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

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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 $kgCO_2$ 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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Strengths and limitations of this study

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57   -   This study provides an environmental assessment (GWP 100, plastic leakage) for different

58   mask type and use strategies.

59   -   It recommends use or reuse strategies based on both performance and environmental

60   impacts.

61   -   The transportation and end-of-life assumptions are representative of an EU context.

62   -   As littering rates are poorly documented, plastic leakage in other geographic regions may

63   significantly differ.

64   -   Masks weight and composition used in this study are taken from regular European masks

65   disregarding the variability from one manufacturer to another.

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Introduction

The COVID-19 crisis has led to dramatic changes in our daily habits. The consequences of these changes on the environment are still poorly understood. The decrease in industrial activity during confinement and the decline in intra- and inter-national mobility has led to a significant drop in CO_2 emissions[1]. An average decrease of 6.4% % in yearly CO_2 emissions was observed worldwide for 2020[2]. Positive effects have also been observed on other air pollutants, such as PM, NOx, SO_2 and on river pollution. However, some observations made in China, near Hubei's epicenter, show an unclear environmental picture, with a lower decrease in air pollutants than expected. This suggests that other effects, such as increased energy demand for household needs, must also be considered [3]. Due to the temporary nature of the confinement measures, some authors argue that the longer-term effects of the COVID-19 crisis on the environmental footprint of human activities remain highly uncertain and may offset the observed short-term environmental benefits [4]. In the United States, a sharp drop in jet fuel and gasoline consumption has been observed during the crisis, leading to a decrease in CO_2 emissions of around 15%. However, it has been estimated that in a scenario of sustainable impact on the economy, the consequences of delayed investment in green energy and traffic-related emission reduction programs alone could outweigh the short-term effects [5]. The evolution of some activities or consumption patterns during the COVID-19 crisis are also likely to worsen the environmental balance: development of e-commerce (increase of transport distances and packaging), high consumption of disinfection products, massive COVID-19 screening in populations (increase in medical consumables).

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

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91 of disposable masks has dramatically increased since the first pandemic wave [6]. By June 2020,

92 China was producing 200 million facemasks per day, 20 times more than in February of the

93 same year [7]. With the second pandemic wave, the wearing of facemasks was mandatory in

94 closed spaces and densely populated areas in many countries. Medical masks and community

95 masks have become essential tools in the fight against the spread of the virus.

96 Given the wide use of facemasks, there is an urgent need to consider the environmental

97 impact of this practice and ways to extend the life of this equipment. Several arguments can

98 be put forward: (1) the bulk of production comes from Asia, resulting in significant use of

99 transportation to supply regions such as Europe and the United States, (2) medical masks are

100 intended for single use, resulting in additional waste and possible littering of used masks, and

101 (3) medical masks and some community masks are made of plastic. Poor management of this

102 waste can therefore contribute to the presence of macroplastics and microplastics in the

103 environment, particularly in the Ocean [8]. Considering that 3% of masks could enter the

104 environment (overall loss rate), it is estimated that up to 1.56 billions disposable masks could

105 have entered the Ocean in 2020, which represents between 4680 and 6240 tons of plastic pollution

106 to the marine environment [9]. Life cycle assessment (LCA) conducted on facemasks in United

107 Kingdom also shows that the environmental impact of disposable masks are generally higher

108 than recycled masks. In the absence of recycling, the production of waste in this country, as

109 a consequence of the use of one mask each day for a year by the entire British population,

110 was estimated at $1{,}24 \cdot 10^5$ tons, including $0{,}66 \cdot 10^5$ tons of non-recyclable contaminated plastic

111 [10]. Many countries are attempting to restrict the use of single-use plastics, including

112 restricting the use of plastic bags. The increase in plastic waste is putting pressure on the

113 waste management system to find new strategies to deal with this change [11]. On the other

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114   hand, there is good evidence that face masks used in the community provide protection

115   against Covid-19 infections [12], even though effectiveness can be very different according to

116   the type of masks, the wearing adherence or the environmental parameters (humidity,

117   heat,..).

118   In this study, we aim to explore and compare the environmental impact of the different masks

119   used in the community and attempt to provide clear recommendations on the best

120   compromise between protection effectiveness and environmental impact.

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Method

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

Mask typology

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

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

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

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150 defined on a voluntary basis. This is the case, for instance, of the French AFNOR label and of the Swiss

151 TESTEX label (referred here below as PES masks). Currently, labelled masks represent only a minority

152 of production, probably due to higher manufacturing costs. While "common" community masks are

153 generally made of cotton or other textiles of natural origin, labelled masks, which require greater

154 technicality, are made of polymers, such as elastane or polyester. Community trade masks without

155 labels were considered to come from the wider European market. For the labelled masks, the origin

156 is more specific, since the AFNOR and TESTEX labelled masks are, to our knowledge, only produced in

157 France and Switzerland respectively.

158

159 **Reuse strategy**

160 The lack of protective means and the need to extend the life cycle of masks during the first COVID-19

161 wave generated numerous studies on their reuse. Although medical masks are normally intended for

162 single use, it has been shown that certain physical treatments such as UVC, microwaves or dry heat

163 can effectively decontaminate them without significantly altering their barrier capacity. The latter

164 method is of particular interest for the treatment of medical masks, as it is accessible in all households.

165 It has been shown exposure to at least 70°C for 30 min is sufficient to effectively decontaminate

166 surgical masks or respirators [14-16].

167 Another alternative, which has yet to be validated, is the wait & reuse strategy. The viability of the

168 virus deposited on a surface decreases significantly after a few hours. Tests on surgical masks have

169 shown that under ambient temperature and humidity conditions (22°C, 65% RH), a 3-log reduction in

170 virus load was achieved after 4 to 7 days [17]. In a similar way to what has been proposed by the

171 N95Decon scientific group for respirators, surgical masks could therefore be stored at room

172 temperature for 7 days before being reused (by the same user).

173 The situation with community masks is more straightforward since they are designed with the intent

174 of cleaning and reusing by the general public. The issue of maintaining performance is also less critical

8

175   since there are no legal requirements for this type of mask. The strategy considered here is therefore

176   that of a reuse after a decontamination at home in a washing machine at 60°C. Labelled community

177   mask are a special situation, since maintaining their performances is conditioned by the limitation of

178   the number of washing cycles, to 20 and 5 washes for the AFNOR and TESTEX labels, respectively [18 19].

179

180   **Environmental Impact assessment**

181   This study follows the methodology of life cycle assessment (LCA) and considers all the life cycle stages

182   of the different masks including production, transport, use (decontamination) and end of life. The

183   primary data sources used and hypothesis are referenced throughout this article. The secondary data

184   used for impact characterization used to perform the LCA analysis are based on the Ecoinvent

185   database (https://www.ecoinvent.org/database/database.html) unless otherwise mentioned; the

186   functional unit (FU) chosen for the comparison of the masks is "to equip one person with a mask during

187   a month". Several environmental impact indicators were considered:

188

189   -   The Global Warming Potential (GWP100) index, which expresses the impact of manufacturing,

190   transporting and recycling masks in terms of greenhouse gases. GWP100 expresses the time-

191   integrated warming effect, over a 100 year period, due to the release of a given greenhouse gas

192   in today's atmosphere, relative to that of carbon dioxide (in mass unit kg)[20].

193   -   The UBP method relies on the methodological concept of ecological scarcity and expresses the

194   environmental impact in terms of eco-points. It encompasses for instance the water footprint of

195   cotton production as well as the biodiversity impact of energy production during the use phase.

196   However. Calculation using the UBP method has been performed and is available in Appendix

197   S1.

198   -   The plastic leakage (PL), which expresses the amount of plastic leaving the technosphere and

199   cumulating in the natural environment. PL measures the quantity of plastic ultimately released

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200   into the ocean or into the other compartments (freshwater, soils, other terrestrial

201   environments) including both microplastics and macroplastics [21] The littering rate used by

202   default for on-the-go plastic is generally ranging between 2% [22] [23] and 12% [24]. A recent study

203   focusing on masks articulates a littering rate of 3% worldwide. In this study, we used a 2%

204   littering rate [21].

205   The destination chosen for masks transport is Switzerland. However, shipping origin and method

206   vary as masks can come from Switzerland, France or China, and be transported either by truck, boat

207   or plane. Different assumptions are made for additional environmental burdens during the use

208   phase of the mask life cycle according to the decontamination method. For the decontamination in

209   a washing machine, we consider a household washing machine cycle running at 60°C during 1h40

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

211   and a soap consumption of 65 g/cycle [25]. For the oven sterilization we assume that, based on

212   personal measurement, an oven running at 70°C during 30 min consumes 0.345 kWh of electricity.

213   In the end of life stage, we assumed that all masks were incinerated after disposal. Heat and

214   electricity recovery efficiencies in Europe vary quite significantly between different plants, at

215   average values of 31% for heat and 12% for electricity [26]. The strategies for using the masks and the

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

221

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 strip

224 [c] One mask is used each weekday, for 10 reuses

225 [d] made from old cloth/fabric

226 [e] Considering the French quality label AFNOR (scenario PES_1) and the Swiss quality label Testex (scenario PES_2)

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

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Results

Global warming potential

231 The CO_2 - 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/CO_2

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 CO_2-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

254 (PP_3) is more than doubled, making it less advantageous than the single-use scenario of medical

255 masks shipped from China by boat (PP_1).

256

257 **Plastic leakage (PL)**

258 The impact of the different scenarios of mask use from the point of view of plastic leakage is

259 presented in Figure 2. Unsurprisingly, cotton masks do not generate plastic leakage. Disposable

260 medical masks have a high PL of 1.8 g/FU. However, this impact can be reduced by a factor of 10 by

261 reuse procedures, which proportionally reduce production needs.

262

263   *Figure 2 about here*

264

265 **Number of reuse**

266 The number of reuses used in the scenarios is based on an estimate of current practices and

267 recommendations. Arguably, this may change depending on usage conditions, material quality, or

268 changes in mask labelling requirements. The effect of the number of reuses on the GWP100 is shown

269 in figure 3. Interestingly, commercial cotton masks (COT_1) reused less than 8 times generate more

270 CO_2eq than disposable medical masks shipped by boat (PP_1). Moreover, when used less than 17

271 times commercial cotton masks (COT_1) generate more CO_2eq than medical masks decontaminated

272 through dry heating (PP_3). The increase in the number of reuse decreases the gap between the two

273 most advantageous scenarios: home-made cotton masks (COT_2) and the recycling of medical masks

274 through a wait and reuse strategy (PP_4).

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277   *Figure 3 about here*

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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 CO_2eq 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_2eq 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 kgCO_2eq (source: Reffnet.ch)

290 and an average 1.5L plastic bottle weight of 32.6 g [27], 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 CO_2eq

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 CO_2eq 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

301   performance requirements for some of these parameters while a high variability in performance is

302   to be expected among unlabelled community masks.

303   The filtration efficiency of the membrane as such has been investigated by several experimental

304   studies. Aydin et al. report filtration efficiencies for large droplets in the 100 μ- 1mm range of over

305   98% for surgical masks and 93-98% for unlabelled community masks of different materials (cotton,

306   polyester and silk)[28]. For finer particles, the performance of unlabelled community masks is however

307   lower. In the 10μ range (PM$_{10}$), Neupane et al. show a filtration efficiency of 94% for surgical masks

308   and 63% and 84% for community masks [29]. Systematic reviews of the laboratory results obtained so

309   far suggest that community masks have satisfactory filtration efficiency for large particles (e.g. >

310   5μm), but that they have only limited effectiveness against aerosols.

311   However, the overall performance of the masks is not limited to filtration efficiency alone and will be

312   affected by leaks due to poor fitting to the face, but also by the way the masks are used. Wearing a

313   face mask in a community logic is moreover primarily intended as a collective protection (by

314   reducing the emission of the wearer), rather than an individual protection. This collective

315   effectiveness is difficult to quantify due to the complexity of exposure situations and the presence of

316   other contamination routes (e.g surface contamination). Randomized studies conducted previously

317   on the transmission of viral infections in the community, showed that wearing a mask provided

318   some protection in the most adherent individuals [30] or when mask use is accompanied by hand

319   hygiene measures and/or education on viral infections [31 32].

