 presented in Figure 2. Unsurprisingly, cotton masks do not generate plastic leakage. Disposable
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16 260 medical masks have a high PL of 1.8 g/FU. However, this impact can be reduced by a factor of 10 by
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18 261 reuse procedures, which proportionally reduce production needs.
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24 263 *Figure 2 about here*
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30 265 **Number of reuse**
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33 266 The number of reuses used in the scenarios is based on an estimate of current practices and
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35 267 recommendations. Arguably, this may change depending on usage conditions, material quality, or
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37 268 changes in mask labelling requirements. The effect of the number of reuses on the GWP100 is shown
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39 269 in figure 3. Interestingly, commercial cotton masks (COT_1) reused less than 8 times generate more
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41 270 CO₂eq than disposable medical masks shipped by boat (PP_1). Moreover, when used less than 17
42
43 271 times commercial cotton masks (COT_1) generate more CO₂eq than medical masks decontaminated
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45 272 through dry heating (PP_3). The increase in the number of reuse decreases the gap between the two
46
47 273 most advantageous scenarios: home-made cotton masks (COT_2) and the recycling of medical masks
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49 274 through a wait and reuse strategy (PP_4).
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Figure 3 about here

278 Discussion

279 The estimation of the environmental impact carried out, shows that there are important differences
 280 between the strategies of use of the masks. At the population level, these differences are not
 281 negligible. We quantified how much CO₂eq impact and plastic leakage would be avoided within a
 282 year in Switzerland if 10% of the entire population was to shift from single-use masks transported by
 283 boat (PP_1) to either a wait and reuse strategy for the same masks (PP_4) or home-made cotton
 284 masks from old fabric (COT_2). Results are reported in Table 2, considering a Swiss population
 285 8'606'033 in 2019 (source: Federal Statistical Office).

	CO ₂ eq impact avoided [t CO ₂ eq.]	Plastic leakage avoided [t PL]
shifting to PP_4	4'077	17
shifting to COT_2	4'400	19

286
 287 *Table 2. Environmental impact of a shift from the use of disposable masks to reuse strategies in 10%*
 288 *of the Swiss population.*

289 For an impact per passenger transport by aircraft (person.km) of 0.129 kgCO₂eq (source: Reffnet.ch)
 290 and an average 1.5L plastic bottle weight of 32.6 g²⁷, the uptake of the wait and reuse strategy by
 291 for the medical masks (PP_4) by 10% of the population would be equivalent to saving CO₂eq
 292 emissions from 5'402 individual flights from Paris to New York and preventing 570'219 plastic
 293 bottles (1.5L) from being littered. Similarly, the uptake of home-made cotton masks (COT_2) by the
 294 same population share would result in CO₂eq emissions savings analogous to 5'830 individual air
 295 travels from Paris to New York, and a plastic leakage avoided corresponding to 513'194 plastic
 296 bottles (1.5L).

297 From the point of view of the effectiveness of their individual or collective protection, masks are not
 298 all equal. The comparison of their performance is not obvious because several parameters influence
 299 their effectiveness (droplet penetration, aerosol penetration, fitting to the face, wettability...)¹² and
 300 only medical masks as well as labelled community masks (e.g. AFNOR label) have minimum

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3 301 performance requirements for some of these parameters while a high variability in performance is
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5 302 to be expected among unlabelled community masks.
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8 303 The filtration efficiency of the membrane as such has been investigated by several experimental
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10 304 studies. Aydin et al. report filtration efficiencies for large droplets in the 100 μ - 1mm range of over
11
12 305 98% for surgical masks and 93-98% for unlabelled community masks of different materials (cotton,
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14 306 polyester and silk)²⁸. For finer particles, the performance of unlabelled community masks is however
15
16 307 lower. In the 10 μ range (PM₁₀), Neupane et al. show a filtration efficiency of 94% for surgical masks
17
18 308 and 63% and 84% for community masks²⁹. Systematic reviews of the laboratory results obtained so
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20 309 far suggest that community masks have satisfactory filtration efficiency for large particles (e.g. >
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22 310 5 μ m), but that they have only limited effectiveness against aerosols.
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26 311 However, the overall performance of the masks is not limited to filtration efficiency alone and will be
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28 312 affected by leaks due to poor fitting to the face, but also by the way the masks are used. Wearing a
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30 313 face mask in a community logic is moreover primarily intended as a collective protection (by
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32 314 reducing the emission of the wearer), rather than an individual protection. This collective
33
34 315 effectiveness is difficult to quantify due to the complexity of exposure situations and the presence of
35
36 316 other contamination routes (e.g surface contamination). Randomized studies conducted previously
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38 317 on the transmission of viral infections in the community, showed that wearing a mask provided
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40 318 some protection in the most adherent individuals³⁰ or when mask use is accompanied by hand
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42 319 hygiene measures and/or education on viral infections^{31 32}.
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47 320 The use of medical masks with a wait and reuse strategy seems to be the most appropriate when
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49 321 considering both environmental impact and effectiveness. Expectations, in terms of mask
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51 322 performance, are generally fairly limited. However, face masks contribute to collective protection by
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53 323 reducing droplet emissions and, to a lesser extent, aerosol emissions from infected wearers.
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56 324 However, the lack of minimum performance requirements for unlabelled community face masks,
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3 325 makes this contribution uncertain. Standardized masks, which offer guarantees in terms of
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5 326 performance and reproducibility, are therefore beneficial from this point of view.
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8 327 Labelled community masks are also an interesting alternative. Their environmental performance is
9
10 328 currently limited by the number of planned cycles of use, which requires frequent replacement. An
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12 329 increase in the number of use cycles covered by the label would reduce significantly their
13
14 330 environmental impact. Overall, our results highlight the need to develop procedures and the
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16 331 legal/operational framework to extend the use of protective equipment during a pandemic. Such an
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18 332 approach would not only reduce the environmental impact of the masks, but also make the public
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20 333 health system more resilient in the event of equipment shortages. Last but not least, adopting a wait
21
22 334 and reuse strategy with medical masks is probably the most economical, which is important in terms
23
24 335 of access to protective measures for people with limited financial resources³³.
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30
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32
33 338 development of this study.
34

35 339 **Competing interests**

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37
38 340 The authors declare no competing interest
39

40 341 **Author contribution**

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43 342 JB, NS, BG and DV developed the study concept and design. AB and JB conducted the impact
44
45 343 assessment. DV wrote the first draft of the manuscript with contributions from JB, AB and NS. All
46
47 344 authors contributed to and have approved the final manuscript.
48
49

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51
52
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54

55 347 **Patient consent for publication**

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58 348 Not required
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60 349 **Data availability statement**

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3 350 Detailed primary and secondary data used for this study are available upon request.
4

5 351 **Ethics approval**
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8 352 This study does not involve research with human subjects.
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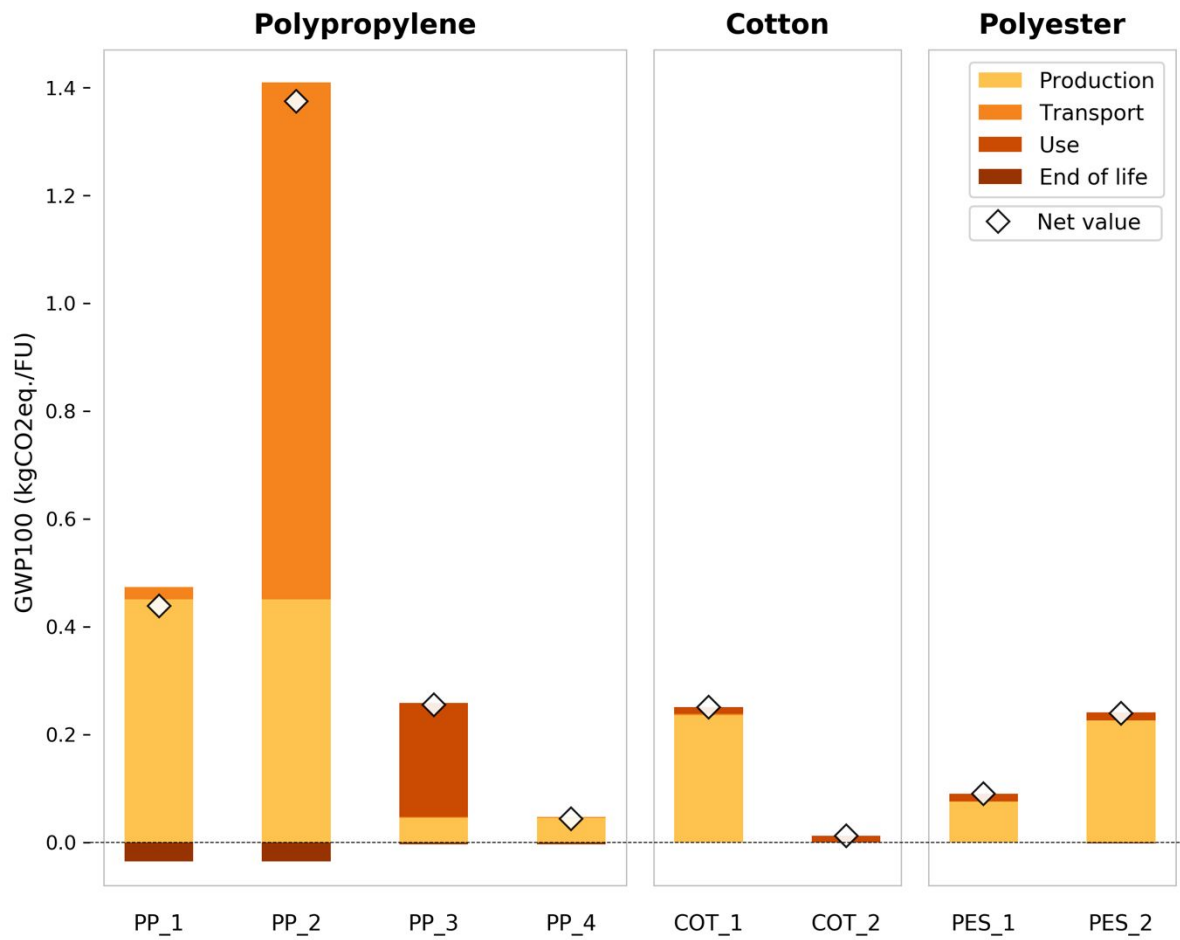


Figure 1. Footprint expressed in GWP100 (kg CO₂ eq./FU) for different scenario of mask uses.

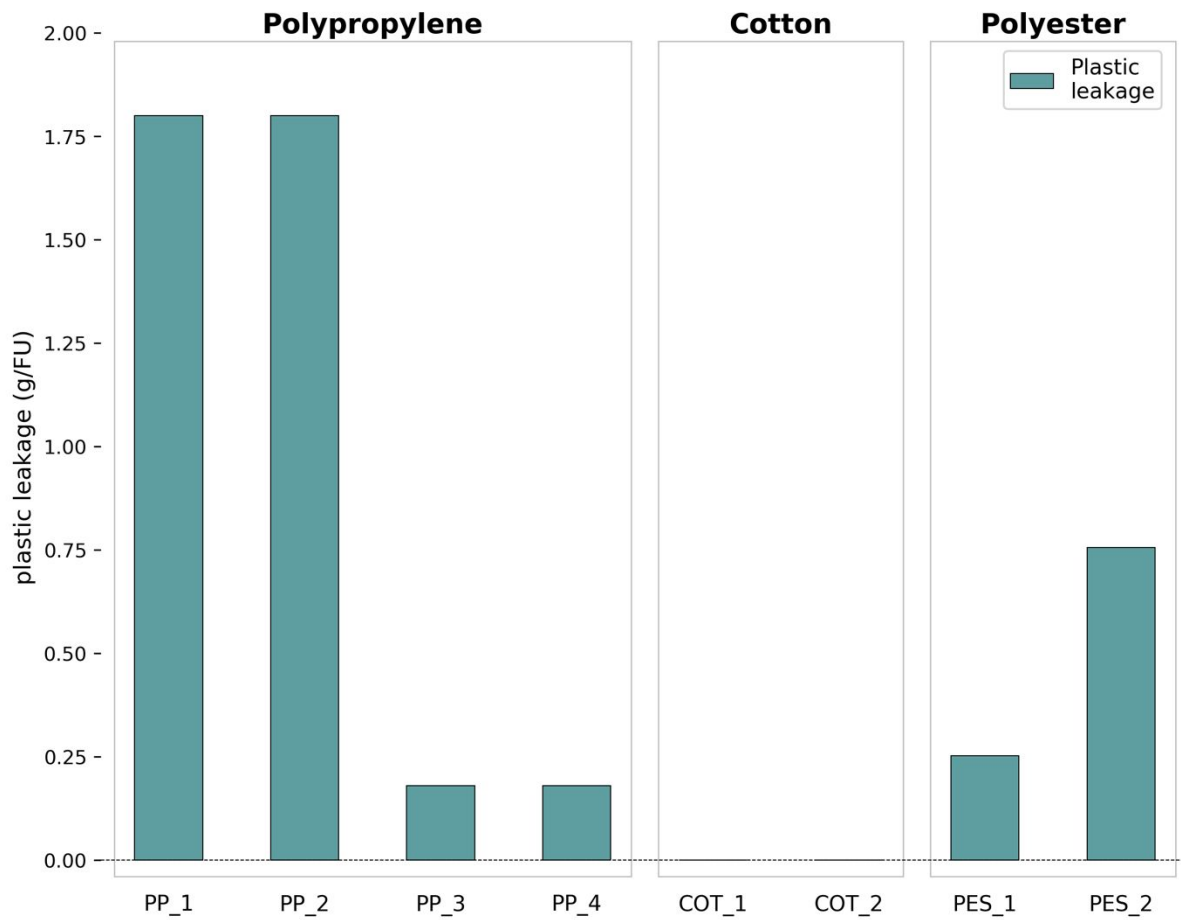


Figure 2. Footprint expressed in plastic leakage (g/FU) for different scenarios of mask uses.

