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Environmental assessment and eco-design of a surgical face mask

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Abstract

After more than one year form the first cases of Sars-Cov-2 infection, it is now clear that the most effective mean to prevent the diffusion of the pandemic is the use of face masks, that however are based on fossil materials and could potentially generate an environmental problem. This study wants to quantitatively investigate the environmental impacts related to the life cycle of a single use surgical mask through the use of the Life Cycle Assessment methodology. Results highlight significant impacts due to the material supply and transport, as well as product packaging and distribution. The study outcomes can be also useful to set potential eco-design strategies for the product environmental improvement.

Keywords: surgical mask; life cycle assessment; eco-design; COVID-19

1. Introduction

On 11th March 2020 the World Health Organization (WHO) declared the Sars-Cov-2 pandemic. Till today more than 200 million infection cases in the world have been confirmed [1]. The virus that causes Covid-19 spreads through air droplets produced by infected people. Other than vaccination, measures to reduce risks of transmitting the infection are social distance, hand hygiene and using face masks [2]. The correct use of face masks is the most effective prevention tool because it acts like a physical barrier for droplets and filters infected subjects' exhalations, especially in places with reduced ventilation or confined spaces [3]. Depending on the typology, face masks must comply with EN 14683:2019 or EN 149:2001 requirements [4][5]. Non-woven filter layers included in face masks are commonly produced with fossil-based materials such as polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polyester (PE) or polypropylene (PP). Spunbond and meltblown are the common weaving methods and they require a lot of water and electricity, obtained mostly from thermoelectric plants [6]. Furthermore, masks efficient functioning is limited in time. This leads to additional environmental issues, because used facial masks become medical-health waste at their end of life (EoL) and must be sent to incineration plants or landfills [7]. In fact, the structure of the product and the regulatory constraints make the recycling process very complicated. Furthermore, if facial masks are abandoned in environment, they could potentially cause damages to the marine ecosystem. It has been demonstrated that facial masks can be ingested by aquatic organisms in the form of microplastics, causing potential damage to human health [8][9].

A recent WHO estimation reports that more than 89 million masks per month are needed to prevent infections [10], highlighting that if the use of masks is very beneficial for the purpose of containing the Covid-19 infection, a correlated environmental problem is emerging. For this reason, scientific studies are promoting to produce masks with biodegradable materials, in order to make their disposal easier [11]. There are also some studies that propose methods of sanitizing masks and increasing their useful life, with ethanol, heat and UV rays as the most common sanitization methods [12][13][14].

Within this context, the present paper concerns single use surgical mask life cycle evaluation, according to the Life Cycle Assessment (LCA) methodology in compliance with the ISO 14040 and ISO 14044 standards. The purpose of this scientific

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study is to evaluate the environmental impacts of the mask in the upstream (materials and transport), core (mask manufacturing) and downstream (mask distribution, use and EoL) macro-phases and it can contribute to the few and preliminary existing LCA studies on the topic [15][16]. It can also help the development of eco-design measures to reduce the environmental impacts of such widespread products. The Italian scenario is considered in this LCA about production, distribution and the mask EoL stages and this study uses data provided by a company involved in mask production, located in central Italy. ReCiPe midpoints and endpoints have been used to evaluate the environmental loads of the various phases of the mask life cycle.

After this introduction about the research context and scientific background, the paper continues with section 2 that presents the first three phases of the LCA study: goal and scope, inventory and impact assessment. Section 3 shows the obtained results at both midpoint and endpoint levels. Finally, section 4 discusses study outcomes and proposes future directions of research.

2. Materials and methods

This section describes the LCA purpose of a disposable surgical mask, Life Cycle Inventory (LCI) data and the methods used for the analysis.

2.1. Goal and scope of the study

The main purpose of the study is to quantify the environmental impacts of the entire life cycle of a surgical mask, highlighting the most environmentally polluting phases (called "hotspots").

The first goal of the LCA analysis is to inform policy makers about these environmental impacts and compare the results with other similar studies. The study could help policy makers, manufacturers and consumers to make choices to increase sustainability in the face mask industry.

The functional unit (FU) for this study is "the production, use and end of life of one single-use surgical mask". This mask is composed by three layers of non-woven fabric in PET and PBT, an aluminum nosepiece and synthetic rubber earloops.

