Article title: The environmental dangers of employing single-use face masks as part of a COVID-19 exit strategy
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Preprint statement: This article is a preprint and has not been peer-reviewed, under consideration and submitted to UCL Open: Environment Preprint for open peer review.
Funder: UKRI/EPSRC
DOI: 10.14324/111.444/000031.v1
Preprint first posted online: 01 May 2020
Keywords: PPE, Disposable, Reusable, face mask, LCA, MFA, N95 respirator, Surgical mask, Pre-symptomatic, Incineration, Sustainability, Systems modelling, Environmental policy and practice

Professor Dan Osborn
Editor-in-Chief UCL Open
UCL Open: Environment

Dear Professor Osborn,

Attached is the manuscript of our Open Commentary entitled "The environmental dangers of employing single-use face masks as part of a COVID-19 exit strategy" which my co-authors and I would like to submit for publication in the journal UCL Open: Environment.

We, the authors of this paper, are a multidisciplinary group of academics including chemists, materials scientists, engineers, designers, artists, and social scientists from University College London. We are part of the UCL Plastic Waste Innovation Hub whose aim is to develop new ways of designing-out waste from plastic packaging (https://www.plasticwastehub.org.uk).

In this Open Commentary we are responding to the current situation in the UK where the general population is under lockdown measures as a result of the COVID-19 pandemic. Without an available vaccine the government is considering different policy options to enable the restoration of freedom of movement and to restart the economy. One measure being considered by many countries is the mandatory wearing of face masks by the general population. This is due to a growing body of evidence to suggest that even basic face masks can be effective in reducing the spread of the virus, by reducing the range and volume of exhaled water droplets containing SARS-CoV-2. Although the World Health Organisation (WHO) does not currently recommend this measure as a means of preventing the spread of COVID-19, a growing number of countries have been adopting this precautionary measure including China, South Korea, Germany, Scotland, Spain amongst many others. In the UK due to shortages of PPE to supply to front-line workers in the hospitals and care homes, there is reluctance to adopt this measure in case this intensifies the shortage of PPE. If and when such PPE shortages abate there may be growing pressure to adopt this precautionary measure. The aim of this paper is to examine the environmental impact of the UK adopting masks for the general population in particular the amount of contaminated plastic waste produced.

We conclude that if the government decides to require the wearing of face masks in public, it should mandate reusable masks and not single-use masks. This will preserve single-use mask supplies for front-line healthcare workers, and reduce the environmental risks associated with the disposal of 66,000 tonnes of contaminated plastic mask waste in the household waste stream. Additionally, the use of reusable masks by the general population would significantly reduce plastic waste and the climate change impact of this policy measure. The methodology of the paper is applicable to the analysis of other countries whose use of single-use masks is also likely to be an important environmental issue for the next 12 months.

Yours Sincerely,

Mark Miodownik FREng
Professor of Materials & Society, UCL
(On behalf of my co-authors)

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The environmental dangers of employing single-use face masks as part of a COVID-19 exit strategy

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Keywords: PPE, Disposable, Reusable, face mask, LCA, MFA, N95 respirator, Surgical mask, Pre-symptomatic, Incineration.

Abstract

- As the UK government defines its lockdown exit strategy, the mandatory wearing of masks in public is likely to be considered.
- The World Health Organisation (WHO) does not currently recommend the use of masks by general populations as a means of preventing the spread of COVID-19, although a growing number of countries have been adopting this precautionary measure.
- The NHS states that there needs to be clear evidence that wearing masks will deliver significant benefits to take the UK out of lockdown, if it is to jeopardise mask supply.
- There is a growing body of evidence to suggest that even basic face masks can be effective in reducing the spread of the virus, by reducing the range and volume of exhaled water droplets containing SARS-CoV-2.
- Most masks available for sale are made from layers of plastics and are designed to be single-use. If every person in the UK used one single-use mask each day for a year, that would create 66,000 tonnes of contaminated plastic waste and create ten times more climate change impact than using reusable masks.
- In a hospital environment, single-use protective wear such as masks and gloves are contaminated items, and there are systems in place for their safe disposal, which involve segregation and incineration.
- No such segregated system exists for the general public, and a policy that makes wearing face masks mandatory will result in thousands of tonnes of contaminated waste deposited in the street and in the household waste.
- Evidence suggests that reusable masks perform most of the tasks of single-use masks without the associated waste stream.
- An extensive public health campaign with clear instructions about how to wear, remove, and wash reusable masks will be needed if this is to become part of the UK government's exit strategy.

Glossary

Asymptomatic describes an individual that shows no symptoms.