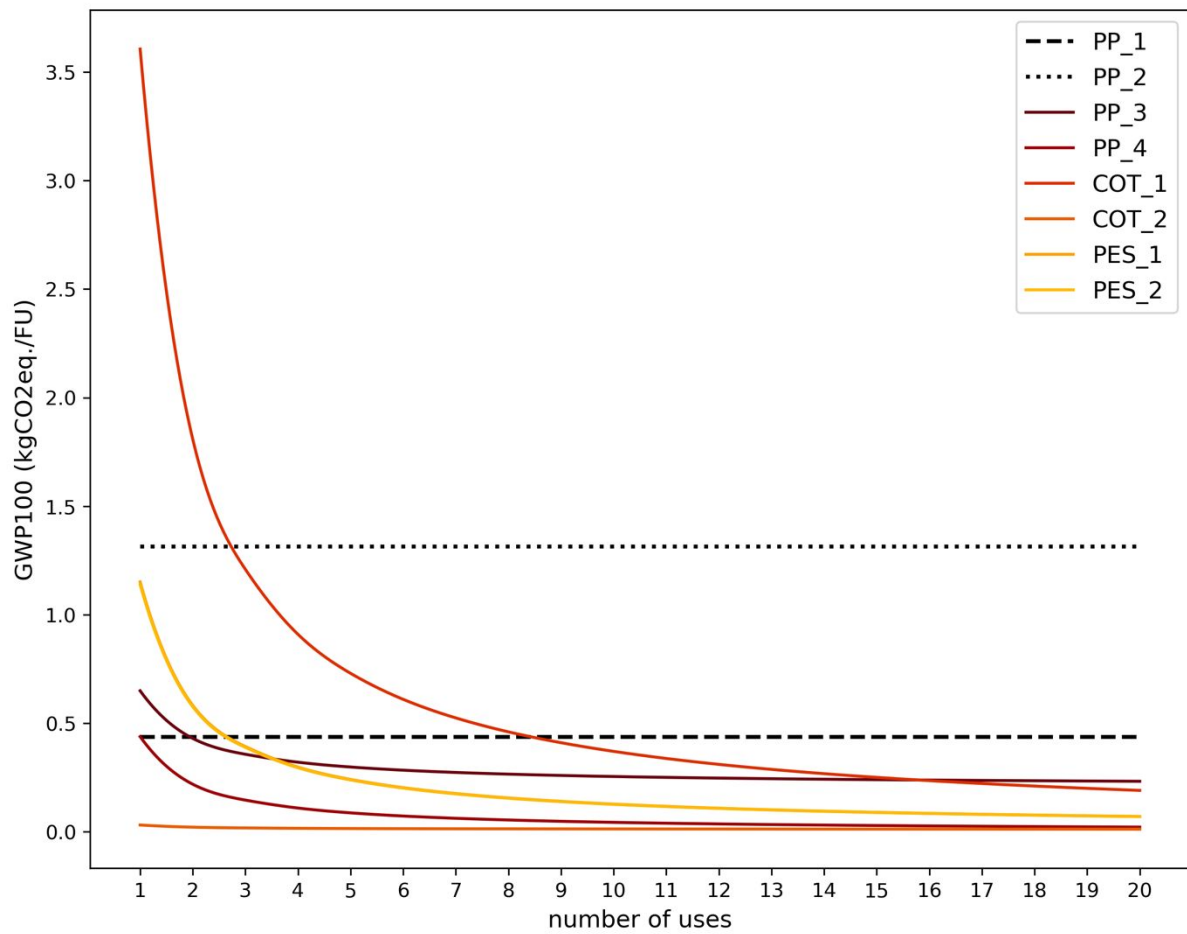


Figure 3. Footprint expressed in GWP100 (kgCO₂eq./FU) for different scenarios as a function of number of uses

Appendix S1

In addition to the Global Warming Potential (GWP100) index, we assessed other environmental impacts with an aggregated impact metric specific to Switzerland called UBP, which is the abbreviation of the German word “Umweltbelastungspunkte”. The UBP method aggregates all individual impacts from a standard LCA assessment into a single parameter. It is based on legally defined targets for pollutant emissions and resource consumption, and measures the differences between current emission values and these specific target values. The further the current status is from the target, the greater the number of points assigned to an emission. For more details, see Frischknecht et al. (Frischknecht and Büsler Knöpfel 2013).

The UBP impacts of the different scenarios of mask use are presented in Figure S1. Similarly to the CO₂-equivalent impacts (see Figure 1), the use of disposable masks brought by plane (scenario PP_2) results in the highest impact in terms of UBP. The largest discrepancies between the global warming potential and UBP results occur in scenarios PP_3 and COT_1. In scenario PP_3, the UBP impact of the use phase is very large with an unfavourable contribution of the electricity consumption to run the oven, while the production phase of the cotton fabric increases the relative impact of cotton masks manufactured abroad (scenario COT_1) with respect to other scenarios when compared with the global warming potential results. Nonetheless, the least impactful scenarios remain the home-made cotton masks (COT_2) and the extended use of medical masks through a wait and reuse strategy (PP_4), which provides a coherent picture when it comes to the best practices for community protection with a mask in times of pandemic.

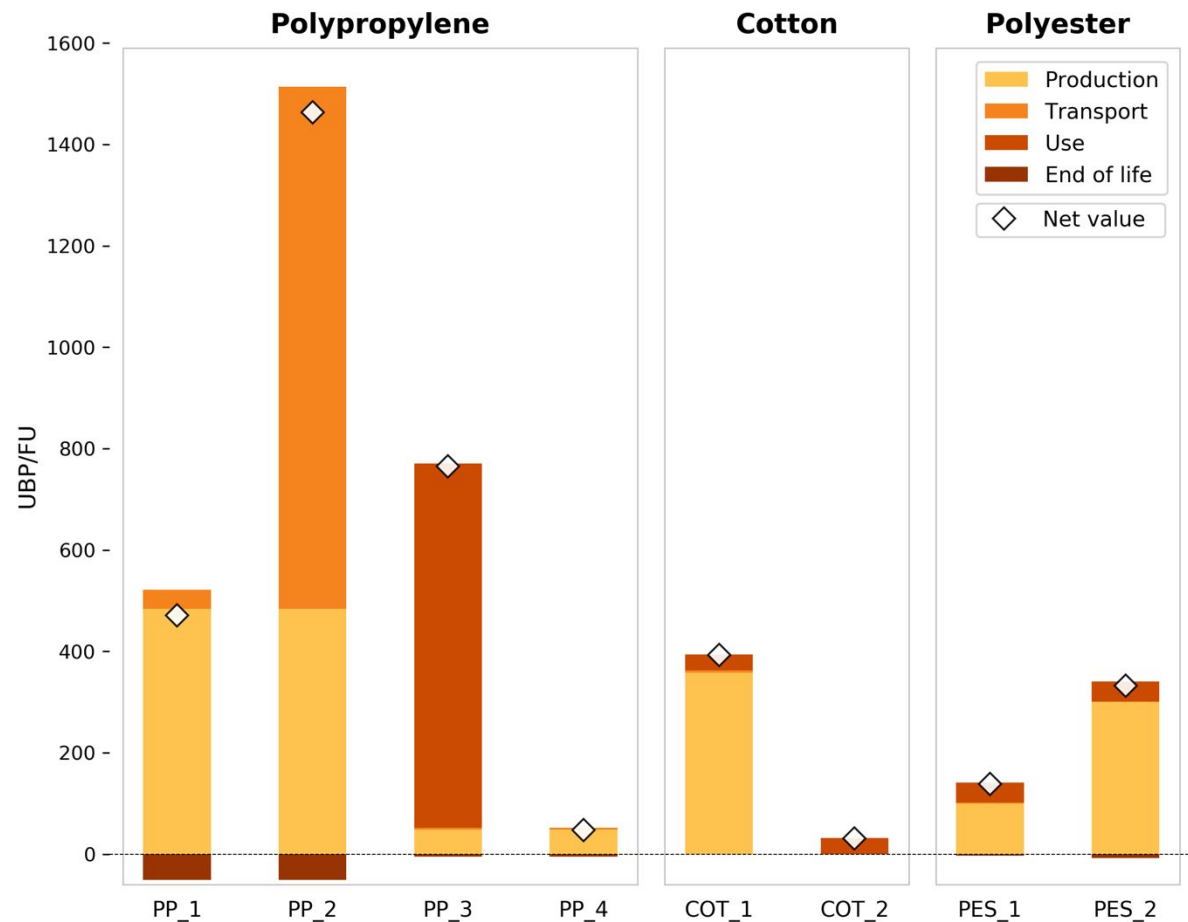


Figure S1. Footprint expressed in UBP /FU for different scenario of mask uses.

Frischknecht, Rolf, and Sybille Büsser Knöpfel. 2013. "Swiss Eco-Factors 2013 according to the Ecological Scarcity Method. Methodological fundamentals and their application in Switzerland." In *Environmental studies* no. 1330, 254. Bern: Federal Office for the Environment.

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4 1 **Which strategy for using medical and community masks? A**
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6 2 **prospective analysis of their environmental impact.**
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49 26 Facemask, community mask, medical mask, recycling, reuse, carbon footprint, COVID-19

29 **Abstract**

30 **Introduction**

31 The use of personal protective equipment, especially medical masks, increased dramatically during
32 the COVID-19 crisis. Medical masks are made of synthetic materials, mainly polypropylene, and a
33 majority of them are produced in China and imported to the European market. The urgency of the
34 need has so far prevailed over environmental considerations.

35 **Objective**

36 Assess the environmental impact of different strategies for the use of facemask

37 **Method**

38 A prospective analysis was conducted to assess the environmental impact of different strategies for
39 the use of medical and community masks. 8 scenarios, differentiating the typologies of masks and the
40 modes of reuse are compared using three environmental impact indicators: the Global Warming
41 Potential (GWP100), the ecological scarcity (UBP method) and the plastic leakage (PL). This study
42 attempts to provide clear recommendations that consider both the environmental impact and the
43 protective effectiveness of face masks used in the community.

44 **Results**

45 The environmental impact of single-use masks is the most unfavorable, with a GWP of 0.4 -1.3 kgCO₂
46 eq., depending on the transport scenario, and a PL of 1.8 g, for a one month protection against COVID-
47 19. The use of home-made cotton masks and prolonged use of medical masks through wait-and-reuse
48 are the scenarios with the lowest impact.

49 **Conclusion**

50 The use of medical masks with a wait and reuse strategy seems to be the most appropriate when
51 considering both environmental impact and effectiveness. Our results also highlight the need to
52 develop procedures and the legal/operational framework to extend the use of protective equipment
53 during a pandemic.

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3 54 **Strengths and limitations of this study**
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- 8 56 - This study provides an environmental assessment based on three indicators (GWP 100, UBP,
9 plastic leakage) for different mask type and use strategies.
10 57
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13 58 - -Eight mask use and reuse strategies were considered.
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15 59 - - The assumptions used in the life cycle assessment (transport, end of life, littering) are
16 based on the European context and do not necessarily apply to other regions.
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20 61 - The weight and composition of the masks used in this study are those of typical,
21 commercially available masks, but do not represent the variability from one manufacturer to
22 62 another.
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65 Introduction

66 The decrease in industrial activity during the COVID-19 confinement and the decline in intra-
67 and inter-national mobility has led to a significant drop in CO₂ emissions¹. An average
68 decrease of 6.4% % in yearly CO₂ emissions was observed worldwide for 2020². Positive
69 effects have also been observed on other air pollutants, such as PM, NO_x, SO₂ and on river
70 pollution³. However, some observations made in China, near Hubei's epicenter, show an
71 unclear environmental picture, with a lower decrease in air pollutants than expected⁴. Due to
72 the temporary nature of the confinement measures, some authors argue that the longer-term
73 effects of the COVID-19 crisis on the environmental footprint of human activities remain
74 highly uncertain and may offset the observed short-term environmental benefits ⁵. In the
75 United States, a sharp drop in jet fuel and gasoline consumption has been observed during
76 the crisis, leading to a decrease in CO₂ emissions of around 15%. However, it has been
77 estimated that in a scenario of sustainable impact on the economy, the consequences of
78 delayed investment in green energy and traffic-related emission reduction programs alone
79 could outweigh the short-term effects ⁶. The evolution of some activities or consumption
80 patterns during the COVID-19 crisis are also likely to worsen the environmental balance:
81 development of e-commerce (increase of transport distances and packaging), high
82 consumption of disinfection products, massive COVID-19 screening in populations (increase
83 in medical consumables).

84 The consumption of protective equipment and most particularly facemasks has also
85 experienced a sharp increase during the crisis^{7 8}. To meet the growing demand, the
86 production of disposable masks has dramatically increased since the first pandemic wave ⁹.
87 By June 2020, China was producing 200 million facemasks per day, 20 times more than in

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3 88 February of the same year¹⁰. With the second pandemic wave, the wearing of facemasks was
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6 89 mandatory in closed spaces and densely populated areas in many countries. Medical masks
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8 90 and community masks have become essential tools in the fight against the spread of the virus.
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10 91 Given the extensive use of facemasks, there is an urgent need to take into account the
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12 92 environmental impact of this practice and ways to extend the life of this equipment. Several
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14 93 arguments can be put forward: (1) the bulk of production comes from Asia¹¹, resulting in
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16 94 significant use of transportation to supply regions such as Europe and the United States, (2)
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18 95 medical masks are intended for single use, resulting in additional waste and possible littering
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20 96 of used masks, and (3) medical masks and some community masks are made of plastic. Poor
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22 97 management of this waste can therefore contribute to the presence of macroplastics and
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24 98 microplastics in the environment, particularly in the Ocean¹². Considering that 3% of masks
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26 99 could enter the environment (overall loss rate), it is estimated that up to 1.56 billions
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28 100 disposable masks could have entered the Ocean in 2020, which represents between 4680 and
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30 101 6240 tons of plastic pollution to the marine environment¹³. Life cycle assessment (LCA)
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32 102 conducted on facemasks in United Kingdom also shows that the environmental impact of
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34 103 disposable masks are generally higher than recycled masks. In the absence of recycling, the
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36 104 production of waste in this country, as a consequence of the use of one mask each day for a
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38 105 year by the entire British population, was estimated at 124'000 tons, including 66'000 tons of
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40 106 non-recyclable contaminated plastic¹⁴. Many countries are attempting to restrict the use of
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42 107 single-use plastics, including restricting the use of plastic bags. The increase in plastic waste
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44 108 is putting pressure on the waste management system to find new strategies to deal with this
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46 109 change¹⁵. On the other hand, there is good evidence that face masks used in the community
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48 110 provide protection against Covid-19 infections¹⁶, even though effectiveness can be very
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3 111 different according to the type of masks, the wearing adherence or the environmental
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8 113 In this study, we aim to explore and compare the environmental impact of the different masks
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10 114 used in the community and attempt to provide clear recommendations on the best
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13 115 compromise between protection effectiveness and environmental impact.
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120 **Method**

121 The environmental impact assessment proposed in this study is based on: (1) the construction of
122 scenarios of mask use in the general population, distinguishing their typology and modalities of reuse,
123 and (2) the analysis of these scenarios using three impact indicators, reflecting global warming, plastic
124 littering and ecological scarcity (UBP method).

