Disposable Medical Masks: Environmental Costs

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Abstract

A massive increase in the use and production of masks worldwide has been seen in the current COVID-19 pandemic, which has contributed to reducing the transmission of the virus globally. This paper aims to evaluate the environmental impacts of disposable medical masks using the Life Cycle Assessment (LCA) method, first for the selected functional unit related to the manufacturing of one disposable medical mask and then for the global manufacturing of this type of mask in 2020. The inventory data was constructed directly from the industry. The system boundaries include the fabric, nose wire, and ear loops parts, transportation of materials, body making, ultrasonic vending, and packaging steps. The results suggest that the global warming potential of a disposable medical mask is 0.02 g CO₂-Eq. for which the main contributor is the packaging step (44%) followed by the life cycle of fabric (27%), and nose wire (14%) parts. In total, 52 billion disposable medical masks used worldwide consumes 25 TJ of energy in 2020. The global warming potential of disposable medical masks supplied in a year of the COVID-19 pandemic is 1.1 Mt CO₂ eq., equivalent to around 1.3 billion return flights from Istanbul to New York. This paper assessed the hotspots in the medical mask, allowing for a significant reduction in the environmental impact of mask use. This can be used as a roadmap for future mask designs.

1. Introduction

In Wuhan, China, the World Health Organization (WHO) China was informed of cases of unknown etiology of pneumonia detected at the end of December 2019. WHO first announced on 12 February 2020 that the cause of these symptoms was a new form of coronavirus (2019-nCoV) and on 11 February 2020 the new virus was called SARS-CoV-2 (WHO, 2020e). As a result of samples taken from patients, the complete SARS-CoV-2 genome sequence was soon mapped by scientists on 7 January 2020. The epidemic was named the "COVID-19" pandemic on 11 February 2020 (WHO, 2020c).

COVID-19, which initially spread in China and then in neighboring countries, later spread to most countries. The disease quickly acquired an international dimension and infected the entire world. As a result, the WHO found COVID-19 an international public health issue and on 30 January 2020 declared it a pandemic (WHO, 2020e; Zheng, 2020).

COVID-19 is mainly a respiratory disease that can vary from patients with very mild, non-respiratory symptoms to serious acute respiratory disease, organ failure sepsis that death (Lai et al., 2020). WHO confirmed person-to-person transmission of COVID-19 through respiratory droplets. Respiratory droplets move through the air as you breathe, sneeze, or speak. Then these droplets can fall in the mouths or noses of those near you or these droplets can be breathed in (WHO, 2020a).

Different proposals have been put forward by governments at all levels to avoid the spread of the virus, including lockdown, social distancing, restriction of movement, isolation, avoiding public or crowded spaces, as well as the use of masks (Fadare & Okoffo, 2020). WHO suggests wearing a face mask in public, where social distance interventions are difficult to sustain, and in places of substantial

community-based dissemination (WHO, 2020a, 2020b). Face masks protect the nose and help to block exhaled droplets and particulate matter to avoid further spread of COVID-19 (Liu & Zhang, 2020; WHO, 2020b).

A face mask serves as a physical shield in front of the nose and mouth (WHO, 2020a). When worn correctly, this type of mask prevents the sick person's respiratory droplets from spreading to the mouth and nose (Leung et al., 2020). Several different kinds of face masks provide users with various degrees of protection. Masks may be disposable or reusable. Industrial half-or full-face respirators with attached cartridge filters and handmade or consumer fabric masks are reusable; disposable ones include N95 respirators and surgical masks. The filtering capability depends on the materials used and the design of the engineering equipment, and therefore the level of protection (Chua et al., 2020).

A recent study has shown that medical masks can prevent symptomatic individuals from transmitting common cold coronaviruses and influenza viruses in actual conditions (Greenhalgh et al., 2020). The disposable medical mask is 3 times more effective than a cloth face mask at preventing transmission (Howard et al., 2020). The disposable medical mask will also not provide maximum protection if it does not suit the face correctly. In the case of contamination, moisture, wear, masks should be changed with new ones (WHO, 2020a).

Since the early 1900s, masks have been used by healthcare workers to avoid surgical wound infection (Oberg & Brosseau, 2008). In Asian countries, masks are used widely by the public. Since the 2003 SARS outbreak, face mask use has become increasingly widespread. During the SARS outbreak, 76% of the population in Hong Kong held a face mask (ECDC, 2020).