320   The use of medical masks with a wait and reuse strategy seems to be the most appropriate when

321   considering both environmental impact and effectiveness. Expectations, in terms of mask

322   performance, are generally fairly limited. However, face masks contribute to collective protection by

323   reducing droplet emissions and, to a lesser extent, aerosol emissions from infected wearers.

324   However, the lack of minimum performance requirements for unlabelled community face masks,

325   makes this contribution uncertain. Standardized masks, which offer guarantees in terms of

326   performance and reproducibility, are therefore beneficial from this point of view.

327   Labelled community masks are also an interesting alternative. Their environmental performance is

328   currently limited by the number of planned cycles of use, which requires frequent replacement. An

329   increase in the number of use cycles covered by the label would reduce significantly their

330   environmental impact. Overall, our results highlight the need to develop procedures and the

331   legal/operational framework to extend the use of protective equipment during a pandemic. Such an

332   approach would not only reduce the environmental impact of the masks, but also make the public

333   health system more resilient in the event of equipment shortages. Last but not least, adopting a wait

334   and reuse strategy with medical masks is probably the most economical, which is important in terms

335   of access to protective measures for people with limited financial resources [33].

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Competing interests

340   The authors declare no competing interest

Author contribution

342   JB, NS, BG and DV developed the study concept and design. AB and JB conducted the impact

343   assessment. DV wrote the first draft of the manuscript with contributions from JB, AB and NS. All

344   authors contributed to and have approved the final manuscript.

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Patient consent for publication

348   Not required

Data availability statement

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

351 **Ethics approval**

352 This study does not involve research with human subjects.

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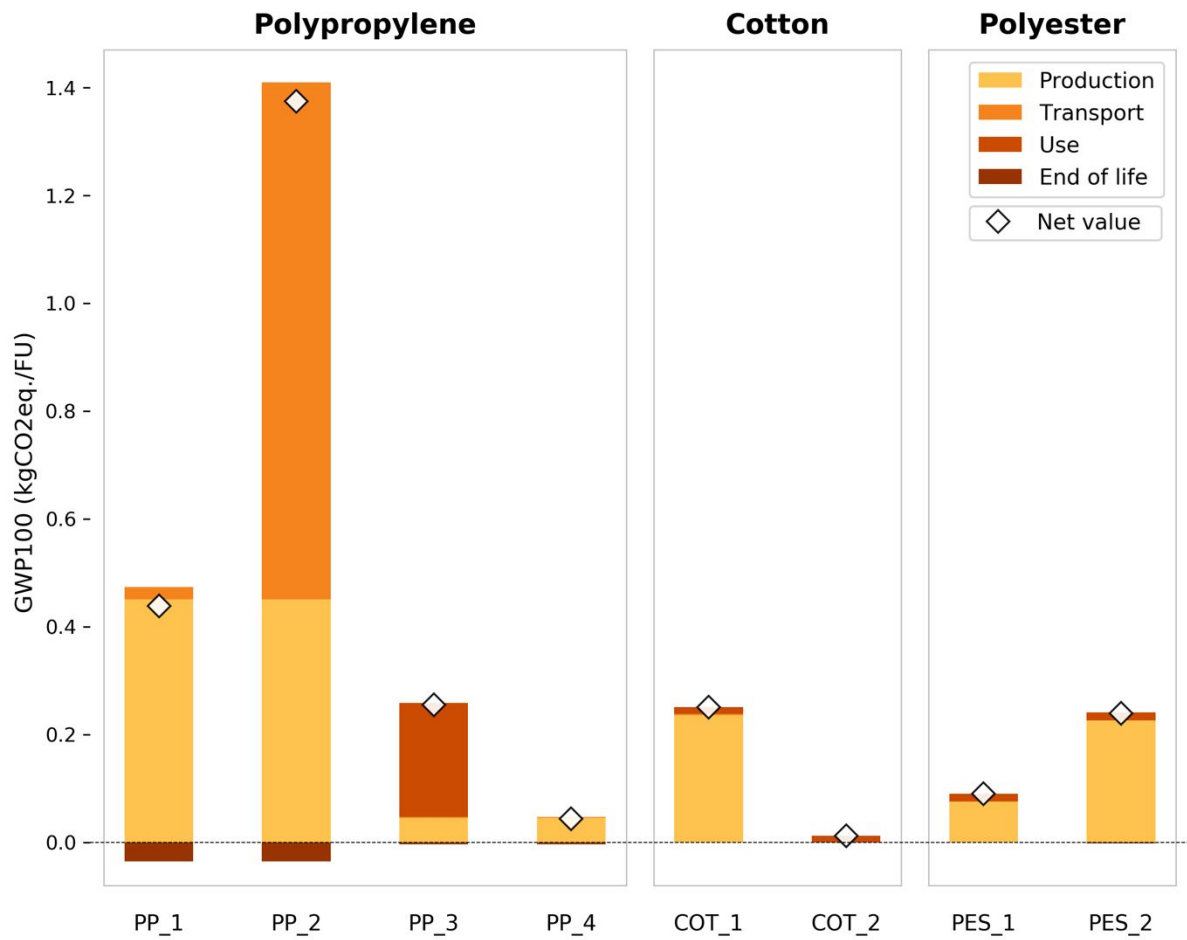52
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Figure 1. Footprint expressed in GWP100 (kg CO₂ eq./FU) for different scenario of mask uses.
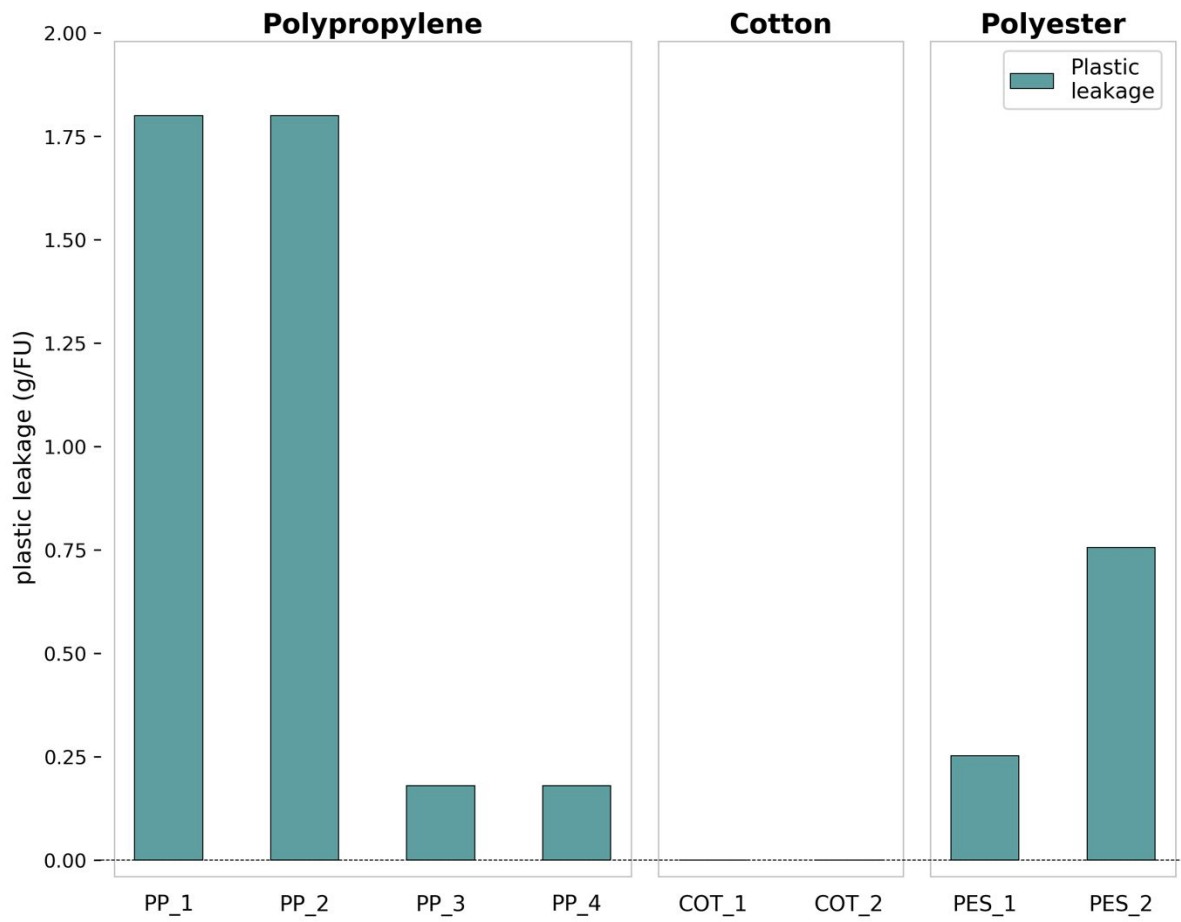
Figure 2. Footprint expressed in plastic leakage (g/FU) for different scenarios of mask uses.
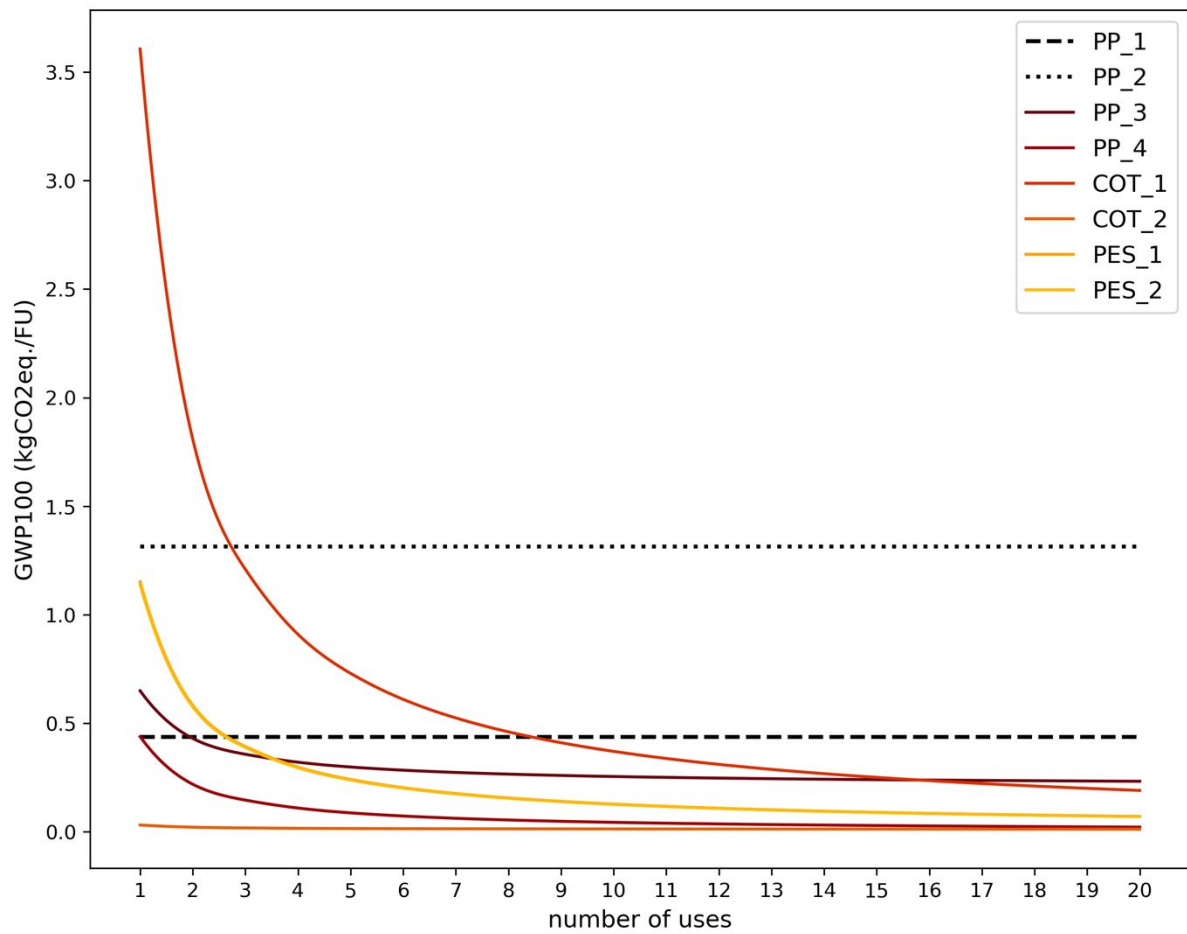
Figure 3. Footprint expressed in GWP100 (kgCO₂eq./FU) for different scenarios as a function of

number of uses

1   **Appendix S1**

2   In addition to the Global Warming Potential (GWP100) index, we assessed other environmental

3   impacts with an aggregated impact metric specific to Switzerland called UBP, which is the

4   abbreviation of the German word "Umweltbelastungpunkte". The UBP method aggregates all

5   individual impacts from a standard LCA assessment into a single parameter. It is based on legally

6   defined targets for pollutant emissions and resource consumption, and measures the differences

7   between current emission values and these specific target values. The further the current status

8   is from the target, the greater the number of points assigned to an emission. For more details,

9   see Frischknecht et al. (Frischknecht and Büsser Knöpfel 2013).