125 **Mask typology**

126 Three types of masks, intended for general public use, were considered: medical masks, community
127 masks and labelled community masks. Filtering facepiece respirators, such as N95 (US) and FFP2 (EU),
128 which are mainly used by healthcare professionals are not considered in this study.

129 Medical masks (or surgical masks) are originally intended for single use and designed to protect
130 patients from possible pathogens exhaled by the medical personnel. In the context of the COVID-19
131 pandemic, these masks have been widely used outside of healthcare settings to protect the public by
132 preventing pathogens from leaving the wearer and thus from being transmitted to others in the
133 vicinity of the wearer. In Europe, medical masks must meet the requirements of EN 14683 and must
134 comply with the Medical Devices Directive (EU) 2017/745. Medical masks are usually constituted of 3
135 different layers of nonwoven fabric, generally in polypropylene (referred here below as PP masks)¹⁷.

136 A majority of them are produced in China and imported by ship in large quantities on the European
137 market. However, during the first pandemic wave in spring 2020, due to the lack of Filtering Facepiece
138 Respirators and medical masks, emergency shipments were made by air.

139 The term community mask encompasses all non-professional masks that are intended to protect the
140 general public from infection, essentially in reducing the emissions from the wearer (source control).

141 Community masks range from homemade cotton masks (referred here below as COT masks) to more
142 or less sophisticated textile masks. Community masks have the advantage that they can be produced
143 locally, either centrally in the case of commercial masks, or at home for personal use. The performance
144 of community masks is not subject to legal requirements, so their quality can vary greatly. In some

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3 145 countries, quality labels have been proposed, allowing minimum performance requirements to be
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5 146 defined on a voluntary basis. This is the case, for instance, of the French AFNOR label and of the Swiss
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7 147 TESTEX label (referred here below as PES masks). Currently, labelled masks represent only a minority
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9 148 of production, probably due to higher manufacturing costs. While "common" community masks are
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11 149 generally made of cotton or other textiles of natural origin, labelled masks, which require greater
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13 150 technicality, are made of polymers, such as elastane or polyester. Community trade masks without
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15 151 labels were considered to come from the wider European market. For the labelled masks, the origin
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17 152 is more specific, since the AFNOR and TESTEX labelled masks are, to our knowledge, only produced in
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19 153 France and Switzerland respectively.
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25 155 **Reuse strategy**

27 156 The lack of protective means and the need to extend the life cycle of masks during the first COVID-19
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29 157 wave generated numerous studies on their reuse. Although medical masks are normally intended for
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31 158 single use, it has been shown that certain physical treatments such as UVC, microwaves or dry heat
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33 159 can effectively decontaminate them without significantly altering their barrier capacity. The latter
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35 160 method is of particular interest for the treatment of medical masks, as it is accessible in all households.
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37 161 It has been shown exposure to at least 70°C for 30 min is sufficient to effectively decontaminate
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39 162 surgical masks or respirators¹⁸⁻²⁰.
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43 163 Another alternative, which has yet to be validated, is the wait & reuse strategy. The viability of the
44
45 164 virus deposited on a surface decreases significantly after a few hours. Tests on surgical masks have
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47 165 shown that under ambient temperature and humidity conditions (22°C, 65% RH), a 3-log reduction in
48
49 166 virus load was achieved after 4 to 7 days²¹. In a similar way to what has been proposed by the
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51 167 N95Decon scientific group for respirators, surgical masks could therefore be stored at room
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53 168 temperature for 7 days before being reused (by the same user).
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3 169 The situation with community masks is more straightforward since they are designed with the intent
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5 170 of cleaning and reusing by the general public. The issue of maintaining performance is also less critical
6
7 171 since there are no legal requirements for this type of mask. The strategy considered here is therefore
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9 172 that of a reuse after a decontamination at home in a washing machine at 60°C. Labelled community
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11 173 mask are a special situation, since maintaining their performances is conditioned by the limitation of
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13 174 the number of washing cycles, to 20 and 5 washes for the AFNOR and TESTEX labels, respectively ²²²³.
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19 176 **Environmental Impact assessment**

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Figure 1 about here

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28 180 This study follows the methodology of life cycle assessment (LCA) and considers all the life cycle stages
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30 181 of the different masks including production, transport, use (decontamination) and end of life (see
31
32 182 Figure 1). The primary data sources used and hypothesis are referenced throughout this article. The
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34 183 secondary data used for impact characterization used to perform the LCA analysis are based on the
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36 184 Ecoinvent database (<https://www.ecoinvent.org/database/database.html>). A proprietary excel tool
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38 185 developed by the authors was used to perform the LCA based on Ecoinvent datasets. Unless otherwise
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40 186 mentioned; the functional unit (FU) chosen for the comparison of the masks is “to equip one person
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42 187 with a mask during a month”. Several environmental impact indicators were considered:
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48 189 - The Global Warming Potential (GWP100) index, which expresses the impact of manufacturing,
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50 190 transporting and recycling masks in terms of greenhouse gases. GWP100 expresses the time-
51
52 191 integrated warming effect, over a 100 year period, due to the release of a given greenhouse gas
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54 192 in today's atmosphere, relative to that of carbon dioxide (in mass unit kg)²⁴.
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3 193 - The UBP method relies on the methodological concept of ecological scarcity and expresses the
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5 194 environmental impact in terms of eco-points. It encompasses for instance the water footprint of
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7 195 cotton production as well as the biodiversity impact of energy production during the use phase.
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9
10 196 However. Calculation using the UBP method has been performed and is available in Appendix
11
12 197 S1.

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14 198 - The plastic leakage (PL), which expresses the amount of plastic leaving the technosphere and
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16 199 cumulating in the natural environment. PL measures the quantity of plastic ultimately released
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18 200 into the ocean or into the other compartments (freshwater, soils, other terrestrial
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20 201 environments) including both microplastics and macroplastics²⁵ Leakage is a result of both loss
21
22 202 and release and can be simply described by the following equation:

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25 203
$$\text{Leakage} = \text{Waste} \cdot \text{Loss rate} \cdot \text{Release rate (with Loss rate = mismanaged rate +}$$

26
27 204
$$\text{littering rate)}$$

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29
30 205 In the case of Switzerland, the only loss occurring is related to littering since the mismanaged
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32 206 rate is equal to 0%. The littering rate will then be assimilated to the leakage rate as we are here
33
34 207 assessing the release rate to all environmental compartments at once. The littering rate used by
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36 208 default for on-the-go plastic is generally ranging between 2%^{26 27} and 12%²⁸. A recent study
37
38 209 focusing on masks articulates a littering rate of 3% worldwide. In this study, we used a 2%
39
40 210 littering rate²⁵.

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42
43 211 The destination chosen for masks transport is Switzerland. However, shipping origin and method
44
45 212 vary as masks can come from Switzerland, France or China, and be transported either by truck, boat
46
47 213 or plane. Different assumptions are made for additional environmental burdens during the use
48
49 214 phase of the mask life cycle according to the decontamination method. For the decontamination in
50
51 215 a washing machine, we consider a household washing machine cycle running at 60°C during 1h40
52
53 216 with a dry load of 6 kg of clothes with an energy use of 1.8 kWh/cycle, a water use of 67.6 L/cycle
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55 217 and a soap consumption of 65 g/cycle²⁹. We have allocated the energy, water and soap used to

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3 218 wash a mask based on the ratio between the weight of the mask and the total dry load of clothes
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5 219 assumed when running one cycle. These consumptions features have then been scaled up to
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7 220 represent the functional unit chosen for the study. For the oven sterilization we assume that, based
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9 221 on personal measurement, an oven running at 70°C during 30 min consumes 0.345 kWh of
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11 222 electricity. As the oven utilization is exclusively dedicated to sterilizing masks, we had to make an
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13 223 assumption on the number of masks being sterilized at once. We assumed that a batch of 5 masks
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15 224 were sterilized for each oven utilization, hence an energy consumption of 0.069 kWh per mask
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17 225 sterilized.
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19 226 In the end of life stage, we assumed that all masks were incinerated after disposal. Heat and
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21 227 electricity recovery efficiencies in Europe vary quite significantly between different plants, at
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23 228 average values of 31% for heat and 12% for electricity³⁰. The strategies for using the masks and the
24
25 229 corresponding assessment parameters are summarized in Table 1.
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231 **Patient and public involvement**

232 No patient involved.

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Scenario	Mask type	Material	Weight [g]	Origin	Transport (main)	Re-use	Consumption mask/month ^a
PP_1	Medical mask	Polypropylene (PP) / Nylon /Aluminium ^b	3.2 (2.5/0.5/0.2)	China	Boat	No	30
PP_2		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Plane	No	30
PP_3		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Boat	Hot drying, 30 min. 70°C	3
PP_4		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Boat	Wait and reuse	3 ^c
COT_1	Unlabelled community mask	Cotton (COT)	5	China	Boat	Washing machine 60°C	2
COT_2		Cotton (COT)	5	Homemade ^d	-	Washing machine 60°C	2
PES_1	Labelled community mask ^e	Elastane / polyester (PES)	6.3 (0.13/6.17)	France	Truck	Washing machine 60°	2
PES_2		Elastane / polyester (PES)	6.3 (0.13/6.17)	Switzerland	Truck	Washing machine 60°	6

236

237 ^a Number of worn-out masks disposed of and then replaced by a user during a month (consumption = 30/nb. of expected reuses)

238 ^a Aluminium nose strip

239 ^c One mask is used each weekday, for 10 reuses

240 ^d made from old cloth/fabric

241 ^e Considering the French quality label AFNOR (scenario PES_1) and the Swiss quality label Testex (scenario PES_2)

242

243 *Table 1. Summary of Mask typology and uses scenarios*

244 Results

245 Global warming potential

246 The CO₂- equivalent impact of the different scenarios of mask use is presented in Figure 2. The use of
247 disposable masks brought by plane (scenario PP_2), as experienced during the Personal Protective
248 Equipment (PPE) shortage of the first pandemic wave, is by far the most detrimental with 1.3 kg/CO₂
249 eq./FU. Without taking this extreme situation into account, a strong variability is observed between
250 the different scenarios of mask use. There is a factor of 30 between the most unfavourable scenario
251 (PP_1 - disposable medical mask brought by boat) and the most favourable scenario (COT_2 – Home-
252 made washable cotton mask). The differences observed are largely due to the absence of
253 manufacturing impact from the second-hand fabric as well as a very low contribution from the usage
254 phase in scenario COT_2. The decontamination of medical masks by heating (PP_3) is not very
255 advantageous, as well as the use of community masks made of polymers, as long as the number of
256 reuse cycles remains limited. Taking into account the discounted emissions from incineration after
257 disposal leads to a negative contribution of the end of life stage to the total CO₂-equivalent emissions
258 in all scenarios except COT_1 and COT_2. The use of labelled community mask (PES_1 and PES_2) has
259 an intermediate environmental impact, the use of AFNOR masks (French label) being more
260 advantageous than the TESTEX mask (Swiss label). The difference between the two is mainly due to
261 the different number of reuses recommended between the two labels. Overall, the most
262 advantageous scenarios are home-made cotton masks (COT_2) and the extended use of medical
263 masks through a wait and reuse strategy (PP_4).

264
265 Figure 2 about here

266
267 Results similar to those of the carbon footprint are obtained by considering a broader impact indicator,
268 such as UBP, which integrates water consumption (see Supplementary file S1). The impact related to
269 use increases for all masks when recycled multiple times. The most advantageous scenarios remain

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2
3 270 however the home-made cotton masks (COT_2) and the extended use of medical masks through a
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5 271 wait and reuse strategy (PP_4). Notably, the impact of decontamination of medical masks by heating
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7 272 (PP_3) is more than doubled, making it less advantageous than the single-use scenario of medical
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9 273 masks shipped from China by boat (PP_1).

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275 **Plastic leakage (PL)**

16 276 The impact of the different scenarios of mask use from the point of view of plastic leakage is
17
18 277 presented in Figure 3. Unsurprisingly, cotton masks do not generate plastic leakage. Disposable
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20 278 medical masks have a high PL of 1.8 g/FU. However, this impact can be reduced by a factor of 10 by
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22 279 reuse procedures, which proportionally reduce production needs.

280

281 *Figure 3 about here*

282 **Number of reuse**

32 283 The number of reuses used in the scenarios is based on an estimate of current practices and
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34 284 recommendations. Arguably, this may change depending on usage conditions, material quality, or
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36 285 changes in mask labelling requirements. The effect of the number of reuses on the GWP100 is shown
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38 286 in figure 4. Interestingly, commercial cotton masks (COT_1) reused less than 8 times generate more
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40 287 CO₂eq than disposable medical masks shipped by boat (PP_1). Moreover, when used less than 17
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42 288 times commercial cotton masks (COT_1) generate more CO₂eq than medical masks decontaminated
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44 289 through dry heating (PP_3). The increase in the number of reuse decreases the gap between the two
45
46 290 most advantageous scenarios: home-made cotton masks (COT_2) and the recycling of medical masks
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48 291 through a wait and reuse strategy (PP_4). The curves for scenarios PES_1 and PES_2 are overlapping
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50 292 in Figure 4 since the composition of EMPA and AFNOR masks has been assumed identical. The only
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52 293 slight difference between these scenarios, although not significant enough to distinguish both curves
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54 294 on the graph, stems from the distinct origins of the masks.