CE marking indicates that a product meets EU safety, health, or environmental requirements. The letters 'CE' appear on the product.

Coronavirus disease 2019 (COVID-19) is a disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2.

Donning and doffing refers to the putting on (donning) and taking off (doffing) of an item of clothing.

End-of-life is a term used to indicate the stage of a product, process, or system when it is disposed of and/or recycled.

Gauze is a loosely woven, or open-meshed cloth used in bandages and surgical dressings.

High-efficiency particulate air (HEPA) filter is a filter that is designed to remove 99.97% of very small (0.3 micron) particles from the air.

Incineration is a waste treatment process that involves the burning of waste materials such as medical waste.

Life cycle assessment (LCA) is an environmental assessment methodology used to analyse the environmental impacts associated with resource utilisation and emissions at each stage of a product, process, or system's life cycle.

Life cycle impact assessment (LCIA) is a method used to clarify the intensity of the results achieved through life cycle assessment with respect to environmental effects such as climate change, human health, and biodiversity.

Material flow analysis (MFA) is a method for quantifying the flow of materials and energy within a system.

Medical mask refers to an unfitted (i.e. loose-fitting) mask worn by an infected person, healthcare worker, or member of the public to reduce the transfer of potentially infectious body fluids between individuals.

Melt blown refers to a non-woven fabric that is produced by using high-velocity hot air to extrude a polymer melt through a row of fine holes, which creates into a fine, self-bonded fibre.

N95 respirator is a respiratory protective device that is worn closely fitted to the face and is very effective at filtering airborne particles – it is designed to remove at least 95% of very small (0.3 micron) particles from the air.

Pathogen refers to a bacteria or virus that causes disease.

Personal protective equipment (PPE) is the protective clothing – gowns, gloves, masks, face shields, or other equipment – designed to protect the wearer's body from infection and injury.

Pre-symptomatic refers to the state before which symptoms appear.

Respirator refers to a device, usually made of gauze that is worn over the mouth and nose, or the entire face to prevent the inhalation of dust, smoke, or other noxious substances.

Respiratory protective equipment (RPE) is a type of personal protective equipment (PPE) designed specifically to protect the wearer from breathing in harmful substances, or for use in oxygen-deficient atmospheres.

Reusable refers to a face mask that is designed to be used for multiple encounters, but that should be removed (‘doffed’) after each encounter. A reusable face mask should also be disinfected (i.e. high-temperature disinfected, dry-heat disinfected, or ultraviolet disinfected) between uses.

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the virus strain that causes coronavirus disease 2019 (COVID-19).

Single-use disposable refers to a face mask that is designed to be thrown away after use. Types include: surgical masks, medical procedure masks, and dust masks.

Spandex is a synthetic fibre made from polyurethane that is very strong and elastic.

Spunbond refers to a non-woven fabric that is produced in one continuous process from extruded filament fibres. Spunbond fabrics are typically made from polypropylene (PP), or a combination of polypropylene and polyethylene (PE).

Introduction

In this Open Commentary we are responding to the current situation in the UK where the general population is under lockdown measures as a result of the COVID-19 pandemic. Without an available vaccine the government is considering different policy options to enable the restoration of freedom of movement and to restart the economy. One measure being considered by many countries is the mandatory wearing of face masks by the general population. This is due to a growing body of evidence to suggest that even basic face masks can be effective in reducing the spread of the virus, by reducing the range and volume of exhaled water droplets containing SARS-CoV-2. Although the World Health Organisation (WHO) does not currently recommend this measure as a means of preventing the spread of COVID-19, a growing number of countries have been adopting this precautionary measure including China, South Korea, Germany, Scotland amongst many others. In the UK due to shortages of PPE to supply to front-line workers in the hospitals and care homes, there is reluctance to adopt this measure in case this intensifies the shortage of PPE. If and when such PPE shortages abate there may be growing pressure to adopt this precautionary measure. The aim of this paper is to examine the environmental impact of the UK adopting masks for the general population in particular the amount of contaminated plastic waste produced.

We, the authors of this paper, are a multidisciplinary group of academics including scientists, engineers, designers, artists, and social scientists from University College London. We are part of the Plastic Waste Innovation Hub (2019) whose aim is to develop new ways of designing-out waste from plastic packaging and create new circular economy business opportunities.

We begin this report by defining the types and anatomy of masks. This is followed by an analysis of the evidence of the effectiveness of masks for preventing the spread of COVID-19 and the role of mask wearing in government exit strategies. We then calculate the environmental impact of the manufacturing, transport use and disposal of **single-use** and reusable face masks. A summary of the behaviour change considerations for implementing widescale reusable mask use is followed by a discussion of the factors important for engaging with the public effectively.