10   The UBP impacts of the different scenarios of mask use are presented in Figure S1. Similarly to

11   the CO_2-equivalent impacts (see Figure 1), the use of disposable masks brought by plane

12   (scenario PP_2) results in the highest impact in terms of UBP. The largest discrepancies between

13   the global warming potential and UBP results occur in scenarios PP_3 and COT_1. In scenario

14   PP_3, the UBP impact of the use phase is very large with an unfavourable contribution of the

15   electricity consumption to run the oven, while the production phase of the cotton fabric

16   increases the relative impact of cotton masks manufactured abroad (scenario COT_1) with

17   respect to other scenarios when compared with the global warming potential results.

18   Nonetheless, the least impactful scenarios remain the home-made cotton masks (COT_2) and the

19   extended use of medical masks through a wait and reuse strategy (PP_4), which provides a

20   coherent picture when it comes to the best practices for community protection with a mask in
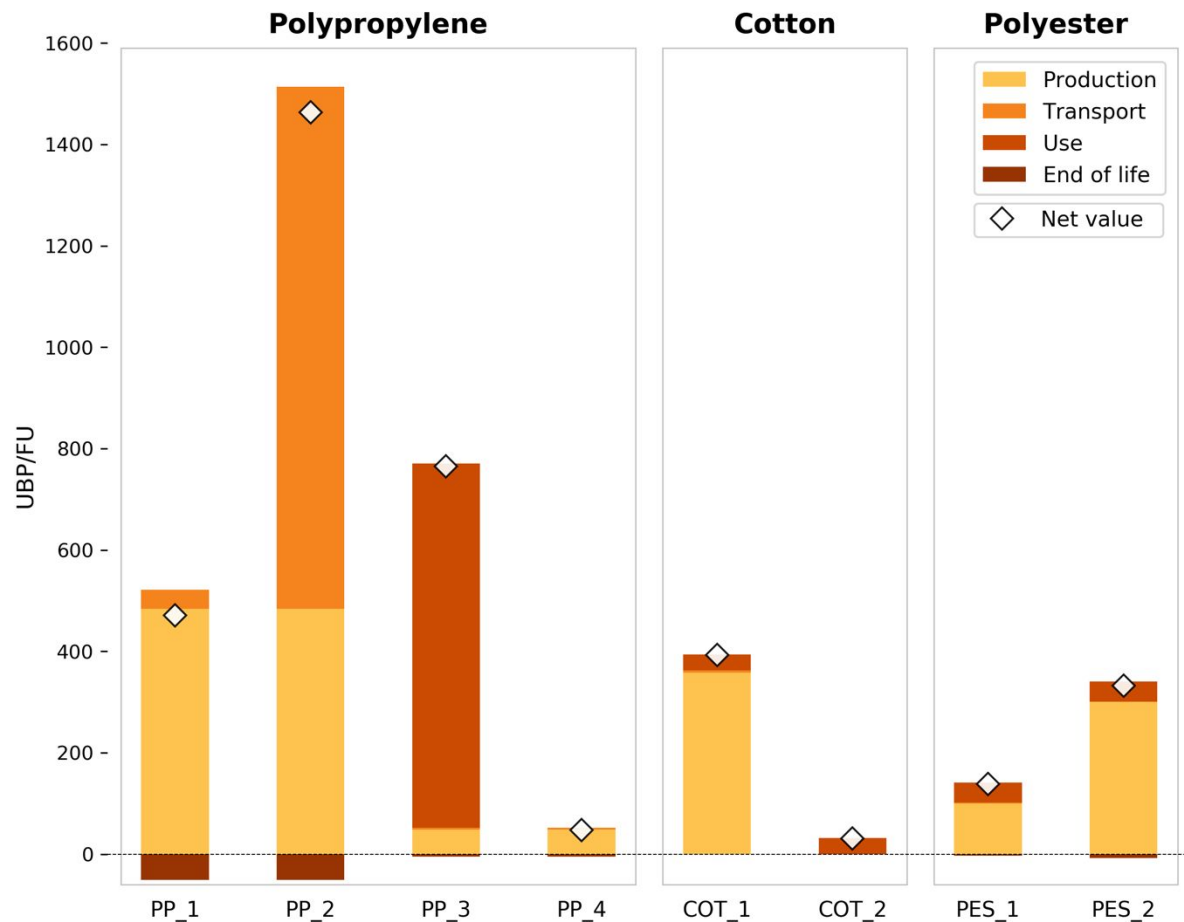
21   times of pandemic.

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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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Which strategy for using medical and community masks? A prospective analysis of their environmental impact.

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Which strategy for using medical and community masks? A prospective analysis of their environmental impact.

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Word count: 3501 (without abstract and references)

1

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 kgCO$_2$

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.

2

54   **Strengths and limitations of this study**

55

56   -   This study provides an environmental assessment based on three indicators (GWP 100, UBP,

57   plastic leakage) for different mask type and use strategies.

58   -   -Eight mask use and reuse strategies were considered.

59   -   - The assumptions used in the life cycle assessment (transport, end of life, littering) are

60   based on the European context and do not necessarily apply to other regions.

61   - The weight and composition of the masks used in this study are those of typical,

62   commercially available masks, but do not represent the variability from one manufacturer to

63   another.

64

3

Introduction

The decrease in industrial activity during the COVID-19 confinement and the decline in intra-

and inter-national mobility has led to a significant drop in CO_2 emissions[1]. An average

decrease of 6.4% % in yearly CO_2 emissions was observed worldwide for 2020[2]. Positive

effects have also been observed on other air pollutants, such as PM, NOx, SO_2 and on river

pollution[3]. However, some observations made in China, near Hubei's epicenter, show an

unclear environmental picture, with a lower decrease in air pollutants than expected[4]. Due to

the temporary nature of the confinement measures, some authors argue that the longer-term

effects of the COVID-19 crisis on the environmental footprint of human activities remain

highly uncertain and may offset the observed short-term environmental benefits [5]. In the

United States, a sharp drop in jet fuel and gasoline consumption has been observed during

the crisis, leading to a decrease in CO_2 emissions of around 15%. However, it has been

estimated that in a scenario of sustainable impact on the economy, the consequences of

delayed investment in green energy and traffic-related emission reduction programs alone

could outweigh the short-term effects [6]. The evolution of some activities or consumption

patterns during the COVID-19 crisis are also likely to worsen the environmental balance:

development of e-commerce (increase of transport distances and packaging), high

consumption of disinfection products, massive COVID-19 screening in populations (increase

in medical consumables).

The consumption of protective equipment and most particularly facemasks has also

experienced a sharp increase during the crisis[7] [8]. To meet the growing demand, the

production of disposable masks has dramatically increased since the first pandemic wave [9].

By June 2020, China was producing 200 million facemasks per day, 20 times more than in

4

88   February of the same year [10]. With the second pandemic wave, the wearing of facemasks was

89   mandatory in closed spaces and densely populated areas in many countries. Medical masks

90   and community masks have become essential tools in the fight against the spread of the virus.

91   Given the extensive use of facemasks, there is an urgent need to take into account the

92   environmental impact of this practice and ways to extend the life of this equipment. Several

93   arguments can be put forward: (1) the bulk of production comes from Asia[11], resulting in

94   significant use of transportation to supply regions such as Europe and the United States, (2)

95   medical masks are intended for single use, resulting in additional waste and possible littering

96   of used masks, and (3) medical masks and some community masks are made of plastic. Poor

97   management of this waste can therefore contribute to the presence of macroplastics and

98   microplastics in the environment, particularly in the Ocean [12]. Considering that 3% of masks

99   could enter the environment (overall loss rate), it is estimated that up to 1.56 billions

100   disposable masks could have entered the Ocean in 2020, which represents between 4680 and

101   6240 tons of plastic pollution to the marine environment [13]. Life cycle assessment (LCA)

102   conducted on facemasks in United Kingdom also shows that the environmental impact of

103   disposable masks are generally higher than recycled masks. In the absence of recycling, the

104   production of waste in this country, as a consequence of the use of one mask each day for a

105   year by the entire British population, was estimated at 124'000 tons, including 66'000 tons of

106   non-recyclable contaminated plastic [14]. Many countries are attempting to restrict the use of

107   single-use plastics, including restricting the use of plastic bags. The increase in plastic waste

108   is putting pressure on the waste management system to find new strategies to deal with this

109   change [15]. On the other hand, there is good evidence that face masks used in the community

110   provide protection against Covid-19 infections [16], even though effectiveness can be very

5

111 different according to the type of masks, the wearing adherence or the environmental

112 parameters (humidity, heat,..).

113 In this study, we aim to explore and compare the environmental impact of the different masks

114 used in the community and attempt to provide clear recommendations on the best

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

7

145 countries, quality labels have been proposed, allowing minimum performance requirements to be

146 defined on a voluntary basis. This is the case, for instance, of the French AFNOR label and of the Swiss

147 TESTEX label (referred here below as PES masks). Currently, labelled masks represent only a minority

148 of production, probably due to higher manufacturing costs. While "common" community masks are

149 generally made of cotton or other textiles of natural origin, labelled masks, which require greater

150 technicality, are made of polymers, such as elastane or polyester. Community trade masks without

151 labels were considered to come from the wider European market. For the labelled masks, the origin

152 is more specific, since the AFNOR and TESTEX labelled masks are, to our knowledge, only produced in

153 France and Switzerland respectively.

154

155 **Reuse strategy**

156 The lack of protective means and the need to extend the life cycle of masks during the first COVID-19

157 wave generated numerous studies on their reuse. Although medical masks are normally intended for

158 single use, it has been shown that certain physical treatments such as UVC, microwaves or dry heat

159 can effectively decontaminate them without significantly altering their barrier capacity. The latter

160 method is of particular interest for the treatment of medical masks, as it is accessible in all households.

161 It has been shown exposure to at least 70°C for 30 min is sufficient to effectively decontaminate

162 surgical masks or respirators [18-20].

163 Another alternative, which has yet to be validated, is the wait & reuse strategy. The viability of the

164 virus deposited on a surface decreases significantly after a few hours. Tests on surgical masks have

165 shown that under ambient temperature and humidity conditions (22°C, 65% RH), a 3-log reduction in

166 virus load was achieved after 4 to 7 days [21]. In a similar way to what has been proposed by the

167 N95Decon scientific group for respirators, surgical masks could therefore be stored at room

168 temperature for 7 days before being reused (by the same user).

8

169 The situation with community masks is more straightforward since they are designed with the intent

170 of cleaning and reusing by the general public. The issue of maintaining performance is also less critical

171 since there are no legal requirements for this type of mask. The strategy considered here is therefore

172 that of a reuse after a decontamination at home in a washing machine at 60°C. Labelled community

173 mask are a special situation, since maintaining their performances is conditioned by the limitation of

174 the number of washing cycles, to 20 and 5 washes for the AFNOR and TESTEX labels, respectively [22] [23].