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Figure 4 about here

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Discussion

Consistent with what has been highlighted by other authors, our results show that switching from single-use to reusable masks can significantly reduce plastic leakage and climate change impact¹⁴. However, analysis of the different scenarios shows considerable variation between reuse strategies, mainly due to the impact of production and recycling. A footprint reduction (GWP100 or UBP) of 50% to 90% can be achieved by switching from a single-use medical mask to a reusable solution. For plastic leakage, this reduction can be from 60% to 100%. At the population level, these differences are not negligible. We quantified how much CO₂eq impact and plastic leakage would be avoided within a year in Switzerland if 10% of the entire population was to shift from single-use masks transported by boat (PP_1) to either a wait and reuse strategy for the same masks (PP_4) or home-made cotton masks from old fabric (COT_2). Results are reported in Table 2, considering a Swiss population 8'606'033 in 2019 (source: Federal Statistical Office).

	CO ₂ eq impact avoided [t CO ₂ eq.]	Plastic leakage avoided [t PL]
shifting to PP_4	4'077	17
shifting to COT_2	4'400	19

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Table 2. Environmental impact of a shift from the use of disposable masks to reuse strategies in 10% of the Swiss population.

For an impact per passenger transport by aircraft (person.km) of 0.129 kgCO₂eq (source: Reffnet.ch) and an average 1.5L plastic bottle weight of 32.6 g³¹, the uptake of the wait and reuse strategy for the medical masks (PP_4) by 10% of the population would be equivalent to saving CO₂eq emissions from 5'402 individual flights from Paris to New York and preventing 513'194 plastic bottles (1.5L)

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3 318 from being littered. Similarly, the uptake of home-made cotton masks (COT_2) by the same
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5 319 population share would result in CO₂eq emissions savings analogous to 5'830 individual air travels
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7 320 from Paris to New York, and a plastic leakage avoided corresponding to 570'219 plastic bottles
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10 321 (1.5L).

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12 322 The environmental impact assessment conducted in this study has several limitations. Data on mask
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14 323 composition, transport and end of life are from the European context. The transposition of these
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16 324 results to other regions, in particular regions with a higher production capacity of medical masks and
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18 325 less reliance on imports, would lead to a modification of the GWP100 and UBP impact. Furthermore,
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20 326 in the absence of precise market distribution data, mask composition and production data were
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22 327 based on typical examples and scenarios rather than statistical data. In practice, there is some
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24 328 variability in manufacturing and shipping arrangements due to different suppliers. From the point of
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26 329 view of the effectiveness of their individual or collective protection, masks are not all equal. The
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28 330 comparison of their performance is not obvious because several parameters influence their
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30 331 effectiveness (droplet penetration, aerosol penetration, fitting to the face, wettability...)¹⁶ and only
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32 332 medical masks as well as labelled community masks (e.g. AFNOR label) have minimum performance
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34 333 requirements for some of these parameters while a high variability in performance is to be expected
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36 334 among unlabelled community masks. We performed an uncertainty analysis based on low and high
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38 335 values for the littering rate (ranging from 0.2% to 12%, with the medium value being set at 2%). We
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40 336 have observed that the plastic leakage results would be changing proportionally to the leakage rate
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42 337 factor between the medium value and the low or high value, but that the climate change or UBP
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44 338 impact results would deviate from the medium case by around 1% or below. No other uncertainty
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46 339 analysis was undertaken for this study.

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48 340 The filtration efficiency of the membrane as such has been investigated by several experimental
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50 341 studies. Aydin et al. report filtration efficiencies for large droplets in the 100 µ- 1mm range of over
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52 342 98% for surgical masks and 93-98% for unlabelled community masks of different materials (cotton,
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54 343 polyester and silk)³². For finer particles, the performance of unlabelled community masks is however

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3 344 lower. In the 10 μ range (PM₁₀), Neupane et al. show a filtration efficiency of 94% for surgical masks
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5 345 and 63% and 84% for community masks³³. Systematic reviews of the laboratory results obtained so
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7 346 far suggest that community masks have satisfactory filtration efficiency for large particles (e.g. >
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9 347 5 μ m), but that they have only limited effectiveness against aerosols.
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12 348 However, the overall performance of the masks is not limited to filtration efficiency alone and will be
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14 349 affected by leaks due to poor fitting to the face, but also by the way the masks are used. Wearing a
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16 350 face mask in a community logic is moreover primarily intended as a collective protection (by
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18 351 reducing the emission of the wearer), rather than an individual protection. This collective
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20 352 effectiveness is difficult to quantify due to the complexity of exposure situations and the presence of
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22 353 other contamination routes (e.g surface contamination). Randomized studies conducted previously
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24 354 on the transmission of viral infections in the community, showed that wearing a mask provided
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26 355 some protection in the most adherent individuals³⁴ or when mask use is accompanied by hand
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28 356 hygiene measures and/or education on viral infections^{35 36}.
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33 357 The use of medical masks with a wear and reuse strategy seems to be the most appropriate when
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35 358 considering both environmental impact and effectiveness. Expectations, in terms of mask
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37 359 performance, are generally fairly limited. However, face masks contribute to collective protection by
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39 360 reducing droplet emissions and, to a lesser extent, aerosol emissions from infected wearers.
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42 361 However, the lack of minimum performance requirements for unlabelled community face masks,
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44 362 makes this contribution uncertain. Standardized masks, which offer guarantees in terms of
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46 363 performance and reproducibility, are therefore beneficial from this point of view.
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49 364 Labelled community masks are also an interesting alternative. Their environmental performance is
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51 365 currently limited by the number of planned cycles of use, which requires frequent replacement. An
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53 366 increase in the number of use cycles covered by the label would reduce significantly their
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55 367 environmental impact. The future use of materials that are less polluting than plastic materials for
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57 368 the manufacture of masks could be an alternative to reduce the environmental cost of their
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3 369 manufacture and plastic leakage. For community masks, this adjustment is relatively simple because
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5 370 many of them are made of cotton and some manufacturers also offer masks made of recycled
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7 371 plastic. For medical masks, a more important effort is necessary because it requires the complete
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9 372 accreditation of the mask according to EN14683. Overall, our results highlight the need to develop
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11 373 procedures and the legal/operational framework to extend the use of protective equipment during a
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13 374 pandemic. Such an approach would not only reduce the environmental impact of the masks, but also
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15 375 make the public health system more resilient in the event of equipment shortages. The scale of the
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17 376 uptake of the reuse strategies suggested in the study by the population will depend on the interest
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19 377 of the government to endorse such practices for community masks and on the efficiency of public
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21 378 awareness campaign. Last but not least, adopting a wait and reuse strategy with medical masks is
22
23 379 probably the most economical, which is important in terms of access to protective measures for
24
25 380 people with limited financial resources³⁷.

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383 development of this study.

384 **Competing interests**

385 The authors declare no competing interest

386 **Author contribution**

387 JB, NS, BG, KS and DV developed the study concept and design. KS and DV conducted the literature
388 review. AB and JB conducted the impact assessment and data analysis. All authors contributed to the
389 data interpretation. DV wrote the first draft of the manuscript with contributions from JB, AB and
390 NS. All authors contributed to and have approved the final manuscript.

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393 **Patient consent for publication**

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5 395 **Data availability statement**
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8 396 Detailed primary and secondary data used for this study are available upon request.
9

10 397 **Ethics approval**
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13 398 This study does not involve research with human subjects.
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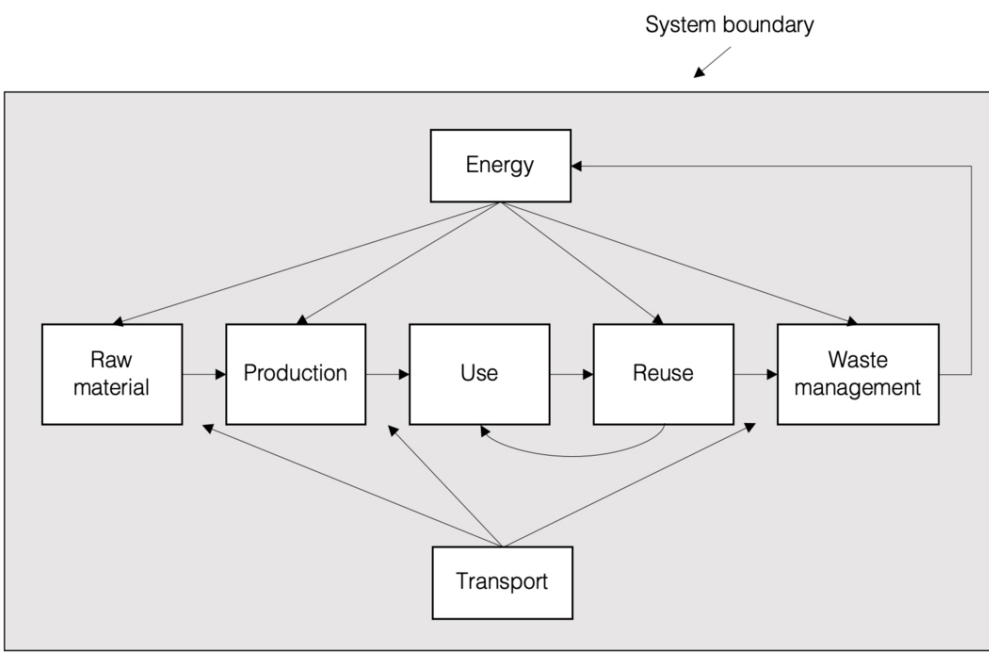


Figure 1. Illustration of the system boundary for all scenarios involved in the study.

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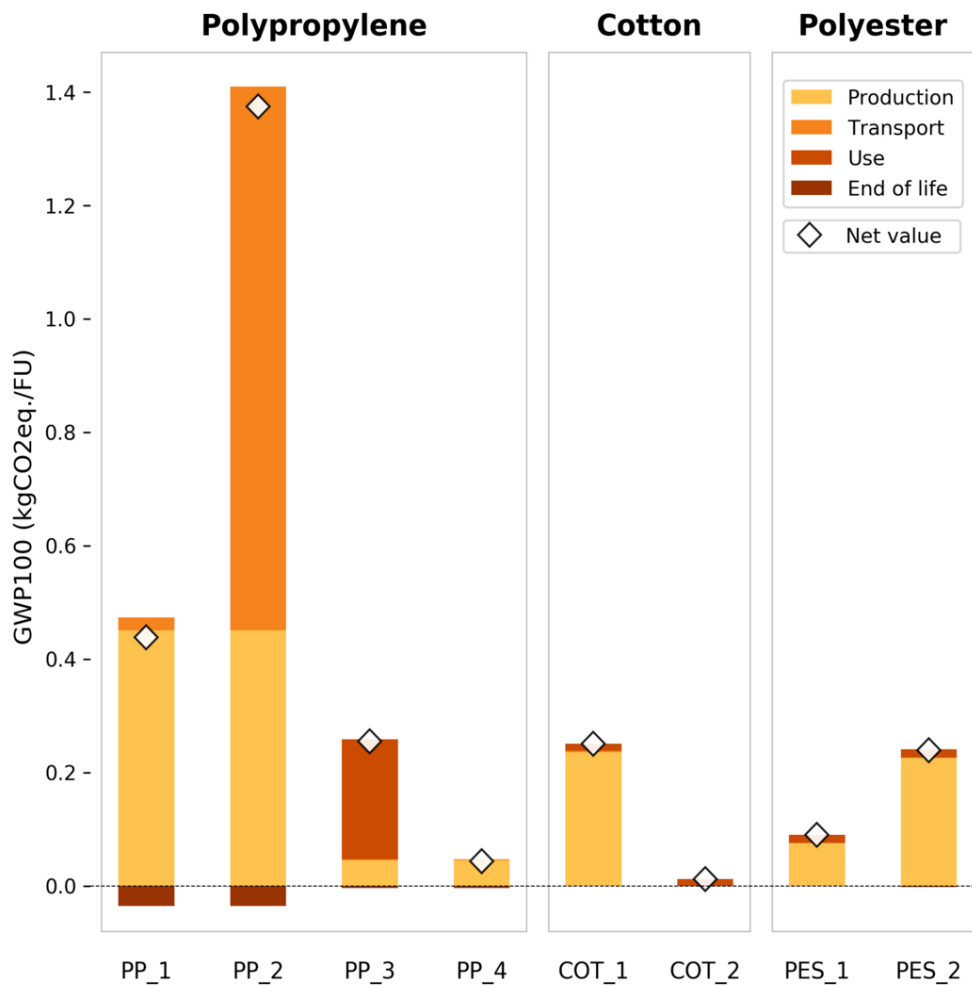


Figure 2. Footprint expressed in GWP100 (kg CO2 eq./FU) for different scenario of mask uses.