In 2020, the relative environmental impacts of face masks have been debated. A growing number of countries make it obligatory to wear face masks outside the home (WHO, 2020a, 2020d). The use of masks has seen a sixfold rise since the beginning of the COVID-19 pandemic (WHO, 2020d). For that reason, a new environmental problem has been created by the rise in the manufacture and the use of face masks worldwide. Globally, disposable medical masks are used millions of times a day, and yet the environmental impacts of this product are scarcely known. There are a limited number of comprehensive studies that assess the environmental sustainability of face masks (Ayse Lisa Allison, 2020; Davies et al., 2013; Fadare & Okoffo, 2020; Klemeš et al., 2020; Schmutz et al., 2020a). Some of the papers compared the environmental impacts of the selected type of masks such as reusable masks and disposable medical masks (Davies et al., 2013; Schmutz et al., 2020b). The scope and selected mask type vary across the papers. Most of the papers only focussed on the solid waste problem of the masks (Ayse Lisa Allison, 2020; Fadare & Okoffo, 2020). Although the information was available regarding the end-of-life of masks, very little information was supplied concerning the mask production. Despite the importance of the industrial production stage, there is scant information on the detailed environmental sustainability assessment of the production of the masks in detail. To improve knowledge about the production of face masks, this study assesses the life cycle environmental sustainability of disposable medical face masks by using real and detailed production data. The inventory data was constructed from the industry.

Besides, for 2020, total life cycle environmental impacts resulting from the total manufacturing of disposable medical masks have been estimated in the global dimension. The methods, assumptions, and inventory data used in the study are detailed in the following parts.

2. Methodology

The focus of this research is on disposable medical face masks. These types of masks are described as masks that are flat and attached to the head with straps that go around the ears. In this paper, life cycle assessment (LCA) has been used as a tool to quantify the environmental impacts of disposable medical masks. LCA is the most common tool for quantifying the environmental effects associated with a product, process, or service's entire life (Baumann & Tillman, 2004). LCA was performed in accordance with the international standards of the ISO 14040 and ISO 14044 series (ISO, 2006a, 2006b). These standard series describe the LCA's four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation. The purpose of the study, the functional unit, the boundary conditions, and the assumptions for the context in which evaluation is being made are defined in the goal and scope definition stage. The second step of the LCA is inventory analysis. The inventory analysis specifies the processes required for raw materials production, use of auxiliary materials, water, and energy during manufacturing, emissions to air, water, and soil during manufacturing, transport of raw materials, and packaging materials. GaBi v9.5 software package (Sphera, 2020) was used to process and analyze the data, model the systems, and calculate the environmental impacts. The impact assessment step evaluates the potential impacts on the environment using the inventory data. The life cycle environmental impacts have been quantified using the CML 2001 impact assessment method (Guinée et al., 2002). Finally, the interpretation step sets out the conclusions and recommendations for the study. The methodology, goal and scope of this research, inventory data and assumptions, and results are detailed in the following parts.

2.1 Aims and scope

The goal of this paper is to estimate the life cycle environmental impacts of a disposable medical mask production and to identify the life cycle stages that cause the greatest impact on the environment.

Two functional units are considered in this study:

- i. A disposable medical mask with nose wire,
- ii. Total manufactured masks in 2020. In total, 52 billion face masks being manufactured in 2020 globally (OceansAsia, 2020).

The system boundaries included all activities from raw material extraction, to medical masks. The life cycle of disposable medical face masks along the supply chain is outlined in Fig. 1. The selected system boundaries include the fabric, nose wire, and ear loop parts, transportation, and face mask production stages. The face mask manufacturing stage consists of body making, ultrasonic vending, and packaging

steps. The manufacturing of the equipment used in the facility and construction and decommissioning of the buildings and end-of-life stage are not included in the system boundary due to a lack of specific data.

2.2 Inventory analysis

Primary data were collected from a face mask manufacturer in Turkey and data gaps were filled using inventories from the GaBi software database (Sphera, 2020). Detailed and real manufacturing data was used for life cycle modeling. Turkey is one of the suppliers of masks to Europe. The life-cycle environmental impacts of the manufacturing of masks in Turkey have been analyzed for the first time in this study.