175

176 **Environmental Impact assessment**

177

178   Figure 1 about here

179

180 This study follows the methodology of life cycle assessment (LCA) and considers all the life cycle stages

181 of the different masks including production, transport, use (decontamination) and end of life (see

182 Figure 1). The primary data sources used and hypothesis are referenced throughout this article. The

183 secondary data used for impact characterization used to perform the LCA analysis are based on the

184 Ecoinvent database (https://www.ecoinvent.org/database/database.html). A proprietary excel tool

185 developed by the authors was used to perform the LCA based on Ecoinvent datasets. Unless otherwise

186 mentioned; the functional unit (FU) chosen for the comparison of the masks is "to equip one person

187 with a mask during a month". Several environmental impact indicators were considered:

188

189 -   The Global Warming Potential (GWP100) index, which expresses the impact of manufacturing,

190   transporting and recycling masks in terms of greenhouse gases. GWP100 expresses the time-

191   integrated warming effect, over a 100 year period, due to the release of a given greenhouse gas

192   in today's atmosphere, relative to that of carbon dioxide (in mass unit kg)[24].

9

193 - The UBP method relies on the methodological concept of ecological scarcity and expresses the

194 environmental impact in terms of eco-points. It encompasses for instance the water footprint of

195 cotton production as well as the biodiversity impact of energy production during the use phase.

196 However. Calculation using the UBP method has been performed and is available in Appendix

197 S1.

198 - The plastic leakage (PL), which expresses the amount of plastic leaving the technosphere and

199 cumulating in the natural environment. PL measures the quantity of plastic ultimately released

200 into the ocean or into the other compartments (freshwater, soils, other terrestrial

201 environments) including both microplastics and macroplastics [25] Leakage is a result of both loss

202 and release and can be simply described by the following equation:

203 $Leakage = Waste \cdot Loss\ rate \cdot Release\ rate$ (with Loss rate = mismanaged rate +

204 littering rate)

205 In the case of Switzerland, the only loss occurring is related to littering since the mismanaged

206 rate is equal to 0%. The littering rate will then be assimilated to the leakage rate as we are here

207 assessing the release rate to all environmental compartments at once. The littering rate used by

208 default for on-the-go plastic is generally ranging between 2% [26][27] and 12% [28]. A recent study

209 focusing on masks articulates a littering rate of 3% worldwide. In this study, we used a 2%

210 littering rate [25].

211 The destination chosen for masks transport is Switzerland. However, shipping origin and method

212 vary as masks can come from Switzerland, France or China, and be transported either by truck, boat

213 or plane. Different assumptions are made for additional environmental burdens during the use

214 phase of the mask life cycle according to the decontamination method. For the decontamination in

215 a washing machine, we consider a household washing machine cycle running at 60°C during 1h40

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

217 and a soap consumption of 65 g/cycle [29]. We have allocated the energy, water and soap used to

10

218   wash a mask based on the ratio between the weight of the mask and the total dry load of clothes

219   assumed when running one cycle. These consumptions features have then been scaled up to

220   represent the functional unit chosen for the study. For the oven sterilization we assume that, based

221   on personal measurement, an oven running at 70°C during 30 min consumes 0.345 kWh of

222   electricity. As the oven utilization is exclusively dedicated to sterilizing masks, we had to make an

223   assumption on the number of masks being sterilized at once. We assumed that a batch of 5 masks

224   were sterilized for each oven utilization, hence an energy consumption of 0.069 kWh per mask

225   sterilized.

226   In the end of life stage, we assumed that all masks were incinerated after disposal. Heat and

227   electricity recovery efficiencies in Europe vary quite significantly between different plants, at

228   average values of 31% for heat and 12% for electricity [30]. The strategies for using the masks and the

229   corresponding assessment parameters are summarized in Table 1.

230

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*

12

244   **Results**

245   **Global warming potential**

246   The CO_2 - 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/CO_2

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 CO_2-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

270 however the home-made cotton masks (COT_2) and the extended use of medical masks through a

271 wait and reuse strategy (PP_4). Notably, the impact of decontamination of medical masks by heating

272 (PP_3) is more than doubled, making it less advantageous than the single-use scenario of medical

273 masks shipped from China by boat (PP_1).

274

Plastic leakage (PL)

276 The impact of the different scenarios of mask use from the point of view of plastic leakage is

277 presented in Figure 3. Unsurprisingly, cotton masks do not generate plastic leakage. Disposable

278 medical masks have a high PL of 1.8 g/FU. However, this impact can be reduced by a factor of 10 by

279 reuse procedures, which proportionally reduce production needs.

280

281 *Figure 3 about here*

Number of reuse

283 The number of reuses used in the scenarios is based on an estimate of current practices and

284 recommendations. Arguably, this may change depending on usage conditions, material quality, or

285 changes in mask labelling requirements. The effect of the number of reuses on the GWP100 is shown

286 in figure 4. Interestingly, commercial cotton masks (COT_1) reused less than 8 times generate more

287 CO_2eq than disposable medical masks shipped by boat (PP_1). Moreover, when used less than 17

288 times commercial cotton masks (COT_1) generate more CO_2eq than medical masks decontaminated

289 through dry heating (PP_3). The increase in the number of reuse decreases the gap between the two

290 most advantageous scenarios: home-made cotton masks (COT_2) and the recycling of medical masks

291 through a wait and reuse strategy (PP_4). The curves for scenarios PES_1 and PES_2 are overlapping

292 in Figure 4 since the composition of EMPA and AFNOR masks has been assumed identical. The only

293 slight difference between these scenarios, although not significant enough to distinguish both curves

294 on the graph, stems from the distinct origins of the masks.

295

296

Figure 4 about here

298

Discussion

300 Consistent with what has been highlighted by other authors, our results show that switching from

301 single-use to reusable masks can significantly reduce plastic leakage and climate change impact[14].

302 However, analysis of the different scenarios shows considerable variation between reuse strategies,

303 mainly due to the impact of production and recycling. A footprint reduction (GWP100 or UBP) of

304 50% to 90% can be achieved by switching from a single-use medical mask to a reusable solution. For

305 plastic leakage, this reduction can be from 60% to 100%. At the population level, these differences

306 are not negligible. We quantified how much CO_2eq impact and plastic leakage would be avoided

307 within a year in Switzerland if 10% of the entire population was to shift from single-use masks

308 transported by boat (PP_1) to either a wait and reuse strategy for the same masks (PP_4) or home-

309 made cotton masks from old fabric (COT_2). Results are reported in Table 2, considering a Swiss

310 population 8'606'033 in 2019 (source: Federal Statistical Office).

	CO_2eq 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

311

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

313 *of the Swiss population.*

314 For an impact per passenger transport by aircraft (person.km) of 0.129 kgCO_2eq (source: Reffnet.ch)

315 and an average 1.5L plastic bottle weight of 32.6 g [31], the uptake of the wait and reuse strategy for

316 the medical masks (PP_4) by 10% of the population would be equivalent to saving CO_2eq emissions

317 from 5'402 individual flights from Paris to New York' and preventing 513'194 plastic bottles (1.5L)

318   from being littered. Similarly, the uptake of home-made cotton masks (COT_2) by the same

319   population share would result in CO_2eq emissions savings analogous to 5'830 individual air travels

320   from Paris to New York, and a plastic leakage avoided corresponding to 570'219 plastic bottles

321   (1.5L).

322   The environmental impact assessment conducted in this study has several limitations. Data on mask

323   composition, transport and end of life are from the European context. The transposition of these

324   results to other regions, in particular regions with a higher production capacity of medical masks and

325   less reliance on imports, would lead to a modification of the GWP100 and UBP impact. Furthermore,

326   in the absence of precise market distribution data, mask composition and production data were

327   based on typical examples and scenarios rather than statistical data. In practice, there is some

328   variability in manufacturing and shipping arrangements due to different suppliers. From the point of

329   view of the effectiveness of their individual or collective protection, masks are not all equal. The

330   comparison of their performance is not obvious because several parameters influence their

331   effectiveness (droplet penetration, aerosol penetration, fitting to the face, wettability...)[16] and only

332   medical masks as well as labelled community masks (e.g. AFNOR label) have minimum performance

333   requirements for some of these parameters while a high variability in performance is to be expected

334   among unlabelled community masks. We performed an uncertainty analysis based on low and high

335   values for the littering rate (ranging from 0.2% to 12%, with the medium value being set at 2%). We

336   have observed that the plastic leakage results would be changing proportionally to the leakage rate

337   factor between the medium value and the low or high value, but that the climate change or UBP

338   impact results would deviate from the medium case by around 1% or below. No other uncertainty

339   analysis was undertaken for this study.

340   The filtration efficiency of the membrane as such has been investigated by several experimental

341   studies. Aydin et al. report filtration efficiencies for large droplets in the 100 μ- 1mm range of over

342   98% for surgical masks and 93-98% for unlabelled community masks of different materials (cotton,

343   polyester and silk)[32]. For finer particles, the performance of unlabelled community masks is however

344 lower. In the 10μ range (PM$_{10}$), Neupane et al. show a filtration efficiency of 94% for surgical masks

345 and 63% and 84% for community masks [33]. Systematic reviews of the laboratory results obtained so

346 far suggest that community masks have satisfactory filtration efficiency for large particles (e.g. >

347 5μm), but that they have only limited effectiveness against aerosols.

348 However, the overall performance of the masks is not limited to filtration efficiency alone and will be

349 affected by leaks due to poor fitting to the face, but also by the way the masks are used. Wearing a

350 face mask in a community logic is moreover primarily intended as a collective protection (by

351 reducing the emission of the wearer), rather than an individual protection. This collective

352 effectiveness is difficult to quantify due to the complexity of exposure situations and the presence of

353 other contamination routes (e.g surface contamination). Randomized studies conducted previously

354 on the transmission of viral infections in the community, showed that wearing a mask provided

355 some protection in the most adherent individuals [34] or when mask use is accompanied by hand

356 hygiene measures and/or education on viral infections [35 36].

357 The use of medical masks with a wait and reuse strategy seems to be the most appropriate when

358 considering both environmental impact and effectiveness. Expectations, in terms of mask

359 performance, are generally fairly limited. However, face masks contribute to collective protection by

360 reducing droplet emissions and, to a lesser extent, aerosol emissions from infected wearers.

361 However, the lack of minimum performance requirements for unlabelled community face masks,

362 makes this contribution uncertain. Standardized masks, which offer guarantees in terms of

363 performance and reproducibility, are therefore beneficial from this point of view.

364 Labelled community masks are also an interesting alternative. Their environmental performance is

365 currently limited by the number of planned cycles of use, which requires frequent replacement. An

366 increase in the number of use cycles covered by the label would reduce significantly their

367 environmental impact. The future use of materials that are less polluting than plastic materials for

368 the manufacture of masks could be an alternative to reduce the environmental cost of their

369   manufacture and plastic leakage. For community masks, this adjustment is relatively simple because

370   many of them are made of cotton and some manufacturers also offer masks made of recycled

371   plastic. For medical masks, a more important effort is necessary because it requires the complete

372   accreditation of the mask according to EN14683. Overall, our results highlight the need to develop

373   procedures and the legal/operational framework to extend the use of protective equipment during a

374   pandemic. Such an approach would not only reduce the environmental impact of the masks, but also

375   make the public health system more resilient in the event of equipment shortages. The scale of the

376   uptake of the reuse strategies suggested in the study by the population will depend on the interest

377   of the government to endorse such practices for community masks and on the efficiency of public

378   awareness campaign. Last but not least, adopting a wait and reuse strategy with medical masks is

379   probably the most economical, which is important in terms of access to protective measures for

380   people with limited financial resources [37].