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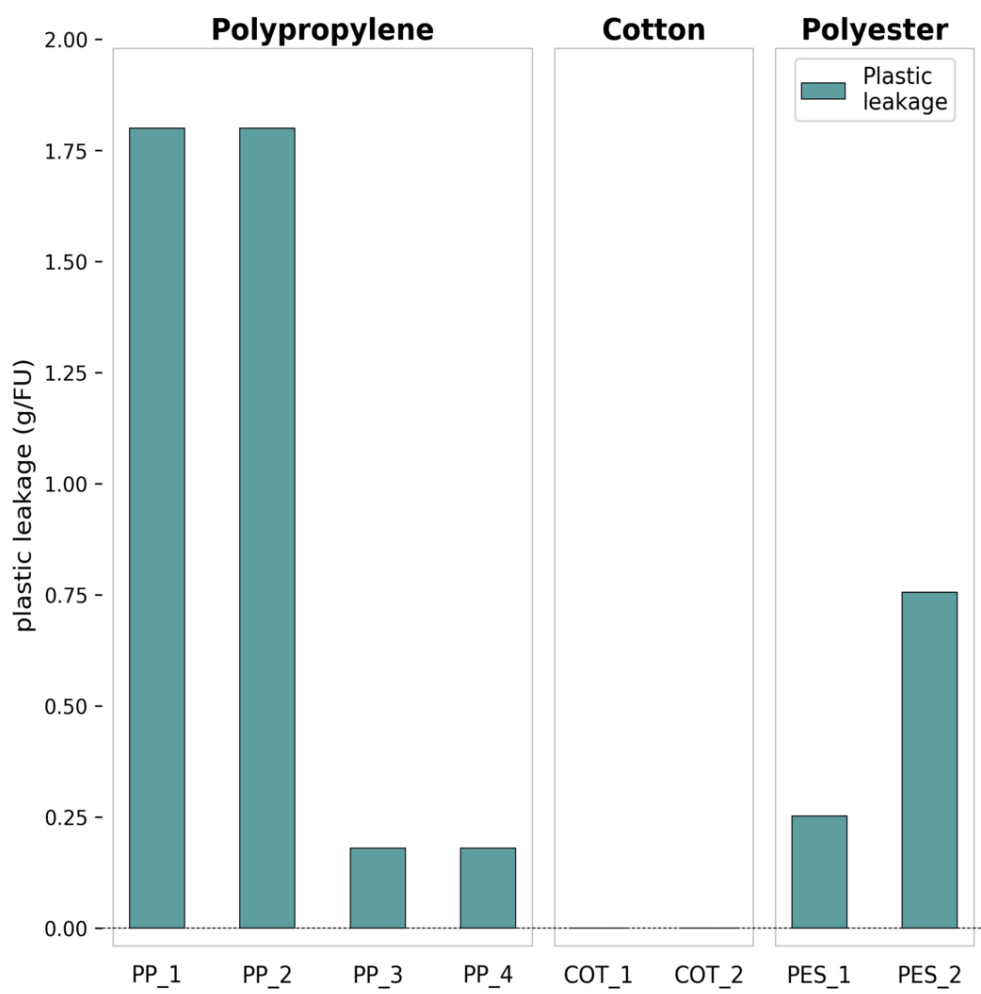


Figure 3. Footprint expressed in plastic leakage (g/FU) for different scenarios of mask uses.
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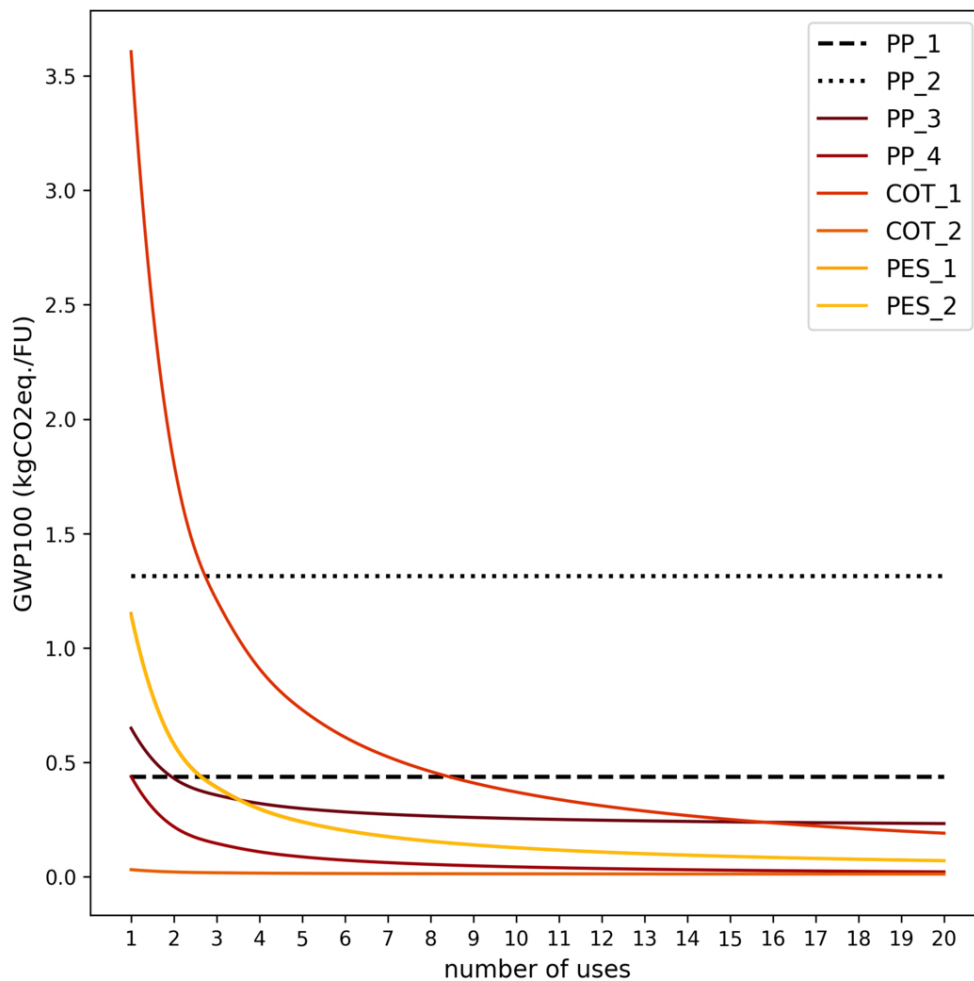


Figure 4. Footprint expressed in GWP100 (kgCO₂eq./FU) for different scenarios as a function of number of uses.

89x89mm (300 x 300 DPI)

Appendix S1

In addition to the Global Warming Potential (GWP100) index, we assessed other environmental impacts with an aggregated impact metric specific to Switzerland called UBP, which is the abbreviation of the German word “Umweltbelastungspunkte”. The UBP method aggregates all individual impacts from a standard LCA assessment into a single parameter. It is based on legally defined targets for pollutant emissions and resource consumption, and measures the differences between current emission values and these specific target values. The further the current status is from the target, the greater the number of points assigned to an emission. For more details, see Frischknecht et al. (Frischknecht and Büsler Knöpfel 2013).

The UBP impacts of the different scenarios of mask use are presented in Figure S1. Similarly to the CO₂-equivalent impacts (see Figure 1), the use of disposable masks brought by plane (scenario PP_2) results in the highest impact in terms of UBP. The largest discrepancies between the global warming potential and UBP results occur in scenarios PP_3 and COT_1. In scenario PP_3, the UBP impact of the use phase is very large with an unfavourable contribution of the electricity consumption to run the oven, while the production phase of the cotton fabric increases the relative impact of cotton masks manufactured abroad (scenario COT_1) with respect to other scenarios when compared with the global warming potential results. Nonetheless, the least impactful scenarios remain the home-made cotton masks (COT_2) and the extended use of medical masks through a wait and reuse strategy (PP_4), which provides a coherent picture when it comes to the best practices for community protection with a mask in times of pandemic.

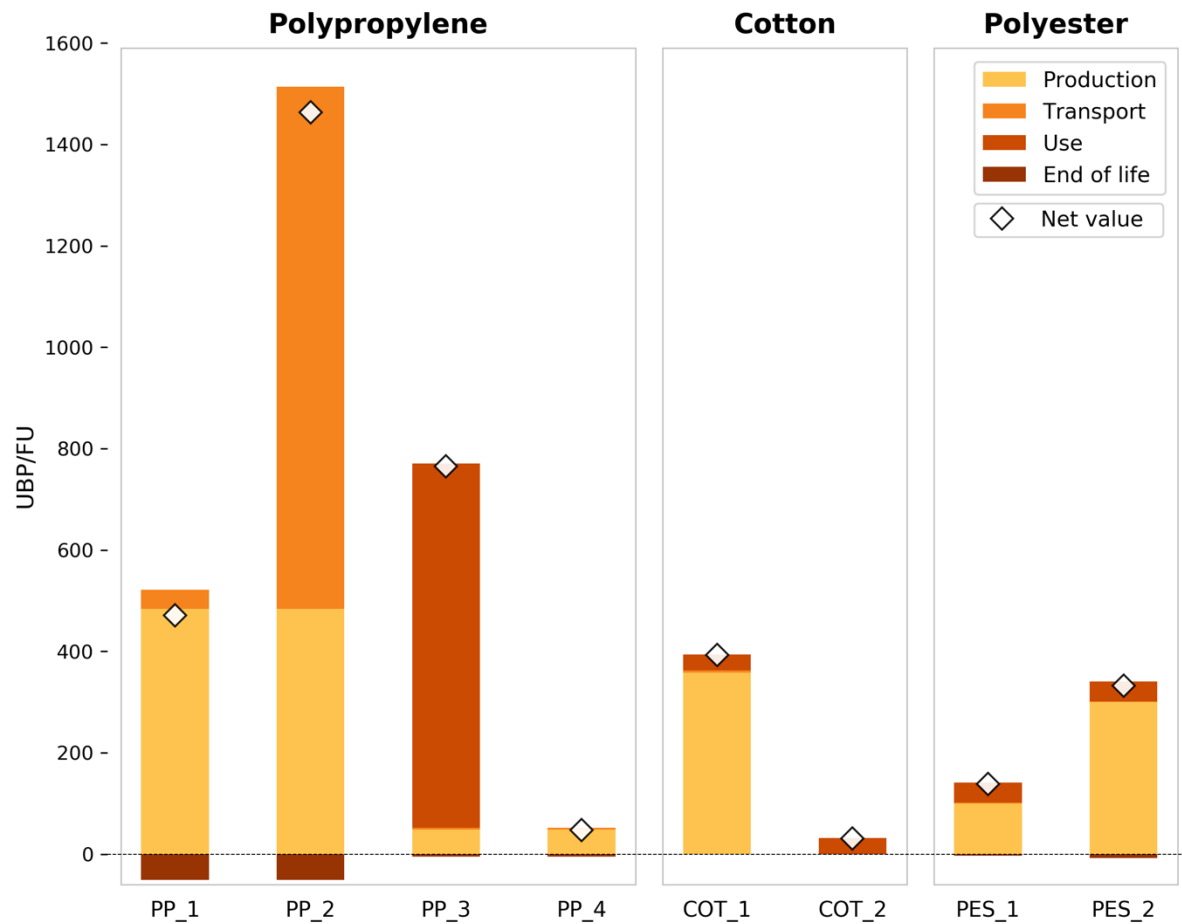


Figure S1. Footprint expressed in UBP /FU for different scenario of mask uses.

Frischknecht, Rolf, and Sybille Büsser Knöpfel. 2013. "Swiss Eco-Factors 2013 according to the Ecological Scarcity Method. Methodological fundamentals and their application in Switzerland." In *Environmental studies* no. 1330, 254. Bern: Federal Office for the Environment.

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4 1 **Which strategy for using medical and community masks? A**
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6 2 **prospective analysis of their environmental impact.**
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31 26 Facemask, community mask, medical mask, recycling, reuse, carbon footprint, COVID-19

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29 **Abstract**

30 **Introduction**

31 The use of personal protective equipment, especially medical masks, increased dramatically during
32 the COVID-19 crisis. Medical masks are made of synthetic materials, mainly polypropylene, and a
33 majority of them are produced in China and imported to the European market. The urgency of the
34 need has so far prevailed over environmental considerations.

35 **Objective**

36 Assess the environmental impact of different strategies for the use of facemask

37 **Method**

38 A prospective analysis was conducted to assess the environmental impact of different strategies for
39 the use of medical and community masks. 8 scenarios, differentiating the typologies of masks and the
40 modes of reuse are compared using three environmental impact indicators: the Global Warming
41 Potential (GWP100), the ecological scarcity (UBP method) and the plastic leakage (PL). This study
42 attempts to provide clear recommendations that consider both the environmental impact and the
43 protective effectiveness of face masks used in the community.

44 **Results**

45 The environmental impact of single-use masks is the most unfavorable, with a GWP of 0.4 -1.3 kgCO₂
46 eq., depending on the transport scenario, and a PL of 1.8 g, for a one month protection against COVID-
47 19. The use of home-made cotton masks and prolonged use of medical masks through wait-and-reuse
48 are the scenarios with the lowest impact.

49 **Conclusion**

50 The use of medical masks with a wait and reuse strategy seems to be the most appropriate when
51 considering both environmental impact and effectiveness. Our results also highlight the need to
52 develop procedures and the legal/operational framework to extend the use of protective equipment
53 during a pandemic.

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3 54 **Strengths and limitations of this study**
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8 56 - This study provides an environmental assessment based on three indicators (GWP 100, UBP,
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10 57 plastic leakage) for different mask type and use strategies.
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13 58 - -Eight mask use and reuse strategies were considered.
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15 59 - - The assumptions used in the life cycle assessment (transport, end of life, littering) are
16
17 60 based on the European context and do not necessarily apply to other regions.
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20 61 - The weight and composition of the masks used in this study are those of typical,
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22 62 commercially available masks, but do not represent the variability from one manufacturer to
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24 63 another.
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65 Introduction

66 The decrease in industrial activity during the COVID-19 confinement and the decline in intra-
67 and inter-national mobility has led to a significant drop in CO₂ emissions¹. An average
68 decrease of 6.4% in yearly CO₂ emissions was observed worldwide for 2020². Positive effects
69 have also been observed on other air pollutants, such as PM, NO_x, SO₂ and on river pollution³.
70 However, some observations made in China, near Hubei's epicenter, show an unclear
71 environmental picture, with a lower decrease in air pollutants than expected⁴. Due to the
72 temporary nature of the confinement measures, some authors argue that the longer-term
73 effects of the COVID-19 crisis on the environmental footprint of human activities remain
74 highly uncertain and may offset the observed short-term environmental benefits⁵. In the
75 United States, a sharp drop in jet fuel and gasoline consumption has been observed during
76 the crisis, leading to a decrease in CO₂ emissions of around 15%. However, it has been
77 estimated that in a scenario of sustainable impact on the economy, the consequences of
78 delayed investment in green energy and traffic-related emission reduction programs alone
79 could outweigh the short-term effects⁶. The evolution of some activities or consumption
80 patterns during the COVID-19 crisis are also likely to worsen the environmental balance:
81 development of e-commerce (increase of transport distances and packaging), high
82 consumption of disinfection products, massive COVID-19 screening in populations (increase
83 in medical consumables).
84 The consumption of protective equipment and most particularly facemasks has also
85 experienced a sharp increase during the crisis^{7 8}. To meet the growing demand, the
86 production of disposable masks has dramatically increased since the first pandemic wave⁹.
87 By June 2020, China was producing 200 million facemasks per day, 20 times more than in

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3 88 February of the same year¹⁰. With the second pandemic wave, the wearing of facemasks was
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5 89 mandatory in closed spaces and densely populated areas in many countries. Medical masks
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8 90 and community masks have become essential tools in the fight against the spread of the virus.
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10 91 Given the extensive use of facemasks, there is an urgent need to take into account the
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12 92 environmental impact of this practice and ways to extend the life of this equipment. Several
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14 93 arguments can be put forward: (1) the bulk of production comes from Asia¹¹, resulting in
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16 94 significant use of transportation to supply regions such as Europe and the United States, (2)
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18 95 medical masks are intended for single use, resulting in additional waste and possible littering
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20 96 of used masks, and (3) medical masks and some community masks are made of plastic. Poor
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22 97 management of this waste can therefore contribute to the presence of macroplastics and
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24 98 microplastics in the environment, particularly in the Ocean¹². Considering that 3% of masks
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26 99 could enter the environment (overall loss rate), it is estimated that up to 1.56 billions
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28 100 disposable masks could have entered the Ocean in 2020, which represents between 4680 and
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30 101 6240 tons of plastic pollution to the marine environment¹³. Life cycle assessment (LCA)
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32 102 conducted on facemasks in United Kingdom also shows that the environmental impact of
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34 103 disposable masks are generally higher than recycled masks. In the absence of recycling, the
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36 104 production of waste in this country, as a consequence of the use of one mask each day for a
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38 105 year by the entire British population, was estimated at 124'000 tons, including 66'000 tons of
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40 106 non-recyclable contaminated plastic¹⁴. Many countries are attempting to restrict the use of
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42 107 single-use plastics, including restricting the use of plastic bags. The increase in plastic waste
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44 108 is putting pressure on the waste management system to find new strategies to deal with this
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46 109 change¹⁵. On the other hand, there is good evidence that face masks used in the community
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48 110 provide protection against Covid-19 infections¹⁶, even though effectiveness can be very
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3 111 different according to the type of masks, the wearing adherence or the environmental
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6 112 parameters (e.g. humidity and heat).
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8 113 In this study, we aim to explore and compare the environmental impact of the different masks
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10 114 used in the community and attempt to provide clear recommendations on the best
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13 115 compromise between protection effectiveness and environmental impact.
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120 **Method**

121 The environmental impact assessment proposed in this study is based on: (1) the construction of
122 scenarios of mask use in the general population, distinguishing their typology and modalities of reuse,
123 and (2) the analysis of these scenarios using three impact indicators, reflecting global warming, plastic
124 littering and ecological scarcity (UBP method).