1. Types and anatomy of masks

A surgical mask is a single-use device designed to retain infective agents present in the exhaled breath. Surgical masks are often referred to as face masks, but not all commercially available face masks are regulated as surgical masks. Surgical masks are made to act as barrier to droplets or aerosols while surgical respirators are made to filter out airborne particles including viruses and bacteria. Surgical masks and surgical respirators are CE marked as medical devices. Surgical masks comply with the EN14683 EU standard and, based on their different performance criteria, are classified as type I, IR, II and IIR. Surgical respirator masks comply with the EN149 EU standard and, based on their filtering performance, are classified as FFP1 (N95 in US and KN95 in China), FFP2 (N99 in US and KN99 in China), and FFP3 (N100 in US and KN100 in China). For example, N95 means that the mask provides the intended effectiveness of filtering 95% of particles with a mass median diameter of 0.3 micrometres.

Surgical masks have a multi-layered structure, where generally a layer of textile is covered on both sides by non-woven bonded fabric. Non-woven fabric has better bacteria filtration efficiency and air permeability, while remaining less slippery than the woven cloth (Henneberry, 2020). It is most commonly made of polypropylene, or, in combination with polyethylene or PET polyester. Heat extrusion is used in the manufacturing where polymer is converted into submicron diameter fibres that are collected onto a rotating belt to generate random laid non-woven web – fabric. Additional processes are used to produce webs with different structure and properties. In a spunbond process, fibers bond with each other as they cool, while in a melt-blown process high-velocity hot air is blown on the extruded fibre to obtain ultra-fine sub-micron filaments. Resulting melt-blown web has a smaller pore size and provides for better filtration efficiency then the spunbonded web. The filtration level of a mask will therefore depend on the types of the non-woven fabrics used for its manufacture and these will vary according to the application. According to the standards surgical masks are made to be effective at filtering out particles such as bacteria above 1 micron.

Masks are made in specialized factories, on a machine line that assembles the non-wovens from bobbins, ultrasonically welds the layers together, and stamps the masks with nose strips, ear loops, and other pieces. China is the biggest producer of surgical masks. The ultra-fine particle-blocking material, the melt-blown fabric, is made using expensive, highly specialised machines, so garment factories haven't been able to simply move their production towards medical-grade surgical masks. They have, however, been producing non-medical grade masks for key workers, including non-clinical health care staff.

Another option available to the general public is the reusable respiratory mask, which provides protection against air pollutants, including airborne pathogens. These reusable masks are multi-layered and often contain a high-efficiency particulate air (HEPA) filter. Some manufacturers of reusable masks (such as Cambridge Mask and Respro®) claim that their products are as effective as standard single-use masks, if used correctly. Cambridge Mask (2020), which produces respirators made with UK military-grade filtration technology, claims their masks are effective for 340 hours. The masks filter out dust and pollution particles such as PM10, PM2.5, and PM0.3, as well as bacteria and viruses, using a unique triple-layer filtration system. Alternatively, Respro® (2020) offers a number of general use respiratory masks with the interchangeable combination filter, suitable for airborne viruses, that should be replaced every 69 hours. Owing to the current high demand for PPE, both manufacturers of reusable masks were out of stock on 20th April 2020.

Simpler reusable masks made from multi-layered cloth are another option; they can be manufactured by a wide range of industries. Such masks were used in the bird flu (H5N1) epidemic of 2004 (Dato et al., 2006). Many DIY mask designs are available requiring materials such as old t-shirts and simple sewing such as that currently recommended by the US Surgeon General (Centers for Disease Control and Prevention, 2020).

2. The effectiveness of masks for preventing the spread of COVID-19

SARS-CoV-2 (the virus strain that causes COVID-19) is a respiratory virus that belongs to the family of previously researched and documented coronaviruses. SARS-CoV-2 is spread primarily through respiratory droplets, or by coming into physical contact with the viral material and self-administering the virus by hand to the mouth or nose (WHO). Data suggests active virus replication in the upper respiratory tract tissues with concentrations of the virus reaching their peak before day five after the onset of symptoms (Wölfel et al., 2020). The transmission of SARS-CoV-2 by asymptomatic individuals has also been documented, suggesting that 40-80% of transmissions occur by people who are pre-symptomatic or asymptomatic (Ferretti et al., Li et al.) Both surgical and N95 masks are effective in preventing the transmission of influenza virus from the wearer (Johnson et al., 2009; Cowling et al., 2010). The level of protection of masks against influenza depends on multiple factors such as the appropriate usage and fit of the mask, level of exposure, compliance, complementary interventions (such as hands washing), early use (Makison Booth et al., 2013, MacIntyre and Chughtai, 2015), as well as the type of mask. Respirators offer superior protection to surgical masks (Makison Booth et al., 2013).