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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**

394   Not required

395   **Data availability statement**

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

397   **Ethics approval**

398   This study does not involve research with human subjects.

399

400

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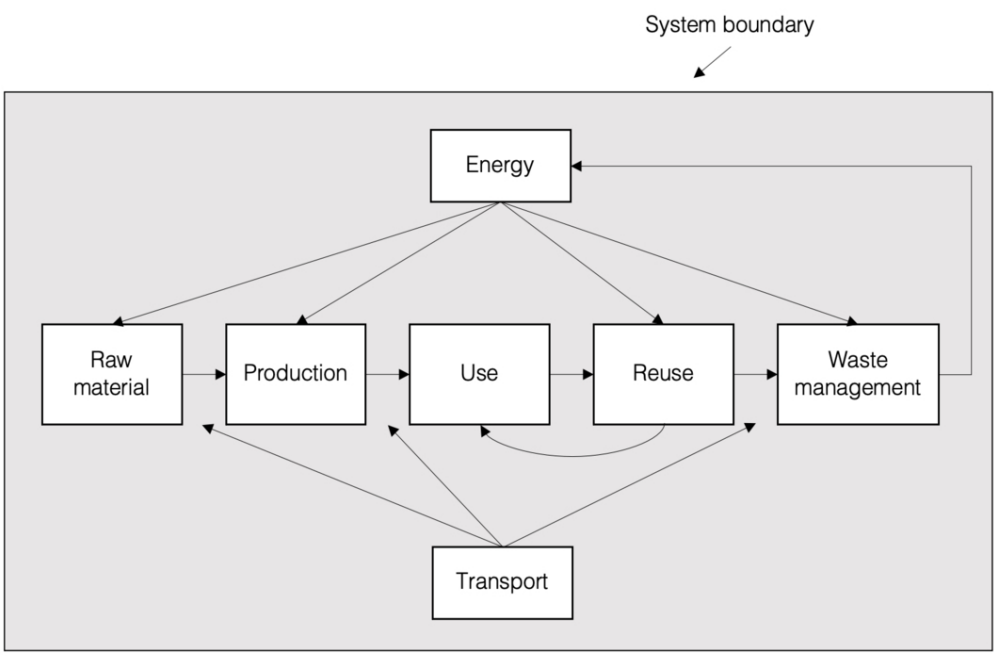
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Figure 1. Illustration of the system boundary for all scenarios involved in the study.
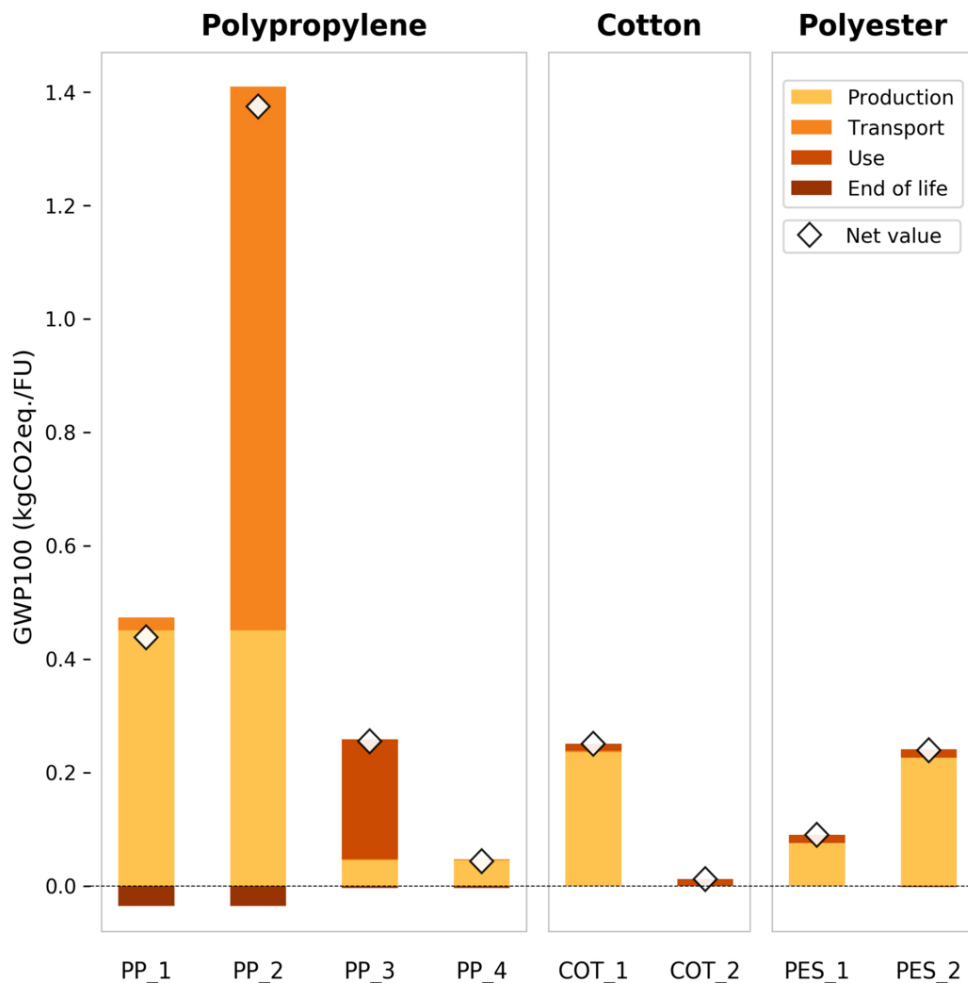
89x89mm (300 x 300 DPI)

Figure 2. Footprint expressed in GWP100 (kg CO2 eq./FU) for different scenario of mask uses.
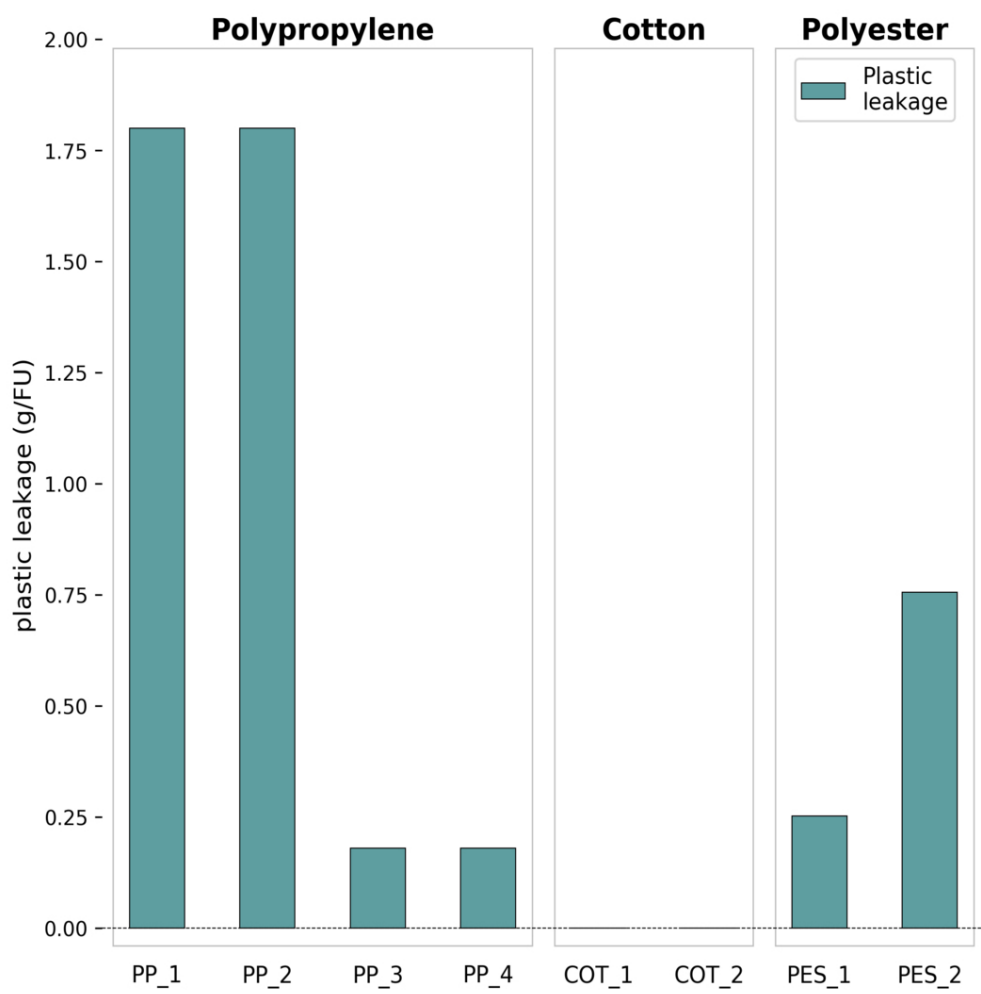
89x89mm (300 x 300 DPI)

Figure 3. Footprint expressed in plastic leakage (g/FU) for different scenarios of mask uses.
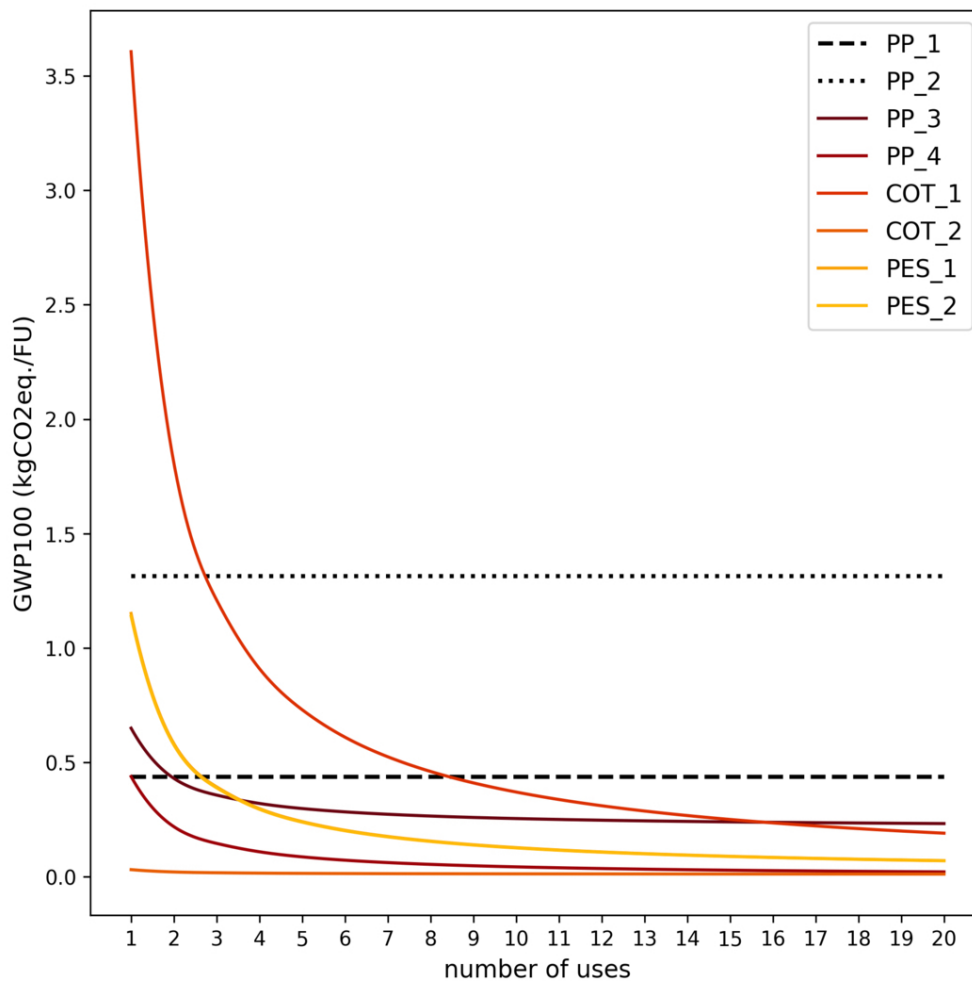
89x89mm (300 x 300 DPI)

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 "Umweltbelastungpunkte". 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 Büsser Knöpfel 2013).