125 **Mask typology**

126 Three types of masks, intended for general public use, were considered: medical masks, community
127 masks and labelled community masks. Filtering facepiece respirators, such as N95 (US) and FFP2 (EU),
128 which are mainly used by healthcare professionals are not considered in this study.

129 Medical masks (or surgical masks) are originally intended for single use and designed to protect
130 patients from possible pathogens exhaled by the medical personnel. In the context of the COVID-19
131 pandemic, these masks have been widely used outside of healthcare settings to protect the public by
132 preventing pathogens from leaving the wearer and thus from being transmitted to others in the
133 vicinity of the wearer. In Europe, medical masks must meet the requirements of EN 14683 and must
134 comply with the Medical Devices Directive (EU) 2017/745. Medical masks are usually constituted of 3
135 different layers of nonwoven fabric, generally in polypropylene (referred here below as PP masks)¹⁷.

136 A majority of them are produced in China and imported by ship in large quantities on the European
137 market. However, during the first pandemic wave in spring 2020, due to the lack of Filtering Facepiece
138 Respirators and medical masks, emergency shipments were made by air.

139 The term community mask encompasses all non-professional masks that are intended to protect the
140 general public from infection, essentially in reducing the emissions from the wearer (source control).

141 Community masks range from homemade cotton masks (referred here below as COT masks) to more
142 or less sophisticated textile masks. Community masks have the advantage that they can be produced
143 locally, either centrally in the case of commercial masks, or at home for personal use. The performance
144 of community masks is not subject to legal requirements, so their quality can vary greatly. In some

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3 145 countries, quality labels have been proposed, allowing minimum performance requirements to be
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5 146 defined on a voluntary basis. This is the case, for instance, of the French AFNOR label and of the Swiss
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7 147 TESTEX label (referred here below as PES masks). Currently, labelled masks represent only a minority
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9 148 of production, probably due to higher manufacturing costs. While "common" community masks are
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11 149 generally made of cotton or other textiles of natural origin, labelled masks, which require greater
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13 150 technicality, are made of polymers, such as elastane or polyester. Community trade masks without
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15 151 labels were considered to come from the wider European market. For the labelled masks, the origin
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17 152 is more specific, since the AFNOR and TESTEX labelled masks are, to our knowledge, only produced in
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19 153 France and Switzerland respectively.
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25 155 **Reuse strategy**

27 156 The lack of protective means and the need to extend the life cycle of masks during the first COVID-19
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29 157 wave generated numerous studies on their reuse. Although medical masks are normally intended for
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31 158 single use, it has been shown that certain physical treatments such as UVC, microwaves or dry heat
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33 159 can effectively decontaminate them without significantly altering their barrier capacity. The latter
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35 160 method is of particular interest for the treatment of medical masks, as it is accessible in all households.
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37 161 It has been shown exposure to at least 70°C for 30 min is sufficient to effectively decontaminate
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39 162 surgical masks or respirators¹⁸⁻²⁰.
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43 163 Another alternative, which has yet to be validated, is the wait & reuse strategy. The viability of the
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45 164 virus deposited on a surface decreases significantly after a few hours. Tests on surgical masks have
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47 165 shown that under ambient temperature and humidity conditions (22°C, 65% RH), a 3-log reduction in
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49 166 virus load was achieved after 4 to 7 days²¹. In a similar way to what has been proposed by the
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51 167 N95Decon scientific group for respirators, surgical masks could therefore be stored at room
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53 168 temperature for 7 days before being reused (by the same user).
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3 169 The situation with community masks is more straightforward since they are designed with the intent
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5 170 of cleaning and reusing by the general public. The issue of maintaining performance is also less critical
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7 171 since there are no legal requirements for this type of mask. The strategy considered here is therefore
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9 172 that of a reuse after a decontamination at home in a washing machine at 60°C. Labelled community
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11 173 mask are a special situation, since maintaining their performances is conditioned by the limitation of
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13 174 the number of washing cycles, to 20 and 5 washes for the AFNOR and TESTEX labels, respectively ²²²³.
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19 176 **Environmental Impact assessment**

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Figure 1 about here

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28 180 This study follows the methodology of life cycle assessment (LCA) and considers all the life cycle stages
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30 181 of the different masks including production, transport, use (decontamination) and end of life (see
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32 182 Figure 1). The primary data sources used and hypothesis are referenced throughout this article. The
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34 183 secondary data used for impact characterization used to perform the LCA analysis are based on the
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36 184 Ecoinvent database (<https://www.ecoinvent.org/database/database.html>). A proprietary excel tool
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38 185 developed by the authors was used to perform the LCA based on Ecoinvent datasets. Unless otherwise
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40 186 mentioned; the functional unit (FU) chosen for the comparison of the masks is “to equip one person
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42 187 with a mask during a month”. Several environmental impact indicators were considered:
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48 189 - The Global Warming Potential (GWP100) index, which expresses the impact of manufacturing,
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50 190 transporting and recycling masks in terms of greenhouse gases. GWP100 expresses the time-
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52 191 integrated warming effect, over a 100 year period, due to the release of a given greenhouse gas
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54 192 in today's atmosphere, relative to that of carbon dioxide (in mass unit kg)²⁴.
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3 193 - The UBP method relies on the methodological concept of ecological scarcity and expresses the
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5 194 environmental impact in terms of eco-points. It encompasses for instance the water footprint of
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7 195 cotton production as well as the biodiversity impact of energy production during the use phase.
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10 196 However. Calculation using the UBP method has been performed and is available in Appendix
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12 197 S1.

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14 198 - The plastic leakage (PL), which expresses the amount of plastic leaving the technosphere and
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16 199 cumulating in the natural environment. PL measures the quantity of plastic ultimately released
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18 200 into the ocean or into the other compartments (freshwater, soils, other terrestrial
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20 201 environments) including both microplastics and macroplastics²⁵. Plastic leakage is a result of
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22 202 both loss and release and can be simply described by the following equation:

$$\begin{aligned} \text{Plastic leakage mass} &= \text{Plastic waste mass} \cdot \text{Leakage rate (with Leakage rate = Loss} \\ &\text{rate} \cdot \text{Release rate, and Loss rate = mismanaged rate + littering rate)} \end{aligned}$$

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29 205 In the case of Switzerland, the only loss occurring is related to littering since the mismanaged
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31 206 rate is equal to 0%. The littering rate will then be assimilated to the leakage rate as we are here
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33 207 assessing the release rate of a low residual value item to all environmental compartments at
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35 208 once, hence equal to 100%. The littering rate used by default for on-the-go plastic is generally
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37 209 ranging between 2%^{26,27} and 12%²⁸. A recent study focusing on masks articulates a littering rate
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39 210 of 3% worldwide. We used a 2% littering rate²⁵, yielding a leakage rate of 2% to all
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41 211 compartments of the environment for the scope of this study.

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44 212 The destination chosen for masks transport is Switzerland. However, shipping origin and method
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46 213 vary as masks can come from Switzerland, France or China, and be transported either by truck, boat
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48 214 or plane. Different assumptions are made for additional environmental burdens during the use
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50 215 phase of the mask life cycle according to the decontamination method. For the decontamination in
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52 216 a washing machine, we consider a household washing machine cycle running at 60°C during 1h40
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54 217 with a dry load of 6 kg of clothes with an energy use of 1.8 kWh/cycle, a water use of 67.6 L/cycle

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3 218 and a soap consumption of 65 g/cycle²⁹. We have allocated the energy, water and soap used to
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5 219 wash a mask based on the ratio between the weight of the mask and the total dry load of clothes
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7 220 assumed when running one cycle. These consumptions features have then been scaled up to
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9 221 represent the functional unit chosen for the study. For the oven sterilization we assume that, based
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11 222 on personal measurement, an oven running at 70°C during 30 min consumes 0.345 kWh of
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13 223 electricity. As the oven utilization is exclusively dedicated to sterilizing masks, we had to make an
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15 224 assumption on the number of masks being sterilized at once. We assumed that a batch of 5 masks
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17 225 were sterilized for each oven utilization, hence an energy consumption of 0.069 kWh per mask
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19 226 sterilized.
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23 227 In the end of life stage, we assumed that all masks were incinerated after disposal. Heat and
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25 228 electricity recovery efficiencies in Europe vary quite significantly between different plants, at
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27 229 average values of 31% for heat and 12% for electricity³⁰. The strategies for using the masks and the
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29 230 corresponding assessment parameters are summarized in Table 1.
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232 **Patient and public involvement**

233 No patient involved.
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Scenario	Mask type	Material	Weight [g]	Origin	Transport (main)	Re-use	Consumption mask/month ^a
PP_1	Medical mask	Polypropylene (PP) / Nylon /Aluminium ^b	3.2 (2.5/0.5/0.2)	China	Boat	No	30
PP_2		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Plane	No	30
PP_3		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Boat	Hot drying, 30 min. 70°C	3
PP_4		Polypropylene (PP) / Nylon /Aluminium	3.2 (2.5/0.5/0.2)	China	Boat	Wait and reuse	3 ^c
COT_1	Unlabelled community mask	Cotton (COT)	5	China	Boat	Washing machine 60°C	2
COT_2		Cotton (COT)	5	Homemade ^d	-	Washing machine 60°C	2
PES_1	Labelled community mask ^e	Elastane / polyester (PES)	6.3 (0.13/6.17)	France	Truck	Washing machine 60°	2
PES_2		Elastane / polyester (PES)	6.3 (0.13/6.17)	Switzerland	Truck	Washing machine 60°	6

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238 ^a Number of worn-out masks disposed of and then replaced by a user during a month (consumption = 30/nb. of expected reuses)

239 ^a Aluminium nose strip

240 ^c One mask is used each weekday, for 10 reuses

241 ^d made from old cloth/fabric

242 ^e Considering the French quality label AFNOR (scenario PES_1) and the Swiss quality label Testex (scenario PES_2)

243

244 *Table 1. Summary of Mask typology and uses scenarios*

245 Results

246 Global warming potential

247 The CO₂- equivalent impact of the different scenarios of mask use is presented in Figure 2. The use of
248 disposable masks brought by plane (scenario PP_2), as experienced during the Personal Protective
249 Equipment (PPE) shortage of the first pandemic wave, is by far the most detrimental with 1.3 kg/CO₂
250 eq./FU. Without taking this extreme situation into account, a strong variability is observed between
251 the different scenarios of mask use. There is a factor of 30 between the most unfavourable scenario
252 (PP_1 - disposable medical mask brought by boat) and the most favourable scenario (COT_2 – Home-
253 made washable cotton mask). The differences observed are largely due to the absence of
254 manufacturing impact from the second-hand fabric as well as a very low contribution from the usage
255 phase in scenario COT_2. The decontamination of medical masks by heating (PP_3) is not very
256 advantageous, as well as the use of community masks made of polymers, as long as the number of
257 reuse cycles remains limited. Taking into account the discounted emissions from incineration after
258 disposal leads to a negative contribution of the end of life stage to the total CO₂-equivalent emissions
259 in all scenarios except COT_1 and COT_2. The use of labelled community mask (PES_1 and PES_2) has
260 an intermediate environmental impact, the use of AFNOR masks (French label) being more
261 advantageous than the TESTEX mask (Swiss label). The difference between the two is mainly due to
262 the different number of reuses recommended between the two labels. Overall, the most
263 advantageous scenarios are home-made cotton masks (COT_2) and the extended use of medical
264 masks through a wait and reuse strategy (PP_4).

266 Figure 2 about here

268 Results similar to those of the carbon footprint are obtained by considering a broader impact indicator,
269 such as UBP, which integrates water consumption (see Supplementary file S1). The impact related to
270 use increases for all masks when recycled multiple times. The most advantageous scenarios remain

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3 271 however the home-made cotton masks (COT_2) and the extended use of medical masks through a
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5 272 wait and reuse strategy (PP_4). Notably, the impact of decontamination of medical masks by heating
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7 273 (PP_3) is more than doubled, making it less advantageous than the single-use scenario of medical
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9 274 masks shipped from China by boat (PP_1).