The details of the data used for this research have been presented in Fig. 2. Primary data were collected on raw materials directly from the manufacturer in Turkey. The background data of the non-woven fabric was obtained from the software database but has been adapted as far as possible to Turkey's conditions by using the country-specific energy and transportation data.

The structure of a disposable medical face is divided into three parts. That is the 3 layers of non-woven fabric part, nose strip, and ear loops. The selected type of disposable medical face mask is produced from polypropylene (PP) spun bond and melt-blown non-woven fabrics, 20–25 g/m² in density. PP is one of the most widely manufactured plastics in the world and can easily be supplied as an oil-based polymer. Spun bond fabrics are produced in one continuous process from extruded filament fibre. Melt-blown fabric is produced by using high-speed hot air to extrude a polymer melt through a series of fine holes, resulting in fine, self-bonded fibres. The nose strip is plastic-coated aluminium. Ear loops are produced from synthetic rubber. Details on the product inventory data have been presented in Fig. 2.

The transportation stage covers all relevant raw materials and packaging materials transport to the facility. Transport distances from raw material sites to manufacturing sites were obtained from the manufacturer. The data comprises the extraction and production of site locations, transportation distances, and types of transport used. Materials required for the production of face masks are produced in Turkey. Non-woven fabrics are produced in Gaziantep/Turkey and transported to the manufacturer via road freight. Other materials used in mask production are also transported to the production facility by road freight as shown in Table 1.

Table 1
Transportation distances for the material supply

Raw material	Transportation distances (km)	Transportation type
Spun bond fabric	1000	Road freight
Melt blown fabric	1000	Road freight
Nose strip	250	Road freight
Ear loops	150	Road freight
Packaging material	300	Road freight

Masks are manufactured in specialized facilities, on a machine line that assembles nonwoven fabric, ultrasonic welds of three layers of non-woven fabric, and stamps mask body with plastic-coated nose wire and elastic ear loops. The ultrasonic melting system is used for disposable medical mask production. Data for fuel inputs and electricity grid mix specific for Turkey were used.

Face masks are supplied in sterile packs. Each of the masks is packed with plastic bags. The packaging stage includes the packaging raw material and energy consumption for the packaging. Details on the production data have been presented in Fig. 2.

3. Results

This part presents and analyses the environmental impacts of disposable medical face mask first for the selected functional unit related to the manufacturing of a mask and then for the global use of this type of face mask in 2020. The LCA software GaBi v.9.5 (Sphera, 2020) was used for the accomplishment of the study. The results are shown in Fig. 3 and Fig. 4, the first showing the environmental impacts of the life cycle per kWh and the latter showing global manufacturing per year. The contribution of different life cycle steps to the total impacts can be seen in Fig. 5. Environmental impacts assessed in this paper include global warming, resource depletion, eutrophication, acidification, ozone layer depletion, ecotoxicity, and human toxicity based on CML 2001-January 2016 (CML, 2017).

3.1 Environmental impacts per disposable medical mask

The life cycle environmental impacts of a disposable medical mask are presented in Fig. 3, with the contributions by considered life cycle stages provided in Fig. 4. The results reveal that the life cycle of the nose wire part is the main hotspot for ADP, HTP, MAETP, and TETP. The packaging stage increases ADP fossil, AP, GWP, and POCP, while body making is the major contributor to EP and FAETP. Most of the ODP occurs due to the life cycle of ear loops. Transportation is not a significant contributor to environmental impacts as materials required to manufacture face masks are supplied locally. Further discussion of the environmental impacts from per disposable medical mask follows.

3.1.1 Abiotic depletion potential (ADP)

As presented in Fig. 3, a disposable medical face mask depletes 0.07 mg Sb-Eq. of abiotic elements. The life cycle of plastic-coated aluminium nose wire contributes nearly 90% to the total, see Fig. 4. The big contributors to this impact are the use of copper (31%), zinc (18%), gold (13%), lead (8%), and molybdenum (6%).

3.1.2 Abiotic depletion potential (ADP fossil)

Fossil resource depletion at the considered type of face mask's life cycle is estimated at 0.5 MJ per mask (Fig. 3). Packaging of the mask (48%) and the life cycle of fabric parts (33%) are the major contributors to ADP fossil due to the manufacturing of PP.