A recent study indicated that surgical face masks could, in a real-life situation, prevent the transmission of common cold coronaviruses and influenza viruses from symptomatic individuals (Leung et al. 2020, Greenhalgh et al., 2020a). However, similar information for the SARS-CoV-2 virus is lacking (Javid et al. 2020). The WHO recommends that PPE masks should be used based on the risk of exposure (e.g., type of activity) and the transmission dynamics of the pathogen (e.g., contact, droplet, or aerosol). They do not recommend face masks for the general public if they are showing no symptoms, and are only accessing public spaces (e.g. schools, malls, train stations) (WHO, 2020). In addition there are fears that the overuse of face masks by the general population will further impact on supply shortages, making access more difficult for healthcare professionals who are most at risk of infection (Mahase, 2020).

The use of masks may give users a false sense of protection, thus encouraging risk-taking. Although the effectiveness of reusable face masks is unclear, a response from MacIntyre et al. (2020) on the shortage of single-use masks states that reusable masks do offer some form of protection. However, protocols on how to use reusable masks alongside complementary interventions should be developed to increase their effectivity in protecting against infection. No mask protects against the transmission of a virus through direct contact, and hand washing is essential prior to using, and after removing it.

There are a limited number of comprehensive studies that evaluate the effectiveness of reusable cloth masks compared to single-use medical/surgical masks. Davies et al. (2013) studied the effectiveness of homemade mask in blocking transmission of the microorganisms in healthy volunteers. They concluded that although homemade masks should be the last resort to prevent droplet transmission from infected individuals, they would be better than no protection. Authors did not recommend the use of homemade face masks as a method of reducing transmission of infection from aerosols. Another study by MacIntyre et al., 2015 in hospital healthcare setting indicates that cloth masks (two layer, made of cotton) have poorer filtration capacities than surgical masks, and due to higher moisture retention, the reuse of cloth mask may increase the risk of infection. The study confirmed the protective effects of hand hygiene however the type of mask was an independent predictor of the viral infection, even adjusted with self-reported compliance on hand hygiene.

Generally, the effectiveness of a cloth masks would depend on the fit, fineness of the cloth and the number of layers indicating that there is potential to design more effective cloth masks. Most single-use face masks have an inbuilt filter. Allowing for the insertion of a filter in a cloth mask, may increase their filtration capacities.
There are concerns that use of masks may give general public a false sense of protection, thus encouraging risk-taking. Protocols should be developed on how to use and clean reusable masks alongside complementary interventions frequent to increase their effectivity in protecting against infection. No mask protects against the transmission of a virus through direct contact, and hand washing is essential prior to using, and after removing it.

3. Role of mask wearing in exit strategies for COVID-19
Wearing masks could have the biggest impact on slowing down the spread of COVID-19, coupled with other precautions such as social distancing, if the government decides to impose mandatory PPE. However, they must weigh up the evidence and consider what is most beneficial to the public, as well as protecting front-line healthcare workers. The WHO discourages mask wearing by the general public on the basis that it might result in a mask shortage for healthcare workers, as well as the limited evidence on non-medical masks protecting individuals from infection. But, as new research is continuously carried out and published on COVID-19, we are seeing a change in opinion and guidance, with increasing numbers of countries and governments advocating the wearing of masks by the general public, including the U.S and Czech Republic.

There is clear scientific evidence to show that N95 respirators and surgical masks give protection to wearers in healthcare settings, but the question remains as to whether these should be used by the general public. New data shows that COVID-19 can be transmitted through tiny drops of sputum (Wölfel *et al*., 2020). Washable, re-usable cloth masks are a potential way forward, with the advantage that these could be made at home. Reusable cloth masks are not as effective in the prevention of infection as N95 respirators and surgical masks. This is because the pores in woven materials are larger than 0.3 microns and cannot, therefore, filter out all of the droplets containing viruses such as SARS-CoV-2, in which the viral particle size is 0.125 microns. As there is research to suggest that simple homemade cloth masks are able to limit the spread of droplets from the wearer and possibly slow down transmission (Rengasamy *et al*., 2010), with some data even suggesting that cloth masks may only be 15% less effective than surgical masks (Davies *et al*., 2013), it follows that cloth masks could be used to aid the prevention of transmission in public (but not stop it fully). This is important given that a large portion of infected people can be asymptomatic while carrying the virus. Due to the severity of this pandemic, it may not be wise to go searching for perfect evidence when it comes to wearing a cloth mask, but rather to act on the knowledge that wearing a mask could have a substantial impact on transmission of the virus. Thus Greenhalgh et al. (2020b) argue in the *BMJ* that wearing a cloth mask is better than wearing no mask at all.