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11 12 13 14 276 **Plastic leakage (PL)**

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17 277 The impact of the different scenarios of mask use from the point of view of plastic leakage is
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19 278 presented in Figure 3. Unsurprisingly, cotton masks do not generate plastic leakage. Disposable
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21 279 medical masks have a high PL of 1.8 g/FU. However, this impact can be reduced by a factor of 10 by
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23 280 reuse procedures, which proportionally reduce production needs.

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29 282 *Figure 3 about here*

30 31 32 283 **Number of reuse**

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35 284 The number of reuses used in the scenarios is based on an estimate of current practices and
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37 285 recommendations. Arguably, this may change depending on usage conditions, material quality, or
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39 286 changes in mask labelling requirements. The effect of the number of reuses on the GWP100 is shown
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41 287 in figure 4. Interestingly, commercial cotton masks (COT_1) reused less than 8 times generate more
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43 288 CO₂eq than disposable medical masks shipped by boat (PP_1). Moreover, when used less than 17
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45 289 times commercial cotton masks (COT_1) generate more CO₂eq than medical masks decontaminated
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47 290 through dry heating (PP_3). The increase in the number of reuse decreases the gap between the two
48
49 291 most advantageous scenarios: home-made cotton masks (COT_2) and the recycling of medical masks
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51 292 through a wait and reuse strategy (PP_4). The curves for scenarios PES_1 and PES_2 are overlapping
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53 293 in Figure 4 since the composition of EMPA and AFNOR masks has been assumed identical. The only
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55 294 slight difference between these scenarios, although not significant enough to distinguish both curves
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57 295 on the graph, stems from the distinct origins of the masks.

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14 300 **Discussion**
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16 301 Consistent with what has been highlighted by other authors, our results show that switching from
17 302 single-use to reusable masks can significantly reduce plastic leakage and climate change impact¹⁴.
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19 303 However, analysis of the different scenarios shows considerable variation between reuse strategies,
20 304 mainly due to the impact of production and recycling. A footprint reduction (GWP100 or UBP) of
21 305 50% to 90% can be achieved by switching from a single-use medical mask to a reusable solution. For
22 306 plastic leakage, this reduction can be from 60% to 100%. At the population level, these differences
23 307 are not negligible. We quantified how much CO₂eq impact and plastic leakage would be avoided
24 308 within a year in Switzerland if 10% of the entire population was to shift from single-use masks
25 309 transported by boat (PP_1) to either a wait and reuse strategy for the same masks (PP_4) or home-
26 310 made cotton masks from old fabric (COT_2). Results are reported in Table 2, considering a Swiss
27 311 population 8'606'033 in 2019 (source: Federal Statistical Office).
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48 313 *Table 2. Environmental impact of a shift from the use of disposable masks to reuse strategies in 10%*
49 314 *of the Swiss population.*
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53 315 For an impact per passenger transport by aircraft (person.km) of 0.129 kgCO₂eq (source: Reffnet.ch)
54 316 and an average 1.5L plastic bottle weight of 32.6 g³¹, the uptake of the wait and reuse strategy for
55 317 the medical masks (PP_4) by 10% of the population would be equivalent to saving CO₂eq emissions
56 318 from 5'402 individual flights from Paris to New York and preventing 513'194 plastic bottles (1.5L)

Figure 4 about here

Discussion

Consistent with what has been highlighted by other authors, our results show that switching from single-use to reusable masks can significantly reduce plastic leakage and climate change impact¹⁴. However, analysis of the different scenarios shows considerable variation between reuse strategies, mainly due to the impact of production and recycling. A footprint reduction (GWP100 or UBP) of 50% to 90% can be achieved by switching from a single-use medical mask to a reusable solution. For plastic leakage, this reduction can be from 60% to 100%. At the population level, these differences are not negligible. We quantified how much CO₂eq impact and plastic leakage would be avoided within a year in Switzerland if 10% of the entire population was to shift from single-use masks transported by boat (PP_1) to either a wait and reuse strategy for the same masks (PP_4) or home-made cotton masks from old fabric (COT_2). Results are reported in Table 2, considering a Swiss population 8'606'033 in 2019 (source: Federal Statistical Office).

	CO ₂ eq impact avoided [t CO ₂ eq.]	Plastic leakage avoided [t PL]
shifting to PP_4	4'077	17
shifting to COT_2	4'400	19

Table 2. Environmental impact of a shift from the use of disposable masks to reuse strategies in 10% of the Swiss population.

For an impact per passenger transport by aircraft (person.km) of 0.129 kgCO₂eq (source: Reffnet.ch) and an average 1.5L plastic bottle weight of 32.6 g³¹, the uptake of the wait and reuse strategy for the medical masks (PP_4) by 10% of the population would be equivalent to saving CO₂eq emissions from 5'402 individual flights from Paris to New York and preventing 513'194 plastic bottles (1.5L)

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3 319 from being littered. Similarly, the uptake of home-made cotton masks (COT_2) by the same
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5 320 population share would result in CO₂eq emissions savings analogous to 5'830 individual air travels
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7 321 from Paris to New York, and a plastic leakage avoided corresponding to 570'219 plastic bottles
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10 322 (1.5L).

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12 323 The environmental impact assessment conducted in this study has several limitations. Data on mask
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14 324 composition, transport and end of life are from the European context. The transposition of these
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16 325 results to other regions, in particular regions with a higher production capacity of medical masks and
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18 326 less reliance on imports, would lead to a modification of the GWP100 and UBP impact. Furthermore,
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20 327 in the absence of precise market distribution data, mask composition and production data were
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22 328 based on typical examples and scenarios rather than statistical data. In practice, there is some
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24 329 variability in manufacturing and shipping arrangements due to different suppliers. From the point of
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26 330 view of the effectiveness of their individual or collective protection, masks are not all equal. The
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28 331 comparison of their performance is not obvious because several parameters influence their
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30 332 effectiveness (droplet penetration, aerosol penetration, fitting to the face, wettability...)¹⁶ and only
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32 333 medical masks as well as labelled community masks (e.g. AFNOR label) have minimum performance
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34 334 requirements for some of these parameters while a high variability in performance is to be expected
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36 335 among unlabelled community masks. We performed an uncertainty analysis based on low and high
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38 336 values for the littering rate (ranging from 0.2% to 12%, with the medium value being set at 2%). We
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40 337 have observed that the plastic leakage results would be changing proportionally to the leakage rate
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42 338 factor between the medium value and the low or high value, but that the climate change or UBP
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44 339 impact results would deviate from the medium case by around 1% or below. No other uncertainty
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46 340 analysis was undertaken for this study.

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48 341 The filtration efficiency of the membrane as such has been investigated by several experimental
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50 342 studies. Aydin et al. report filtration efficiencies for large droplets in the 100 µ- 1mm range of over
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52 343 98% for surgical masks and 93-98% for unlabelled community masks of different materials (cotton,
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54 344 polyester and silk)³². For finer particles, the performance of unlabelled community masks is however

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3 345 lower. In the 10 μ range (PM₁₀), Neupane et al. show a filtration efficiency of 94% for surgical masks
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5 346 and 63% and 84% for community masks³³. Systematic reviews of the laboratory results obtained so
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7 347 far suggest that community masks have satisfactory filtration efficiency for large particles (e.g. >
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9 348 5 μ m), but that they have only limited effectiveness against aerosols.
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12 349 However, the overall performance of the masks is not limited to filtration efficiency alone and will be
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14 350 affected by leaks due to poor fitting to the face, but also by the way the masks are used. Wearing a
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16 351 face mask in a community logic is moreover primarily intended as a collective protection (by
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18 352 reducing the emission of the wearer), rather than an individual protection. This collective
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20 353 effectiveness is difficult to quantify due to the complexity of exposure situations and the presence of
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22 354 other contamination routes (e.g surface contamination). Randomized studies conducted previously
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24 355 on the transmission of viral infections in the community, showed that wearing a mask provided
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26 356 some protection in the most adherent individuals³⁴ or when mask use is accompanied by hand
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28 357 hygiene measures and/or education on viral infections^{35 36}.
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33 358 The choice of the most appropriate strategy must consider both environmental impact and
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35 359 effectiveness. In terms of mask performance, expectations are generally quite limited from a
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37 360 community protection perspective. To some extent, all masks contribute to community protection by
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39 361 reducing droplet emissions and, to a lesser extent, aerosol emissions from infected wearers. In the
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41 362 absence of minimum performance requirements, this protection is highly uncertain for unlabeled
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43 363 community face masks. Standardized masks, such as medical masks, which offer guarantees in
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45 364 terms of performance and reproducibility, are therefore more advantageous from this point of view.
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47 365 Labelled community masks are also an interesting alternative. Their environmental performance is
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49 366 currently limited by the number of planned cycles of use, which requires frequent replacement. An
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51 367 increase in the number of use cycles covered by the label would reduce significantly their
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53 368 environmental impact. The future use of materials that are less polluting than plastic materials for
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55 369 the manufacture of masks could be an alternative to reduce the environmental cost of their
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57 370 manufacture and plastic leakage. For community masks, this adjustment is relatively simple because
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59 371 many of them are made of cotton and some manufacturers also offer masks made of recycled

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3 372 plastic. For medical masks, a more important effort is necessary because it requires the complete
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5 373 accreditation of the mask according to EN14683. The scale of the uptake of the reuse strategies
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7 374 suggested in the study by the population will depend on the interest of the government to endorse
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10 375 such practices for community masks and on the efficiency of public awareness campaign. Last but
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12 376 not least, adopting a wait and reuse strategy with medical masks is probably the most economical,
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14 377 which is important in terms of access to protective measures for people with limited financial
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16 378 resources³⁷.

379 **Conclusion**

380 The use of medical masks with a wait-and-reuse strategy appears to be the most appropriate, as it is
381 a good compromise between environmental impact and protective efficacy and is accessible in
382 economic terms. Labeled community masks are also an interesting alternative, with an increase in
383 the number of use cycles. Overall, our results highlight the need to develop procedures and the
384 legal/operational framework to extend the use of protective equipment during a pandemic. Such an
385 approach would not only reduce the environmental impact of the masks, but also make the public
386 health system more resilient in the event of equipment shortages. They also highlight the need to
387 explore the use of materials that are less polluting than plastics to make the filter material.

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392 development of this study.

393 **Competing interests**

394 The authors declare no competing interest

395 **Author contribution**

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2
3 396 JB, NS, BG, KS and DV developed the study concept and design. KS and DV conducted the literature
4
5 397 review. AB and JB conducted the impact assessment and data analysis. All authors contributed to the
6
7 398 data interpretation. DV wrote the first draft of the manuscript with contributions from JB, AB and
8
9
10 399 NS. All authors contributed to and have approved the final manuscript.

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14
15 401 The authors received no funding to perform this study.

16 17 402 **Patient consent for publication**

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20 403 Not required

21 22 404 **Data availability statement**

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25 405 Detailed primary and secondary data used for this study are available upon request.

26 27 406 **Ethics approval**

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30 407 This study does not involve research with human subjects.

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47 513 **Figure 1. Illustration of the system boundary for all scenarios involved in the study.**

48 514
49 515 **Figure 2. Footprint expressed in GWP100 (kg CO₂ eq./FU) for different scenario of mask uses.**

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51 517 **Figure 3. Footprint expressed in plastic leakage (g/FU) for different scenarios of mask uses.**

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53 519 **Figure 4. Footprint expressed in GWP100 (kgCO₂eq./FU) for different scenarios as a function of
54 520 number of uses.**

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For peer review only

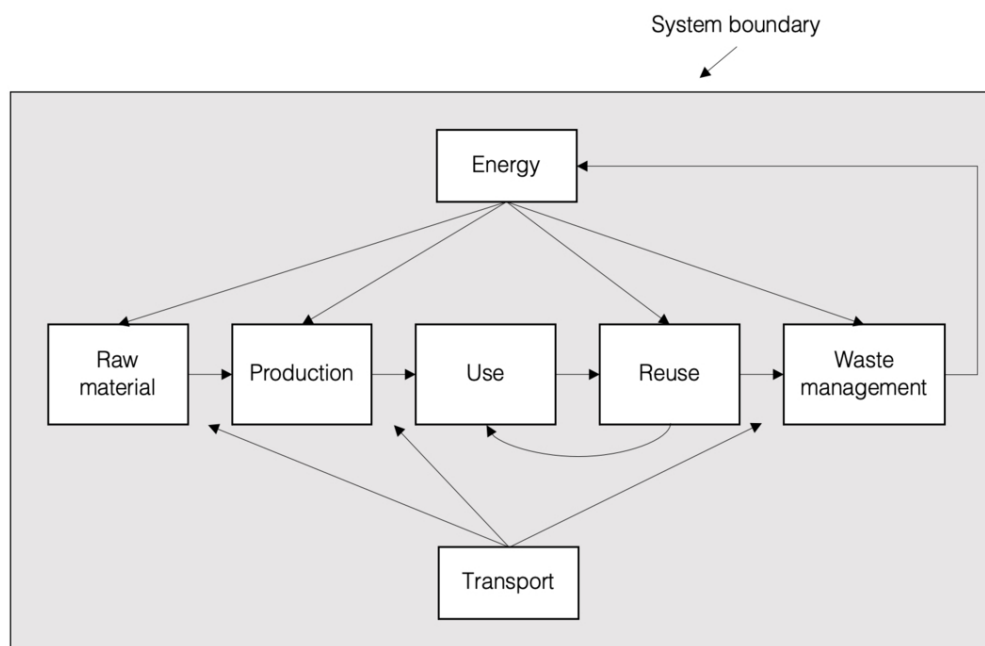


Figure 1. Illustration of the system boundary for all scenarios involved in the study.