The system boundaries, from "cradle to grave", include the phases from the production and procurement of materials to the EoL scenario. In fact, single-use surgical face mask is considered to be contaminated once worn and should not be reused or recycled [17].

Figure 1 shows the unit processes divided into upstream, core, downstream with related inputs and outputs.

2.2. Life Cycle Inventory (LCI)

The LCI consists in the quantification of all input and output flows. Table 1 reports data related to the energy and raw materials consumption, air, water and soil emissions and all waste produced in each phase. All these data are referred to the production of one surgical mask. Primary data have been provided by an Italian manufacturer of surgical masks. The following assumptions have been considered to collect data:

a) use of Google Maps to calculate transport distances related to material supply; for the distribution phase of the face mask it was estimated an average distance of 300 km. The means of transport are lorry, ship and van;
b) primary data for upstream and downstream phases outputs (emissions) where not available, thus data from the Ecoinvent v3.7 LCI database have been considered valid;
c) incineration has been considered for the mask end of life; an average distance of 200 km is estimated from the consumer to the incineration plant;
d) for the energy recovery process, percentages of 55.5% for plastics and 19,9% for cardboard were considered as directed to incineration, according to the available literature data [18]. The electricity produced by waste materials through incineration is 0,67 kWh/ton [19].

2.3. Life Cycle Impact Assessment (LCIA)

This LCA study has been carried out through the support of the Simapro 9.2.0.2 software tool (equipped with Ecoinvent 3.7 database). Concerning the quantification of the environmental impacts, both the ReCiPe midpoint impact categories and endpoint damage categories [23] have been used in order to have a comprehensive view of the potential impacts on the environment together with the main causes, as demonstrated in previous studies [24].