The UBP impacts of the different scenarios of mask use are presented in Figure S1. Similarly to

the CO_2-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
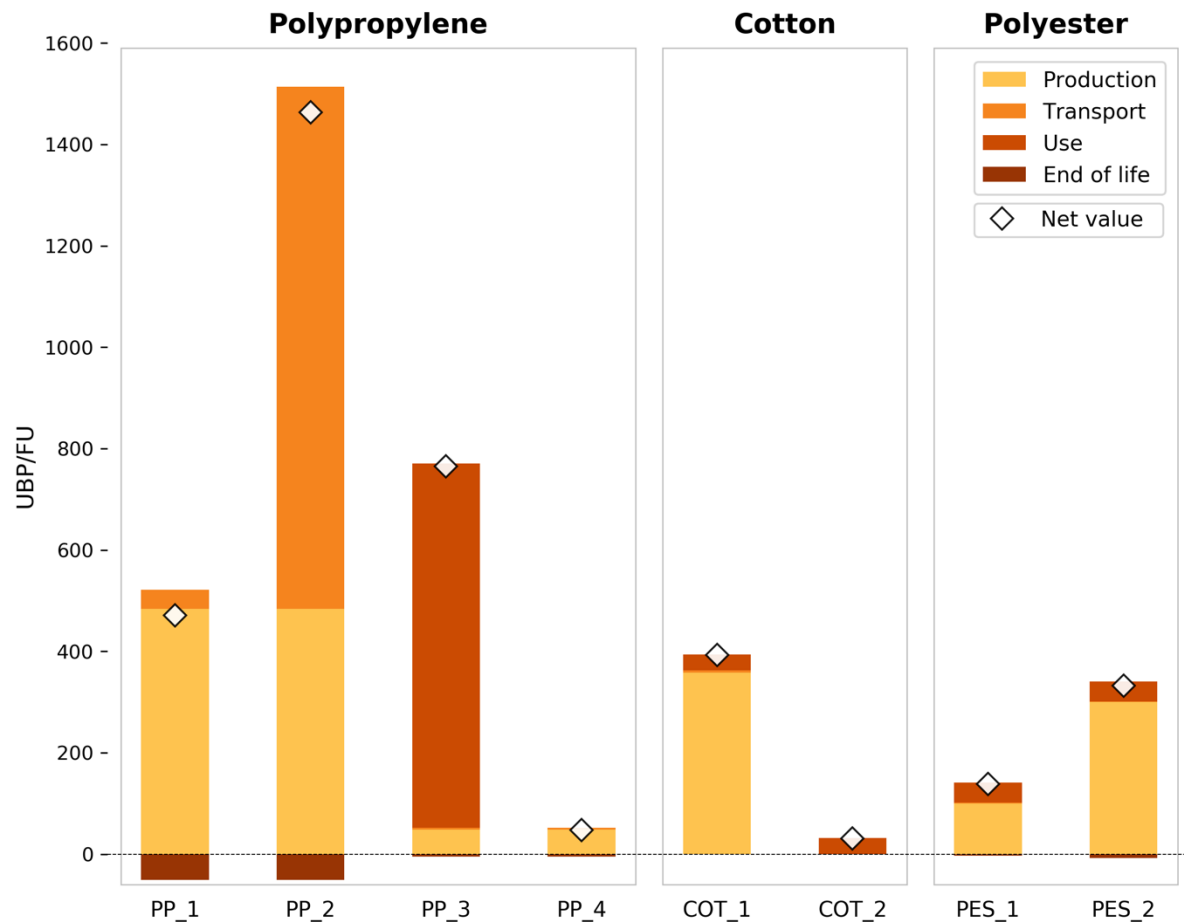
times of pandemic.

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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Which strategy for using medical and community masks? A prospective analysis of their environmental impact.

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1 **Which strategy for using medical and community masks? A**

2 **prospective analysis of their environmental impact.**

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23

24

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26 Facemask, community mask, medical mask, recycling, reuse, carbon footprint, COVID-19

27

28

1

Abstract

Introduction

The use of personal protective equipment, 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

A prospective analysis was conducted to assess the environmental impact of different strategies for the use of medical and community masks. 8 scenarios, differentiating the typologies of masks and the modes of reuse are compared using three environmental impact indicators: the Global Warming Potential (GWP100), the ecological scarcity (UBP method) 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 kgCO$_2$ 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.

2

54 **Strengths and limitations of this study**

55

56 - This study provides an environmental assessment based on three indicators (GWP 100, UBP,

57 plastic leakage) for different mask type and use strategies.

58 - -Eight mask use and reuse strategies were considered.

59 - - The assumptions used in the life cycle assessment (transport, end of life, littering) are

60 based on the European context and do not necessarily apply to other regions.

61 - The weight and composition of the masks used in this study are those of typical,

62 commercially available masks, but do not represent the variability from one manufacturer to

63 another.

64

3

Introduction

The decrease in industrial activity during the COVID-19 confinement and the decline in intra- and inter-national mobility has led to a significant drop in CO_2 emissions[1]. An average decrease of 6.4% in yearly CO_2 emissions was observed worldwide for 2020[2]. Positive effects have also been observed on other air pollutants, such as PM, NOx, SO_2 and on river pollution[3]. However, some observations made in China, near Hubei's epicenter, show an unclear environmental picture, with a lower decrease in air pollutants than expected[4]. Due to the temporary nature of the confinement measures, some authors argue that the longer-term effects of the COVID-19 crisis on the environmental footprint of human activities remain highly uncertain and may offset the observed short-term environmental benefits [5]. In the United States, a sharp drop in jet fuel and gasoline consumption has been observed during the crisis, leading to a decrease in CO_2 emissions of around 15%. However, it has been estimated that in a scenario of sustainable impact on the economy, the consequences of delayed investment in green energy and traffic-related emission reduction programs alone could outweigh the short-term effects [6]. The evolution of some activities or consumption patterns during the COVID-19 crisis are also likely to worsen the environmental balance: development of e-commerce (increase of transport distances and packaging), high consumption of disinfection products, massive COVID-19 screening in populations (increase in medical consumables).

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

4

88　February of the same year [10]. With the second pandemic wave, the wearing of facemasks was

89　mandatory in closed spaces and densely populated areas in many countries. Medical masks

90　and community masks have become essential tools in the fight against the spread of the virus.

91　Given the extensive use of facemasks, there is an urgent need to take into account the

92　environmental impact of this practice and ways to extend the life of this equipment. Several

93　arguments can be put forward: (1) the bulk of production comes from Asia[11], resulting in

94　significant use of transportation to supply regions such as Europe and the United States, (2)

95　medical masks are intended for single use, resulting in additional waste and possible littering

96　of used masks, and (3) medical masks and some community masks are made of plastic. Poor

97　management of this waste can therefore contribute to the presence of macroplastics and

98　microplastics in the environment, particularly in the Ocean [12]. Considering that 3% of masks

99　could enter the environment (overall loss rate), it is estimated that up to 1.56 billions

100　disposable masks could have entered the Ocean in 2020, which represents between 4680 and

101　6240 tons of plastic pollution to the marine environment [13]. Life cycle assessment (LCA)

102　conducted on facemasks in United Kingdom also shows that the environmental impact of

103　disposable masks are generally higher than recycled masks. In the absence of recycling, the

104　production of waste in this country, as a consequence of the use of one mask each day for a

105　year by the entire British population, was estimated at 124'000 tons, including 66'000 tons of

106　non-recyclable contaminated plastic [14]. Many countries are attempting to restrict the use of

107　single-use plastics, including restricting the use of plastic bags. The increase in plastic waste

108　is putting pressure on the waste management system to find new strategies to deal with this

109　change [15]. On the other hand, there is good evidence that face masks used in the community

110　provide protection against Covid-19 infections [16], even though effectiveness can be very

5

111 different according to the type of masks, the wearing adherence or the environmental

112 parameters (e.g. humidity and heat).

113 In this study, we aim to explore and compare the environmental impact of the different masks

114 used in the community and attempt to provide clear recommendations on the best

115 compromise between protection effectiveness and environmental impact.

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6

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).

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

7

145   countries, quality labels have been proposed, allowing minimum performance requirements to be

146   defined on a voluntary basis. This is the case, for instance, of the French AFNOR label and of the Swiss

147   TESTEX label (referred here below as PES masks). Currently, labelled masks represent only a minority

148   of production, probably due to higher manufacturing costs. While "common" community masks are

149   generally made of cotton or other textiles of natural origin, labelled masks, which require greater

150   technicality, are made of polymers, such as elastane or polyester. Community trade masks without

151   labels were considered to come from the wider European market. For the labelled masks, the origin

152   is more specific, since the AFNOR and TESTEX labelled masks are, to our knowledge, only produced in

153   France and Switzerland respectively.

154

155   **Reuse strategy**

156   The lack of protective means and the need to extend the life cycle of masks during the first COVID-19

157   wave generated numerous studies on their reuse. Although medical masks are normally intended for

158   single use, it has been shown that certain physical treatments such as UVC, microwaves or dry heat

159   can effectively decontaminate them without significantly altering their barrier capacity. The latter

160   method is of particular interest for the treatment of medical masks, as it is accessible in all households.

161   It has been shown exposure to at least 70°C for 30 min is sufficient to effectively decontaminate

162   surgical masks or respirators [18-20].

163   Another alternative, which has yet to be validated, is the wait & reuse strategy. The viability of the

164   virus deposited on a surface decreases significantly after a few hours. Tests on surgical masks have

165   shown that under ambient temperature and humidity conditions (22°C, 65% RH), a 3-log reduction in

166   virus load was achieved after 4 to 7 days [21]. In a similar way to what has been proposed by the

167   N95Decon scientific group for respirators, surgical masks could therefore be stored at room

168   temperature for 7 days before being reused (by the same user).

8

169   The situation with community masks is more straightforward since they are designed with the intent

170   of cleaning and reusing by the general public. The issue of maintaining performance is also less critical

171   since there are no legal requirements for this type of mask. The strategy considered here is therefore

172   that of a reuse after a decontamination at home in a washing machine at 60°C. Labelled community

173   mask are a special situation, since maintaining their performances is conditioned by the limitation of

174   the number of washing cycles, to 20 and 5 washes for the AFNOR and TESTEX labels, respectively [22] [23].

175

176   **Environmental Impact assessment**

177

178   Figure 1 about here

179

180   This study follows the methodology of life cycle assessment (LCA) and considers all the life cycle stages

181   of the different masks including production, transport, use (decontamination) and end of life (see

182   Figure 1). The primary data sources used and hypothesis are referenced throughout this article. The

183   secondary data used for impact characterization used to perform the LCA analysis are based on the

184   Ecoinvent database (https://www.ecoinvent.org/database/database.html). A proprietary excel tool

185   developed by the authors was used to perform the LCA based on Ecoinvent datasets. Unless otherwise

186   mentioned; the functional unit (FU) chosen for the comparison of the masks is "to equip one person

187   with a mask during a month". Several environmental impact indicators were considered:

188

189   -   The Global Warming Potential (GWP100) index, which expresses the impact of manufacturing,

190   transporting and recycling masks in terms of greenhouse gases. GWP100 expresses the time-

191   integrated warming effect, over a 100 year period, due to the release of a given greenhouse gas

192   in today's atmosphere, relative to that of carbon dioxide (in mass unit kg)[24].

9

193 - The UBP method relies on the methodological concept of ecological scarcity and expresses the

194 environmental impact in terms of eco-points. It encompasses for instance the water footprint of

195 cotton production as well as the biodiversity impact of energy production during the use phase.

196 However. Calculation using the UBP method has been performed and is available in Appendix

197 S1.

198 - The plastic leakage (PL), which expresses the amount of plastic leaving the technosphere and

199 cumulating in the natural environment. PL measures the quantity of plastic ultimately released

200 into the ocean or into the other compartments (freshwater, soils, other terrestrial

201 environments) including both microplastics and macroplastics [25]. Plastic leakage is a result of

202 both loss and release and can be simply described by the following equation:

203 $Plastic\ leakage\ mass = Plastic\ waste\ mass \cdot Leakage\ rate$ (with Leakage rate = Loss

204 rate . Release rate, and Loss rate = mismanaged rate + littering rate)

205 In the case of Switzerland, the only loss occurring is related to littering since the mismanaged

206 rate is equal to 0%. The littering rate will then be assimilated to the leakage rate as we are here

207 assessing the release rate of a low residual value item to all environmental compartments at

208 once, hence equal to 100%. The littering rate used by default for on-the-go plastic is generally

209 ranging between 2% [26][27] and 12% [28]. A recent study focusing on masks articulates a littering rate

210 of 3% worldwide. We used a 2% littering rate [25], yielding a leakage rate of 2% to all

211 compartments of the environment for the scope of this study.

212 The destination chosen for masks transport is Switzerland. However, shipping origin and method

213 vary as masks can come from Switzerland, France or China, and be transported either by truck, boat

214 or plane. Different assumptions are made for additional environmental burdens during the use

215 phase of the mask life cycle according to the decontamination method. For the decontamination in

216 a washing machine, we consider a household washing machine cycle running at 60°C during 1h40

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

10

218 and a soap consumption of 65 g/cycle [29]. We have allocated the energy, water and soap used to

219 wash a mask based on the ratio between the weight of the mask and the total dry load of clothes

220 assumed when running one cycle. These consumptions features have then been scaled up to

221 represent the functional unit chosen for the study. For the oven sterilization we assume that, based

222 on personal measurement, an oven running at 70°C during 30 min consumes 0.345 kWh of

223 electricity. As the oven utilization is exclusively dedicated to sterilizing masks, we had to make an

224 assumption on the number of masks being sterilized at once. We assumed that a batch of 5 masks

225 were sterilized for each oven utilization, hence an energy consumption of 0.069 kWh per mask

226 sterilized.