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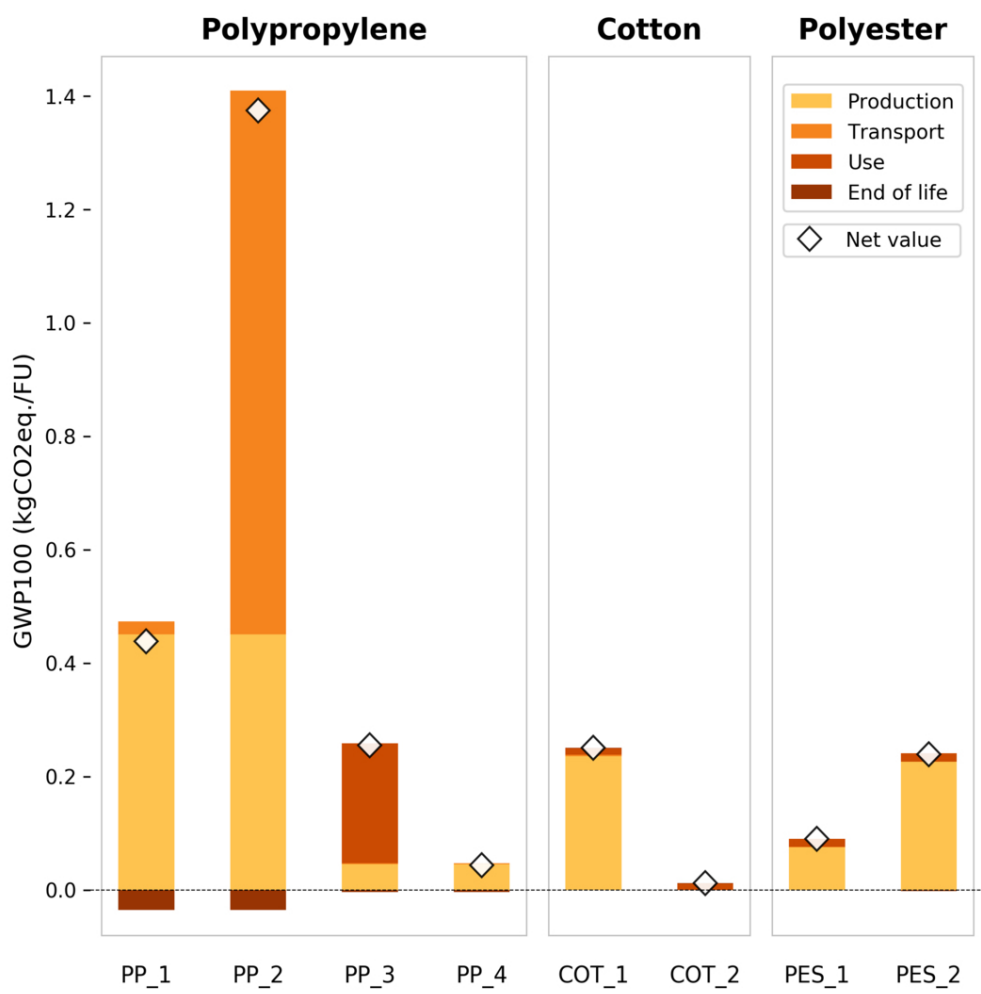


Figure 2. Footprint expressed in GWP100 (kg CO2 eq./FU) for different scenario of mask uses.

89x89mm (300 x 300 DPI)

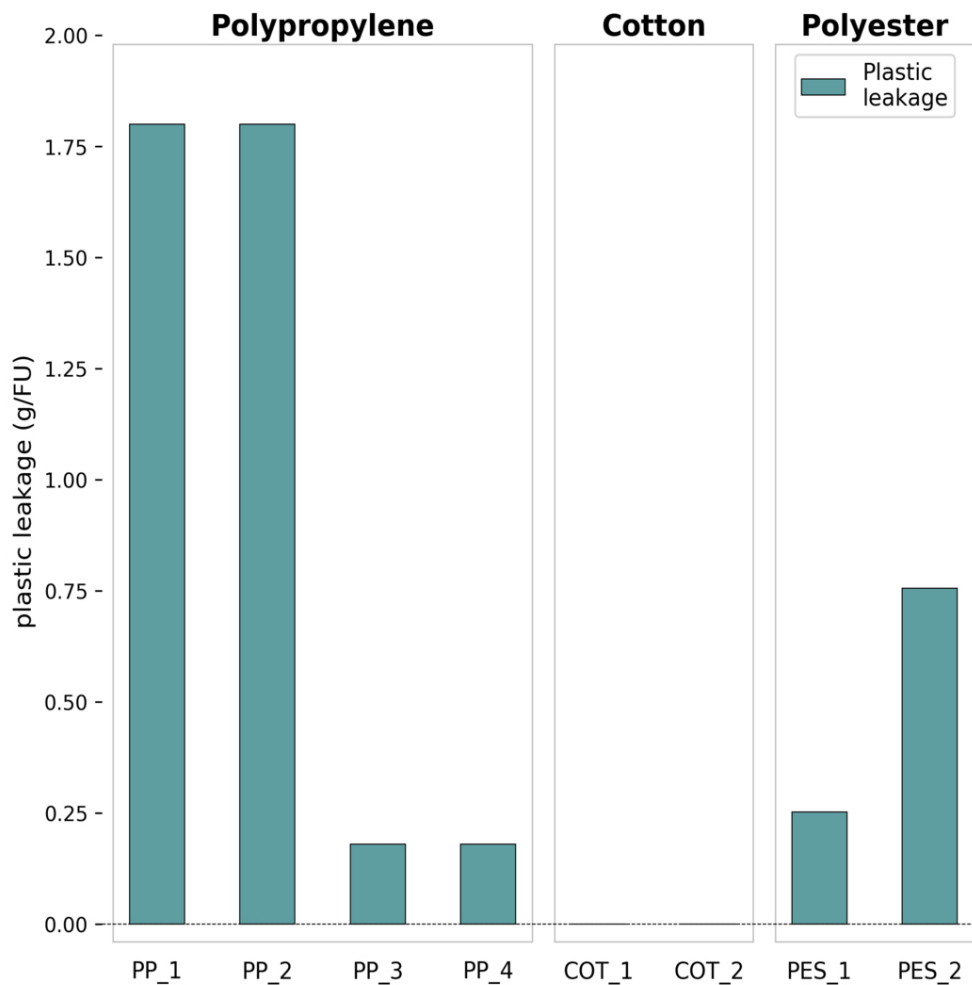


Figure 3. Footprint expressed in plastic leakage (g/FU) for different scenarios of mask uses.

89x89mm (300 x 300 DPI)

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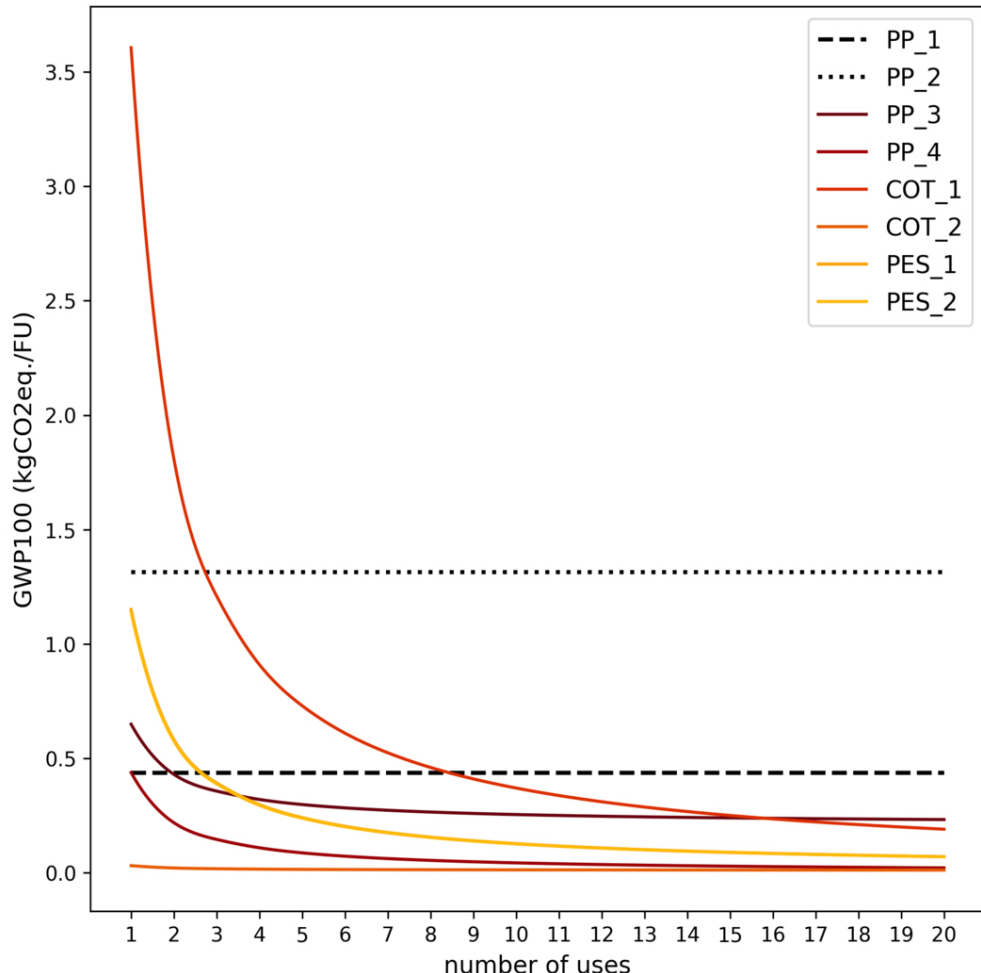


Figure 4. Footprint expressed in GWP100 (kgCO2eq./FU) for different scenarios as a function of number of uses.

89x89mm (300 x 300 DPI)

Appendix S1

In addition to the Global Warming Potential (GWP100) index, we assessed other environmental impacts with an aggregated impact metric specific to Switzerland called UBP, which is the abbreviation of the German word “Umweltbelastungspunkte”. The UBP method aggregates all individual impacts from a standard LCA assessment into a single parameter. It is based on legally defined targets for pollutant emissions and resource consumption, and measures the differences between current emission values and these specific target values. The further the current status is from the target, the greater the number of points assigned to an emission. For more details, see Frischknecht et al. (Frischknecht and Büsler Knöpfel 2013).

The UBP impacts of the different scenarios of mask use are presented in Figure S1. Similarly to the CO₂-equivalent impacts (see Figure 1), the use of disposable masks brought by plane (scenario PP_2) results in the highest impact in terms of UBP. The largest discrepancies between the global warming potential and UBP results occur in scenarios PP_3 and COT_1. In scenario PP_3, the UBP impact of the use phase is very large with an unfavourable contribution of the electricity consumption to run the oven, while the production phase of the cotton fabric increases the relative impact of cotton masks manufactured abroad (scenario COT_1) with respect to other scenarios when compared with the global warming potential results. Nonetheless, the least impactful scenarios remain the home-made cotton masks (COT_2) and the extended use of medical masks through a wait and reuse strategy (PP_4), which provides a coherent picture when it comes to the best practices for community protection with a mask in times of pandemic.

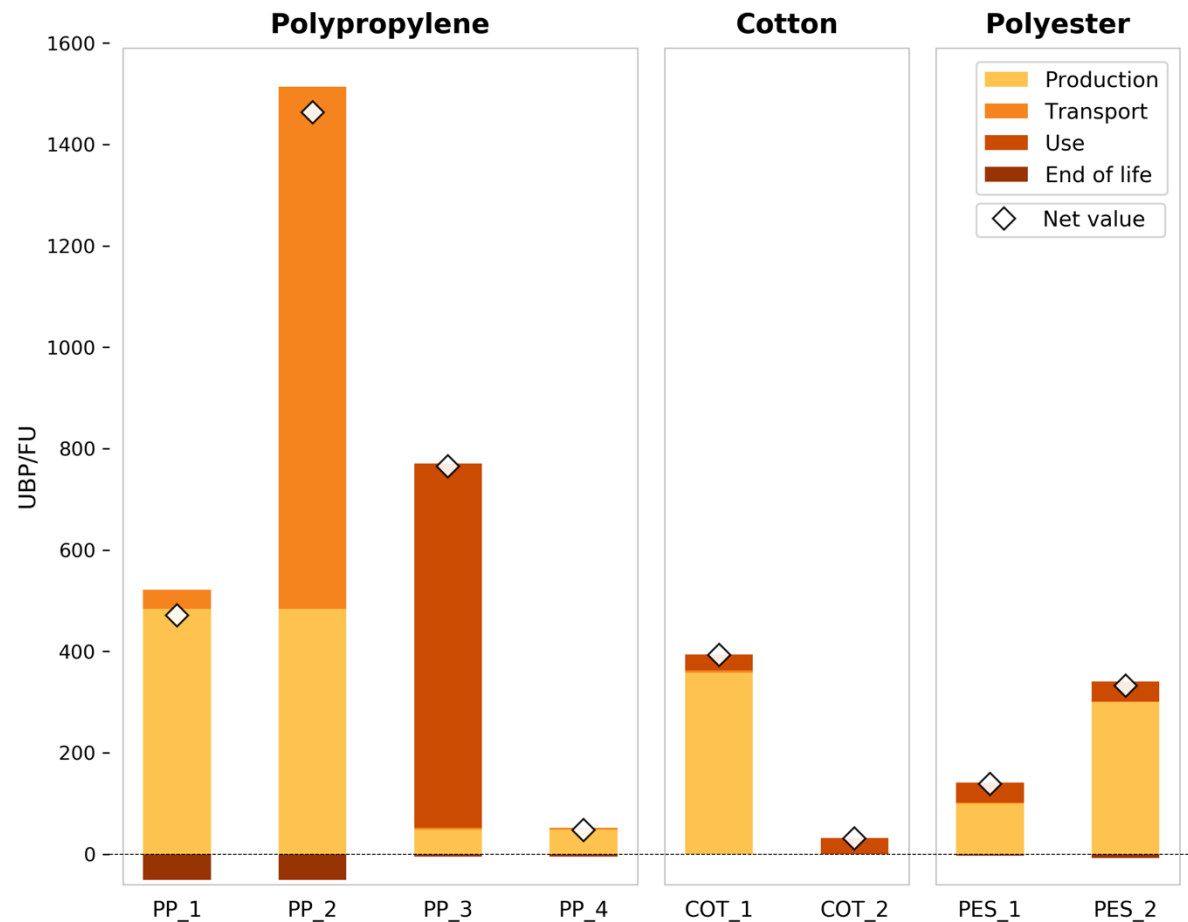


Figure S1. Footprint expressed in UBP /FU for different scenario of mask uses.

Frischknecht, Rolf, and Sybille Büsser Knöpfel. 2013. "Swiss Eco-Factors 2013 according to the Ecological Scarcity Method. Methodological fundamentals and their application in Switzerland." In *Environmental studies* no. 1330, 254. Bern: Federal Office for the Environment.