3.1.3 Acidification potential (AP)

The disposable medical mask has an AP of 0.09 g SO₂-Eq. a piece of mask. The emissions of SO₂, NO_x, and N₂O to air contribute 72%, 14%, and 12% of the total, respectively. As can be seen from Fig. 4, packaging of the product (49%), the life cycle of fabrics (22%) and nose wire (12%), and body maker step (11%) are the biggest contributors to the total AP.

3.1.4 Eutrophication potential (EP)

Figure 3 and Fig. 4 reveal that the EP for a disposable medical face mask is equal to 0.02 g PO₄-Eq. with 30%, 25%, and 20% arising from the body maker step, fabric body part, and packaging step, respectively. This impact is mainly due to the emissions of NO_x and PO₄ to air and water.

3.1.5 Freshwater aquatic ecotoxicity potential (FAETP)

As presented in Fig. 3, a disposable medical face mask has an estimated FAETP of 3.2 g dichlorobenzene (DCB)-Eq. Almost all this impact is due to the emissions to the freshwater of metals including nickel, beryllium, cobalt, vanadium, and copper mostly during body maker step (35%) and life cycle of plastic-coated nose wire (26%) and fabric body parts (23%).

3.1.6 Global warming potential (GWP)

As can be seen from Fig. 3, the estimated value for GWP for a mask is 0.02 g CO₂-Eq. The CO₂ emissions account for 85% of the total GWP, with contributions of 14% from CH₄. The biggest contributors to the greenhouse gas emissions are the packaging of the mask (44%) and the life cycle of fabric (27%) parts due to the emissions from PP production. The third-largest contributor to GWP is the life cycle of plastic-coated nose wire (14%), see Fig. 4.

3.1.7 Human toxicity potential (HTP)

The HTP from the disposable medical mask is estimated at 10 g DCB-Eq. per mask (Fig. 3), due to the organic emissions (56%), inorganic emissions (8%), and heavy metal emissions (7%) to air. The major source of this impact is the life cycle of plastic-coated nose wire, contributing 53% to the total. The

second-largest contributor is the body maker stage (18%) due to PP production and high energy consumption of this stage (Fig. 4).

3.1.8 Marine aquatic ecotoxicity potential (MAETP)

As shown in Fig. 3 and Fig. 4, the MAETP of a disposable medical mask is equal to 11.5 kg DCB-Eq. of which 36% and 28% are due to the nose wire part and body maker stage, respectively. The third-biggest contributor to this impact is the fabric part (18%).

3.1.9 Ozone layer depletion potential (ODP)

The ODP of the disposable medical face mask is estimated at 0.4 μg R11-eq./mask. This is mainly due to the life cycle of ear loops (44%), see Fig. 4. The other biggest contributors are the life cycle of nose wire (19%) and fabric (11%) parts and body maker step (15%). Halons 1211 and 1301 are almost entirely (99%) responsible for the ODP.

3.1.10 Photochemical oxidant creation potential (POCP)

The disposable medical face mask has a POCP of 0.01 g Ethene-Eq. per mask. As shown in Fig. 4, it is mainly due to mask packaging which contributes 47% to the total. The other main burdens contributing to this impact include the life cycle of fabric (30%) and nose wire (11%) parts.

3.1.11 Terrestrial ecotoxicity potential (TETP)

The TETP of a face mask is estimated at 0.04 g DCB-Eq. (Fig. 3). respectively. Mercury, chromium, and vanadium emissions to air and soil are the main contributors. The life cycle of plastic-coated nose wire, body maker stage, fabric, and ear loops contribute 52%, 15%, 14%, and 13%, respectively.

3.2 Total environmental impacts of global use of disposable medical masks in 2020

This part of the study presents the total environmental impacts of the global use of disposable medical face masks in 2020, based on the impacts calculated for a single mask discussed in the previous section. Figure 5 demonstrates the annual environmental effects of masks used worldwide. In total, 52 billion disposable medical masks being produced in 2020 globally (OceansAsia, 2020).

As indicated in Fig. 5, 52 billion disposable medical masks used worldwide in 2020 consumes 25 TJ of energy. The total annual GWP is estimated at around 1.1 Mt CO₂ Eq. from the global mask sector.