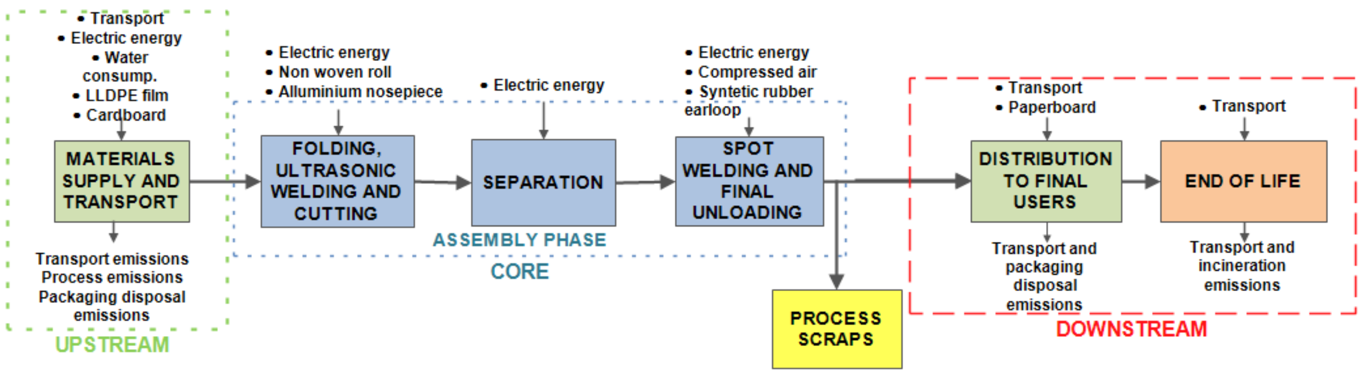

Figure 1. Details of the unit processes included in the LCA study

Table 1. Life Cycle Inventory

PHASE	INPUT			OUTPUT (Assumptions)	DATA SOURCE
UPSTREAM					
MATERIALS SUPPLY AND TRANSPORT	SPUNBOND PET 1,68g (two layers)	ELECTRIC ENERGY 0,0012 kWh	CHINA-ITALY: -TRUCK 1480 km - SHIP 7500 km - VAN 35 km	a); b)	Literature data for transport and energy consumption [20]
	MELTBLOWN PBT 0,84 g (one layer)	ELECTRIC ENERGY 0,0081 kWh		a); b)	Literature data for transport and energy consumption [21]
	SYNTHETIC RUBBER EARLOOP 0,42 g	ELECTRIC ENERGY 0,0003 kWh	CHINA-ITALY: -TRUCK 810 km - SHIP 7500 km - VAN 35 km	a); b)	Literature data for transport and energy consumption [22]
	ALUMINIUM NOSEPIECE 0,34 g	/		a); b)	Literature data for transport
	LDPE FILM 0,06 g	/	/	b)	Primary data
	CARDBOARD BOX (EARLOOP) 0,14 g CARDBOARD BOX (NOSEPIECE) 0,16 g	/	/	b)	Primary data
CORE					
FOLDING, ULTRASONIC WELDING AND CUTTING	SPUNBOND PET 1,68 g (two layers) MELTBLOWN PBT 0,84 g ALUMINIUM NOSEPIECE 0,34 g	ELECTRIC ENERGY 0,0006 kWh	/	None	Primary data
SEPARATION	/	ELECTRIC ENERGY 0,0003 kWh	/	None	Primary data
SPOT WELDING AND FINAL UNLOADING	SYNTHETIC RUBBER EARLOOP 0,42 g	ELECTRIC ENERGY 0,0006 kWh COMPRESSED AIR 4,8 l	/	None	Primary data
PROCESS SCRAPS	/	/	0,0264 g	c); d)	Primary data
DOWNSTREAM					
DISTRIBUTION TO FINAL USER	KRAFT PAPER BOX 0,72 g VAN 300 km (to private consumers)	/	/	55,5% LDPE FILM incineration 19,9 % CARDOARD incineration a); b); c); d)	Primary data for packaging and transport Literature data for output [18]
END OF LIFE	GARBAGE TRUCK 200 km	/	/	ELECTRIC ENERGY 0,67 kWh/ton a); b); c); d)	Primary data for transport Literature data for output [19]

3. Results

This section describes the results of the LCA analysis and therefore the environmental loads, with details for each ReCiPe impact and damage category. According to the LCA goal (i.e. to highlight most critical phases and contributions to environmental midpoint and endpoint), this analysis allows to discover which life cycle phase of the considered disposable mask is the most critical. Such information is essential to guide future improvement strategies for disposable surgical masks.

3.1. Environmental impacts at midpoint level

The midpoint impacts are shown in Table 2 in which the split of contributions for each unit process in terms of each impact category is reported. All the 18 ReCiPe midpoint impact categories are considered: (i) Global warming potential (GWP), (ii) Ozone depletion potential (ODP), (iii) Ionizing radiation potential (IRP), (iv) Photochemical oxidant formation potential: humans (HOFP), (v) Particulate matter formation potential (PMFP), (vi) Photochemical oxidant formation potential: ecosystems (EOFP), (vii)Terrestrial acidification potential (TAP), (viii) Freshwater eutrophication potential (FEP), (ix) Marine eutrophication potential (MEP), (x) Terrestrial ecotoxicity potential (TETP), (xi) Freshwater ecotoxicity potential (FETP), (xii) Marine ecotoxicity potential (METP), (xiii) Human carcinogenic toxicity (HTP_C), (xiv) Human non-carcinogenic toxicity (HTP_{NC}), (xv) Agricultural land occupation potential (LOP), (xvi) Surplus ore potential (SOP), (xvii) Fossil fuel potential (FFP), (xviii) Water consumption potential (WCP).

A first important outcome of this analysis is related to the most impactful phase of the mask life cycle that is the “1. Materials Supply and Transport” for almost all the ReCiPe impact categories. The impacts obtained for this phase are in the range 45% – 82%, excluding the LOP indicator. The higher contributions, with respect to the total, have been obtained in the categories PMFP (82%), TAP (81%), FFP (76%), HTP_C (74%), SOP (74%), HOFP (72%), EOFP (72%), WCP (72%). For all such categories the most critical flows are related to the materials used to manufacture the facemask, particularly the spunbond and meltblown non-woven fabrics, and with a lower contribution the synthetic rubber earloops. Concerning the LOP impact category, instead, the contribution of the “1. Materials Supply and Transport” phase is only 7% of the total, while the dominant flow is the “5. Distribution to final user”, with impacts mainly caused by the kraft paper boxes used to package the masks.