227 In the end of life stage, we assumed that all masks were incinerated after disposal. Heat and

228 electricity recovery efficiencies in Europe vary quite significantly between different plants, at

229 average values of 31% for heat and 12% for electricity [30]. The strategies for using the masks and the

230 corresponding assessment parameters are summarized in Table 1.

231

Patient and public involvement

233 No patient involved.

234

235

11

236

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

237

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*

12

245 **Results**

246 **Global warming potential**

247 The CO_2 - 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/CO_2

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 CO_2-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).

265

266 Figure 2 about here

267

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

271 however the home-made cotton masks (COT_2) and the extended use of medical masks through a

272 wait and reuse strategy (PP_4). Notably, the impact of decontamination of medical masks by heating

273 (PP_3) is more than doubled, making it less advantageous than the single-use scenario of medical

274 masks shipped from China by boat (PP_1).

275

276 **Plastic leakage (PL)**

277 The impact of the different scenarios of mask use from the point of view of plastic leakage is

278 presented in Figure 3. Unsurprisingly, cotton masks do not generate plastic leakage. Disposable

279 medical masks have a high PL of 1.8 g/FU. However, this impact can be reduced by a factor of 10 by

280 reuse procedures, which proportionally reduce production needs.

281

282 *Figure 3 about here*

283 **Number of reuse**

284 The number of reuses used in the scenarios is based on an estimate of current practices and

285 recommendations. Arguably, this may change depending on usage conditions, material quality, or

286 changes in mask labelling requirements. The effect of the number of reuses on the GWP100 is shown

287 in figure 4. Interestingly, commercial cotton masks (COT_1) reused less than 8 times generate more

288 CO_2eq than disposable medical masks shipped by boat (PP_1). Moreover, when used less than 17

289 times commercial cotton masks (COT_1) generate more CO_2eq than medical masks decontaminated

290 through dry heating (PP_3). The increase in the number of reuse decreases the gap between the two

291 most advantageous scenarios: home-made cotton masks (COT_2) and the recycling of medical masks

292 through a wait and reuse strategy (PP_4). The curves for scenarios PES_1 and PES_2 are overlapping

293 in Figure 4 since the composition of EMPA and AFNOR masks has been assumed identical. The only

294 slight difference between these scenarios, although not significant enough to distinguish both curves

295 on the graph, stems from the distinct origins of the masks.

296

297

298   *Figure 4 about here*

299

Discussion

301   Consistent with what has been highlighted by other authors, our results show that switching from

302   single-use to reusable masks can significantly reduce plastic leakage and climate change impact[14].

303   However, analysis of the different scenarios shows considerable variation between reuse strategies,

304   mainly due to the impact of production and recycling. A footprint reduction (GWP100 or UBP) of

305   50% to 90% can be achieved by switching from a single-use medical mask to a reusable solution. For

306   plastic leakage, this reduction can be from 60% to 100%. At the population level, these differences

307   are not negligible. We quantified how much CO_2eq impact and plastic leakage would be avoided

308   within a year in Switzerland if 10% of the entire population was to shift from single-use masks

309   transported by boat (PP_1) to either a wait and reuse strategy for the same masks (PP_4) or home-

310   made cotton masks from old fabric (COT_2). Results are reported in Table 2, considering a Swiss

311   population 8'606'033 in 2019 (source: Federal Statistical Office).

	CO_2eq 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

312

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

314   *of the Swiss population.*

315   For an impact per passenger transport by aircraft (person.km) of 0.129 kgCO_2eq (source: Reffnet.ch)

316   and an average 1.5L plastic bottle weight of 32.6 g [31], the uptake of the wait and reuse strategy for

317   the medical masks (PP_4) by 10% of the population would be equivalent to saving CO_2eq emissions

318   from 5'402 individual flights from Paris to New York, and preventing 513'194 plastic bottles (1.5L)

319 from being littered. Similarly, the uptake of home-made cotton masks (COT_2) by the same

320 population share would result in CO_2eq emissions savings analogous to 5'830 individual air travels

321 from Paris to New York, and a plastic leakage avoided corresponding to 570'219 plastic bottles

322 (1.5L).

323 The environmental impact assessment conducted in this study has several limitations. Data on mask

324 composition, transport and end of life are from the European context. The transposition of these

325 results to other regions, in particular regions with a higher production capacity of medical masks and

326 less reliance on imports, would lead to a modification of the GWP100 and UBP impact. Furthermore,

327 in the absence of precise market distribution data, mask composition and production data were

328 based on typical examples and scenarios rather than statistical data. In practice, there is some

329 variability in manufacturing and shipping arrangements due to different suppliers. From the point of

330 view of the effectiveness of their individual or collective protection, masks are not all equal. The

331 comparison of their performance is not obvious because several parameters influence their

332 effectiveness (droplet penetration, aerosol penetration, fitting to the face, wettability...)[16] and only

333 medical masks as well as labelled community masks (e.g. AFNOR label) have minimum performance

334 requirements for some of these parameters while a high variability in performance is to be expected

335 among unlabelled community masks. We performed an uncertainty analysis based on low and high

336 values for the littering rate (ranging from 0.2% to 12%, with the medium value being set at 2%). We

337 have observed that the plastic leakage results would be changing proportionally to the leakage rate

338 factor between the medium value and the low or high value, but that the climate change or UBP

339 impact results would deviate from the medium case by around 1% or below. No other uncertainty

340 analysis was undertaken for this study.

341 The filtration efficiency of the membrane as such has been investigated by several experimental

342 studies. Aydin et al. report filtration efficiencies for large droplets in the 100 μ- 1mm range of over

343 98% for surgical masks and 93-98% for unlabelled community masks of different materials (cotton,

344 polyester and silk)[32]. For finer particles, the performance of unlabelled community masks is however

345 lower. In the 10μ range (PM_{10}), Neupane et al. show a filtration efficiency of 94% for surgical masks

346 and 63% and 84% for community masks [33]. Systematic reviews of the laboratory results obtained so

347 far suggest that community masks have satisfactory filtration efficiency for large particles (e.g. >

348 5μm), but that they have only limited effectiveness against aerosols.

349 However, the overall performance of the masks is not limited to filtration efficiency alone and will be

350 affected by leaks due to poor fitting to the face, but also by the way the masks are used. Wearing a

351 face mask in a community logic is moreover primarily intended as a collective protection (by

352 reducing the emission of the wearer), rather than an individual protection. This collective

353 effectiveness is difficult to quantify due to the complexity of exposure situations and the presence of

354 other contamination routes (e.g surface contamination). Randomized studies conducted previously

355 on the transmission of viral infections in the community, showed that wearing a mask provided

356 some protection in the most adherent individuals [34] or when mask use is accompanied by hand

357 hygiene measures and/or education on viral infections [35 36].

358 The choice of the most appropriate strategy must consider both environmental impact and

359 effectiveness. In terms of mask performance, expectations are generally quite limited from a

360 community protection perspective. To some extent, all masks contribute to community protection by

361 reducing droplet emissions and, to a lesser extent, aerosol emissions from infected wearers. In the

362 absence of minimum performance requirements, this protection is highly uncertain for unlabeled

363 community face masks. Standardized masks, such as medical masks, which offer guarantees in

364 terms of performance and reproducibility, are therefore more advantageous from this point of view.

365 Labelled community masks are also an interesting alternative. Their environmental performance is

366 currently limited by the number of planned cycles of use, which requires frequent replacement. An

367 increase in the number of use cycles covered by the label would reduce significantly their

368 environmental impact. The future use of materials that are less polluting than plastic materials for

369 the manufacture of masks could be an alternative to reduce the environmental cost of their

370 manufacture and plastic leakage. For community masks, this adjustment is relatively simple because

371 many of them are made of cotton and some manufacturers also offer masks made of recycled

372   plastic. For medical masks, a more important effort is necessary because it requires the complete

373   accreditation of the mask according to EN14683. The scale of the uptake of the reuse strategies

374   suggested in the study by the population will depend on the interest of the government to endorse

375   such practices for community masks and on the efficiency of public awareness campaign. Last but

376   not least, adopting a wait and reuse strategy with medical masks is probably the most economical,

377   which is important in terms of access to protective measures for people with limited financial

378   resources [37].

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.

388

389

393   Competing interests

394   The authors declare no competing interest

395   Author contribution

396 JB, NS, BG, KS and DV developed the study concept and design. KS and DV conducted the literature

397 review. AB and JB conducted the impact assessment and data analysis. All authors contributed to the

398 data interpretation. DV wrote the first draft of the manuscript with contributions from JB, AB and

399 NS. All authors contributed to and have approved the final manuscript.

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402 **Patient consent for publication**