The economy-class return flight from Istanbul to New York emits an average of 0.8 tons of CO₂ per passenger (ICAO, 2020). The global warming potential of disposable medical masks supplied worldwide in a year of the COVID-19 pandemic is 1.1 Mt CO₂ eq., equivalent to around 1.3 billion return flights from Istanbul to New York.

Textile manufacturing is one of the most polluting sectors, emitting 1.2 billion tonnes of CO₂ Eq. each year, more than international aircraft and maritime transportation (Ellen MacArthur Foundation, 2017). Greenhouse gases emitted by disposable masks used last year amounted to approximately 1/1000th of the total annual greenhouse gases emitted by the global textile sector. These numbers demonstrate the magnitude of the environmental effects caused by the use of masks.

4. Conclusions

The COVID-19 virus is primarily transmitted through respiratory droplets and communication routes between individuals. Droplet transmission happens while a person is in direct contact with an infected individual and for example, by coughing or sneezing, exposure to potentially infectious respiratory droplets occurs. The usage of face masks is part of a comprehensive package of preventive and control measures that can reduce the spread of COVID-19. Masks may be used either for the protection of healthy people or source control reasons. The use of masks has seen a rise dramatically since the beginning of the COVID-19 pandemic.

This study estimated the life cycle environmental impacts of a disposable medical face mask. Further, it considered the total global effects of using this type of face masks in 2020. The environmental sustainability analysis is carried out first at the level of product and then at the sectoral level, focusing on the production of disposable medical masks globally. Turkey is one of the suppliers of masks to Europe. For the first time, this study has measured the environmental effects of the life cycle of the manufacture of masks in Turkey.

The results suggest that the greenhouse gas emissions of a disposable medical face mask are 0.02 g CO₂-Eq. for which the main contributor is the packaging step (44%) followed by the life cycle of fabric (27%) and nose wire (14%) parts.

The life cycle of the nose wire component is the main hotspot for ADP, HTP, MAETP, and TETP. The packaging stage increases ADP fossil, AP, GWP, and POCP, while body making is the key contributor to EP and FAETP. Almost all the ODP is due to the life cycle of the ear loops. Transportation is not a significant contributor to environmental impacts as materials required to manufacture face masks are supplied locally.

In total, 52 billion disposable medical masks used worldwide consumes 25 TJ of energy in 2020. The global warming potential of disposable medical masks supplied in 2020 is 1.1 Mt CO₂ Eq. Globally, the textile industry emits 1.2 billion tonnes of CO₂ Eq. per year. The significance of the environmental effects caused by the use of masks is demonstrated in this comparison.

The environmental impact of fabrics and plastic-coated nose wires are substantial and require urgent review to mitigate the environmental impacts. Disposable medical mask's environmental impacts could be improved by using alternative materials to produce packaging material, fabric body, ear loops, and nose wire parts. Recycling these parts could also decrease the life cycle environmental impacts of the

disposable medical mask. The current work can be extended to compare the environmental costs of different face masks such as N95 respirators or reusable fabric masks.

This paper describes emission hotspots in each face mask, allowing for a significant reduction in the environmental impact of face mask use. This can be used as a roadmap for future face mask sector.

Abbreviations

ADP Abiotic Depletion Potential of Elements

ADP fossil Abiotic Depletion Potential of Fossil Fuels

AP Acidification Potential

CML Centrum Voor Milieuwetenschappen

DCB Dichlorobenzene

EP Eutrophication Potential

FAETP Freshwater Aquatic Ecotoxicity Potential

GWP Global Warming Potential

HTP Human Toxicity Potential

ISO International Standardization Organization

LCA Life Cycle Assessment

MAETP Marine Aquatic Ecotoxicity Potential

ODP Ozone Layer Depletion Potential

POCP Photochemical Ozone Creation Potential

PP Polypropylene

TETP Terrestrial Ecotoxicity Potential

WHO World Health Organization

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

The author confirms sole responsibility for the following: study conception and design, data collection and calculation, LCA analysis and interpretation of results, and manuscript preparation.

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Figures

Figure 1

Life cycle stages of disposable medical face mask

Figure 2

Life cycle inventory of production of the disposable medical mask

Figure 3

Life cycle environmental impacts of a mask [Some impacts have been scaled to fit. The environmental indicators considered]

Figure 4

Contribution of different inputs and life cycle stages to the total impact

Figure 5

Annual environmental impacts

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