Non-negligible contributions are due to the “6. End of Life”, particularly for what regards the MEP (45% of the total, more or less the same as the phase “1. Materials Supply and Transport”), METP (29%), FETP (28%) and GWP (27%). In this case the combined effect of the emissions on the air, caused by the incineration process, and emissions on the soil/groundwater, caused by the landfilling of residual materials, determines such high impacts for the abovementioned indicators. The implementation of more sustainable EoL scenarios (e.g. development of specific EoL processes for the recovery/reuse of fossil-based materials derived from disposable masks) would be an effective strategy to reduce impacts in these categories.

Regarding the facemask core processes (i.e. “2. Folding - Ultrasonic welding – Cutting”, “3. Separation” and “4. Spot welding - Final unloading”), they are relevant only in terms of the IRP impact category (about 29% of the total impact). Anyway, for all the midpoint indicators the most critical manufacturing phase is the “4. Spot welding - Final unloading”, where the compressed air consumed by the welding machine contributes with a relevant portion of the impact (about 80% of the impacts due to manufacturing processes).

Table 2. ReCiPe midpoint results

Impact Category	Total	1. Materials Supply and Transport	2. Folding - Ultrasonic welding - Cutting	3. Separation	4. Spot welding - Final unloading	5. Distribution to final user	6. End of Life
GWP [kg CO2 eq]	3,49E-02	2,17E-02	2,58E-04	1,29E-04	9,07E-04	2,62E-03	9,29E-03
ODP [kg CFC11 eq]	9,80E-09	6,20E-09	2,00E-10	1,00E-10	6,00E-10	1,80E-09	9,00E-10
IRP [kBq Co-60 eq]	9,84E-04	5,06E-04	2,83E-05	1,41E-05	2,47E-04	1,76E-04	1,20E-05
HOFP [kg NOx eq]	8,57E-05	6,19E-05	4,65E-07	2,33E-07	2,19E-06	1,22E-05	8,79E-06
PMFP [kg PM2.5 eq]	4,46E-05	3,67E-05	2,78E-07	1,39E-07	1,63E-06	3,85E-06	1,95E-06
OFP [kg NOx eq]	8,73E-05	6,25E-05	4,74E-07	2,37E-07	2,23E-06	1,26E-05	9,19E-06
TAP [kg SO2 eq]	9,92E-05	8,08E-05	8,10E-07	4,05E-07	3,88E-06	8,91E-06	4,35E-06
FEP [kg P eq]	7,29E-06	5,05E-06	7,64E-08	3,82E-08	8,59E-07	1,24E-06	2,66E-08
MEP [kg N eq]	2,42E-06	1,08E-06	7,20E-09	3,60E-09	5,48E-08	1,54E-07	1,12E-06
TETP [kg 1,4-DCB]	5,16E-02	2,98E-02	3,11E-04	1,55E-04	3,99E-03	1,57E-02	1,67E-03
FETP [kg 1,4-DCB]	2,26E-03	1,08E-03	2,28E-05	1,14E-05	3,35E-04	1,86E-04	6,26E-04
METP [kg 1,4-DCB]	3,01E-03	1,41E-03	2,82E-05	1,41E-05	4,20E-04	2,53E-04	8,82E-04
HTP_C [kg 1,4-DCB]	2,68E-03	1,98E-03	1,29E-05	6,46E-06	2,82E-04	3,48E-04	5,79E-05
HTP_{NC} [kg 1,4-DCB]	3,79E-02	2,20E-02	2,01E-04	1,01E-04	4,28E-03	4,35E-03	6,96E-03
LOP [m2a crop eq]	1,31E-02	9,34E-04	5,72E-05	2,86E-05	1,96E-04	1,18E-02	1,18E-05

Impact Category	Total	1. Materials Supply and Transport	2. Folding - Ultrasonic welding - Cutting	3. Separation	4. Spot welding - Final unloading	5. Distribution to final user	6. End of Life
SOP [kg Cu eq]	1,09E-04	8,03E-05	4,84E-07	2,42E-07	1,83E-05	8,68E-06	7,97E-07
FFP [kg oil eq]	6,71E-03	5,13E-03	7,99E-05	3,99E-05	2,51E-04	8,41E-04	3,60E-04
WCP [m^3]	1,44E-04	1,03E-04	5,05E-06	2,53E-06	1,63E-05	1,58E-05	1,61E-06

3.2. Environmental impacts at endpoint level

Results of the endpoint analysis are reported in Table 3, with details in terms of the three ReCiPe damage categories and of the Single Score indicator.