403 Not required

404 **Data availability statement**

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

406 **Ethics approval**

407 This study does not involve research with human subjects.

408

409

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

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

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

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519 **Figure 4. Footprint expressed in GWP100 (kgCO2eq./FU) for different scenarios as a function of**
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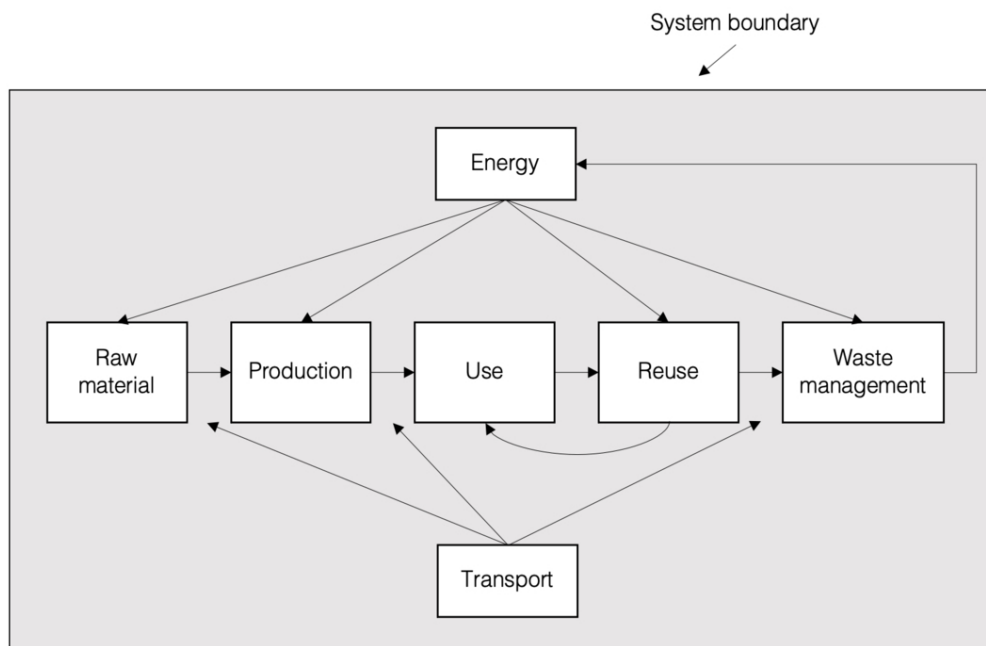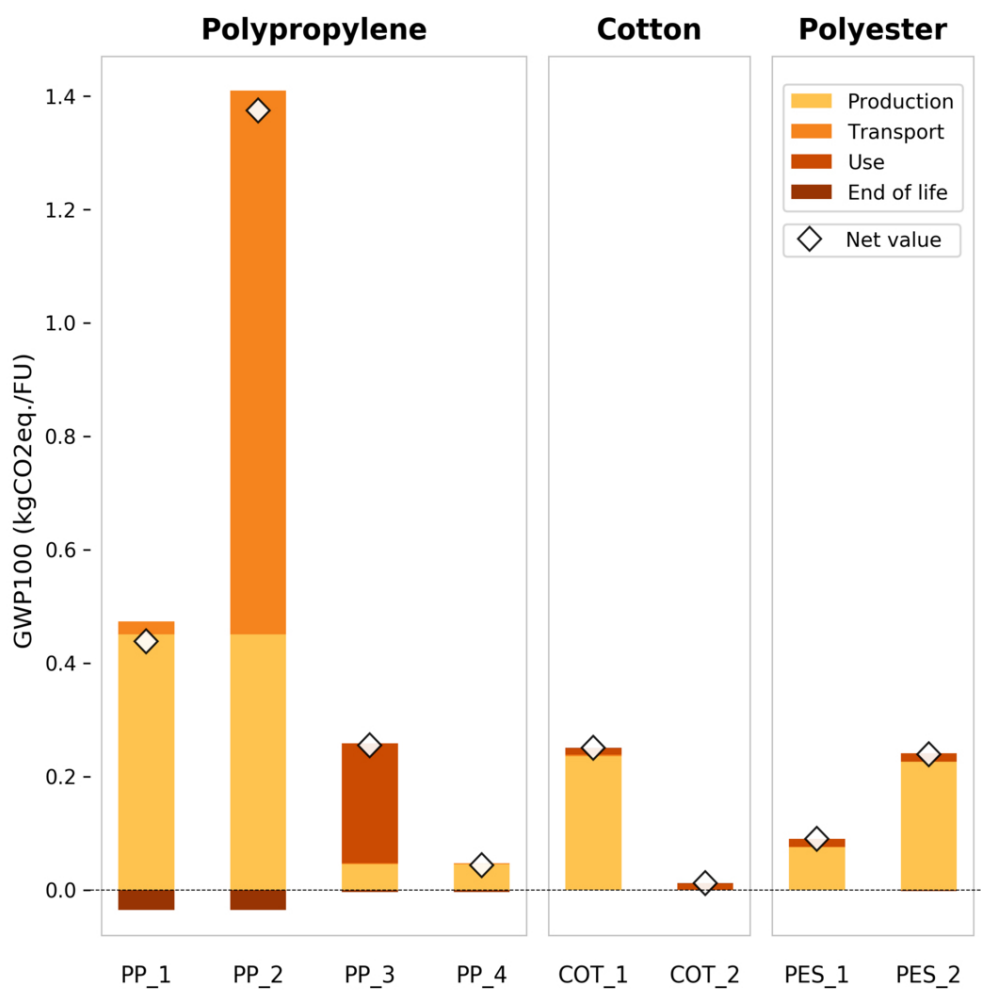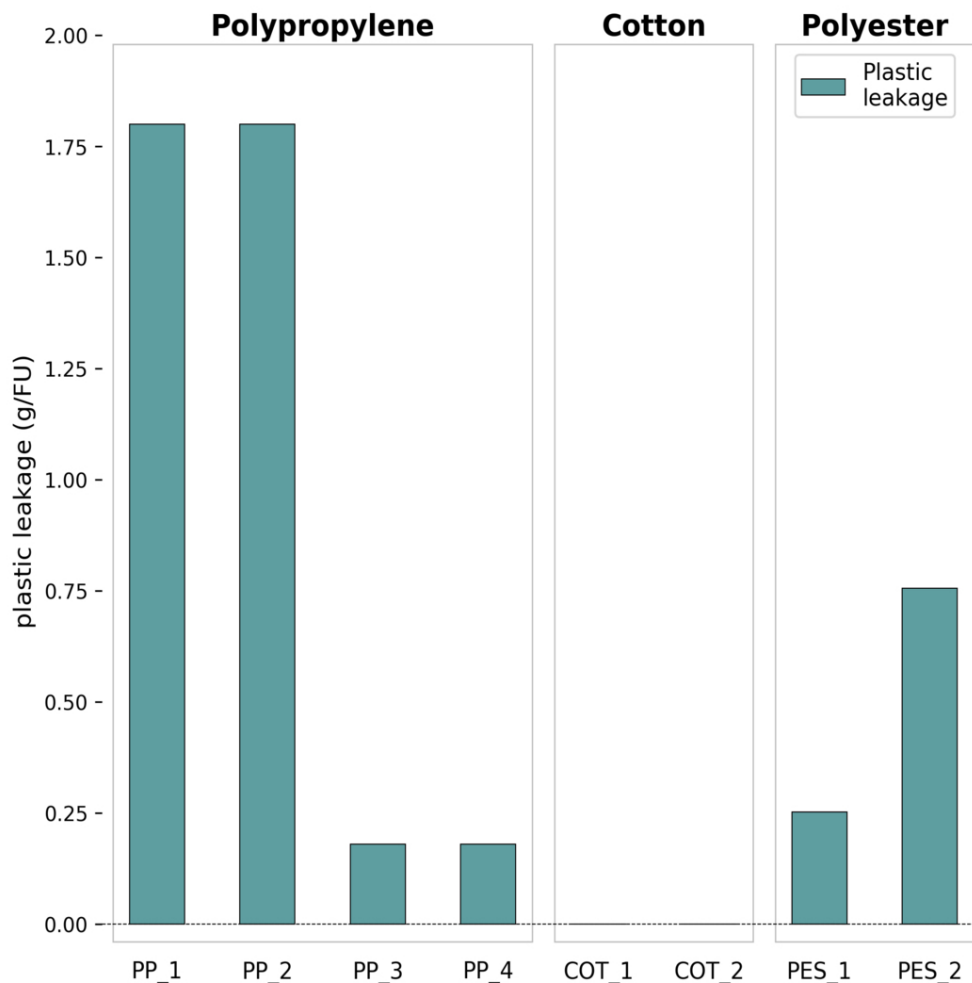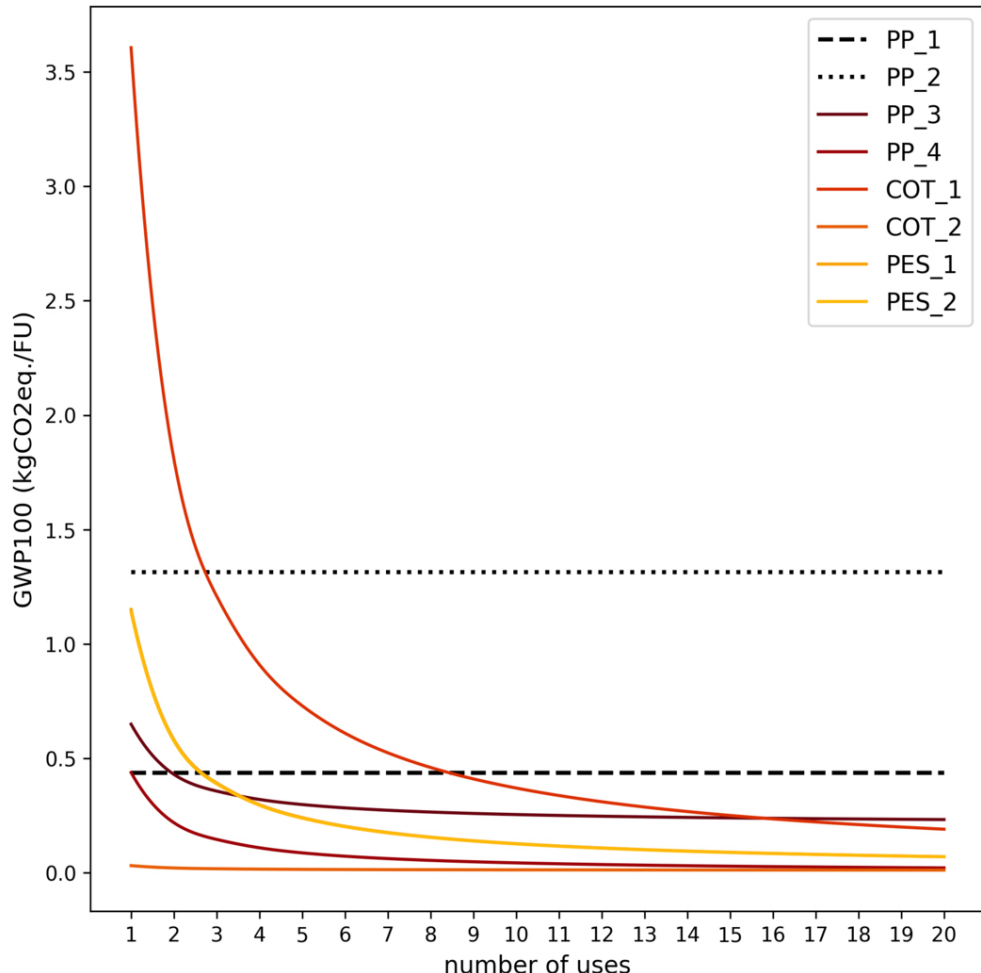Figure 1. Illustration of the system boundary for all scenarios involved in the study.

89x89mm (300 x 300 DPI)

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.

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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 "Umweltbelastungpunkte". 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 Büsser Knöpfel 2013).

The UBP impacts of the different scenarios of mask use are presented in Figure S1. Similarly to the CO_2-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.
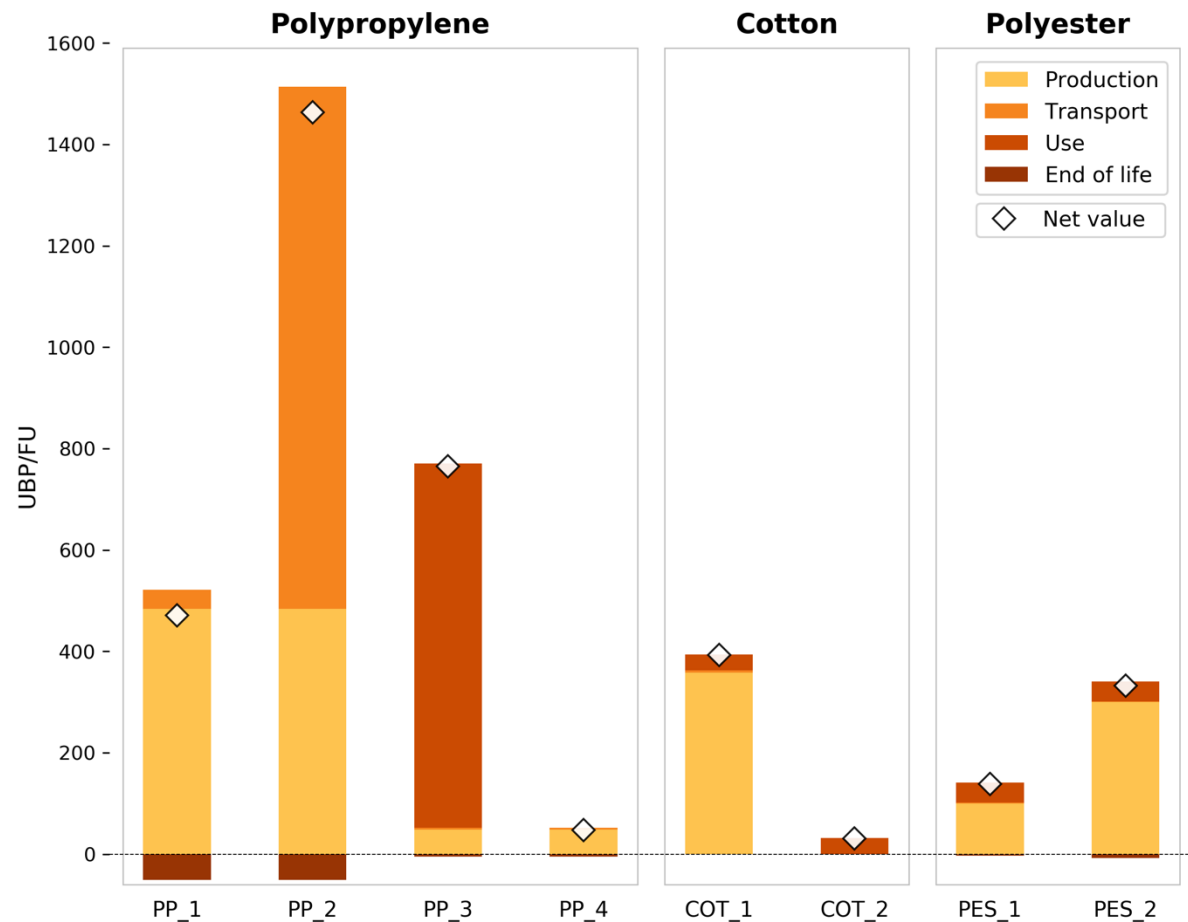
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Figure S1. Footprint expressed in UBP /FU for different scenario of mask uses.

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.