In terms of Human health, the production and transport of materials (phase 1), spot welding (phase 4) and EoL (phase 6) showed the most significant values. The causes of such results are due to the typologies of raw materials used for nonwoven fabrics, synthetic earloops and aluminum nosepiece. They are all produced by fossil resources, as ethylene glycol, xylene and terephthalic acid for nonwoven fabrics and earloops, or aluminum hydroxide, responsible of high Chemical Oxygen Demand (COD) emissions, for nosepiece. Traditional energy sources, fossil fuels used by transportation vehicles and EoL incineration residues are also responsible of significant pollution phenomena.

For Ecosystems and Resources categories none particularly relevant contribution can be observed. It is possible affirm that the main causes for these two damage categories are the extraction of fossil oil for all materials production, for transport and electricity, as well as the exploitation of forest resources for cardboard packaging.

Table 3. ReciPe endpoint results

Damage category	Total	1. Materials Supply and Transport	2. Folding - Ultrasonic welding - Cutting	3. Separation	4. Spot welding - Final unloading	5. Distribution to final user	6. End of Life
Single Score [mPt]	1,38E+00	9,51E-01	9,16E-03	4,58E-03	6,56E-02	1,51E-01	2,03E-01
Human health [mPt]	1,30E+00	9,16E-01	8,56E-03	4,28E-03	6,34E-02	1,17E-01	1,94E-01
Ecosystems [mPt]	6,87E-02	2,69E-02	4,25E-04	2,12E-04	1,73E-03	3,17E-02	7,78E-03
Resources [mPt]	1,20E-02	7,73E-03	1,72E-04	8,61E-05	4,58E-04	2,42E-03	1,14E-03

4. Discussion and Conclusions

This paper deals with the life cycle environmental assessment of a currently very common product: the disposable surgical mask. The study has been executed according to the ISO 14040-44 standards guidelines. Primary and secondary data are used to model an as accurate as possible LCI of all the unit processes related to mask production, distribution and EoL. The assessment of the impacts has been carried out at midpoint and endpoint levels through the ReCiPe midpoint H and ReCiPe endpoint H/A methods.

Briefly, the results obtained highlight that the phases of materials production, mask fabrication and distribution to final users represent the main environmental criticalities of the analyzed life cycle. More in details, results interpretation shows that electricity production from traditional sources (thermoelectric power plants powered by diesel, burning oil or coal), fuels used for transport operations (diesel or bunker fuel for ships) and materials synthetized from fossil resources (polyethylene terephthalate, aluminum and synthetic rubber) are the main causes of environmental loads for single use surgical masks. However, a minimum benefit can be derived from the mask and its packaging energy recovery (EoL).

Regardless of the Sars-Cov 19 pandemic decreasing trend, the nonwoven-based surgical masks are and will be used for other applications, as in medical environment. Thus, as outcome of this analysis, a series of eco-design improvements to reduce the environmental loads of face masks in the most polluting life cycle phases can be proposed:

- change general logistics by reducing transport operations, in particular for materials procurement or try to supply them from production sites located near the face mask manufacturers;
- install photovoltaic systems (with storage) for energy self-production in every production site in which a phase of surgical mask life cycle is realized;
- develop filters with high durability (e.g. surface activated materials);
- develop more sustainable EoL processes dedicated to the treatment of disposable masks, as substitutes for incineration or landfill scenarios;
- change the materials used to make the disposable mask, in particular by replacing the polyethylene / polybutylene terephthalate with recycled, biodegradable and/or bio-based plastics after a technical-health feasibility study.

Concerning this latter, a preliminary investigation has been conducted. First of all, a substitute nonwoven material, based on polylactic acid (PLA), with the same technical characteristics of the original fossil-based materials (mainly in terms of breathability and bacteria filtration efficiency as required by EN 14683:2019) has been found in literature [25], to assure the technical feasibility of such eco-design strategy. The successive environmental assessment and comparison with the original solution demonstrated that at midpoint level only for FETP, METP and HTP_{NC} categories a reduction of impacts has been observed. Such preliminary results demonstrated that further studies are needed to find better eco-design strategies in a life cycle perspective in order to guarantee clear environmental benefits for all the potential impacts on natural environments (e.g. industrial symbiosis to product PLA instead of using dedicated corn crops, composting as EoL scenario).

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