The safe disinfection and reuse of single-use masks has been studied recently by Liao et al. (2020). They showed that several methods, including hot air (75°C, 30 mins), UV light (254 nm, 8W, 30 mins), and steam (10 mins) are all promising and effective methods. However, it is not yet known how many times this can be performed before the masks become ineffective or mechanically fail. Some anecdotal evidence indicates that due to the scarcity of face masks as well as their cost, members of the public are disinfecting single-use masks by leaving them in the sun for 72 hours.

With a growing number of countries making the wearing of face masks outside the home compulsory, price increases and limits on supply are to be expected. Currently, in the UK a pack of twenty single-use surgical masks costs approximately £10, while reusable masks cost between £5 and £20 for a pack of four. If mask wearing is mandated, these costs are highly likely to spike due to high demand. Local manufacturing of reusable masks could be scaled up reasonably easily in the UK, providing a boost to the UK economy without impacting on the supply of single-use masks to the NHS. Countries such as Portugal (Safe Communities Portugal, 2020) and France (Afnor, 2020) have issued guidance for the manufacture of such masks, including a 'stamp of quality' in Portugal based on the Health DG guidelines (Safe Communities Portugal, 2020).

4. Environmental impact of face masks

Face masks intended for medical use and protection against viruses are designed and regulated as disposable. If every person in the UK used one disposable surgical mask each day for a year, this would create over 124,000 tonnes of unrecyclable plastic waste (66,000 tonnes of contaminated waste and 57,000 tonnes of plastic packaging, see Table 2). In light of this, the following questions should be taken into consideration before recommending the mandatory adoption of disposable face masks: (1) Should PPE from households be collected separately; (2) Can the UK cope with an additional waste stream collection?

Used (and potentially contaminated) face masks are considered medical waste and typically directed to incineration when they arise from a clinical setting. However, there is currently no specific waste stream for these products if used by the general public. Conventionally, waste PPE is placed in mixed general waste at a household level, which may put waste collectors at risk of contracting infections. The Association of Cities and Regions for Sustainable Resource Management has advised keeping contaminated waste in a double bag for 72 hours before disposing into general waste. Considering that the half-life of the virus is 5.6 hours, this seems reasonable. However, the storing of contaminated waste for 72 hours prior to entering the general waste may need to be monitored to prevent the risk to waste disposal workers. There may also be storage issues, both at households and waste treatment sites, as the total waste increases.

In order to minimise the public health issues associated with the disposal of contaminated plastic waste, local councils could install special disposal units for contaminated masks in every street, as well as make hand sanitisers readily available, i.e. in public spaces and on transport networks. In the UK, there are currently 68 incinerators with a combined capacity of 12.2 million tonnes of waste (McGlone, 2019). In 2018, a total of 10.9 million tonnes waste were processed (McGlone, 2019), thus, on a national level, the waste arising from potential PPE waste can be processed.

In this study, we carried out a life cycle assessment (LCA) in order to understand the environmental impact of different UK-wide face mask-adoption scenarios. Five scenarios for the public use of face masks were explored, as summarised in Table 1.

Table 1: Summary of scenarios compared in the comparative study.

Scenario Number	Mask Type	Mask Use per Day	Number of Masks per Person per Year	Addition Filters	Number of Filters per Person per Year	Mask Treatment	Filter Treatment
1	Single-use	1	365	No	0	Disposed at the end of day.	N/A
2	Reusable	1	2	No	0	Manual washing	N/A
3	Reusable	1	2	Yes	365	Manual washing	Disposed at the end of day.
4	Reusable	1	4	No	0	Machine washing	N/A
5	Reusable	1	4	Yes	365	Machine washing	Disposed at the end of day.

This study assumed the use of one mask per person per day, which is deemed optimistic since the number of masks necessarily depends on an individual's behaviour. However, the difference in environmental impact between the different scenarios is relative. A scaling factor can be applied to the environmental impact results to reflect the actual impacts, if on average more than one mask is used daily. Reusable masks were modelled as if used in rotation: if an individual has two masks, it was assumed that only manual washing is possible due to the necessity of frequent washes. With four masks, it was assumed that they could be bulk washed with normal laundry. Full study assumptions (and results) can be found in the Appendix.

The LCA comparative study showed that the use of reusable masks significantly reduces the amount of waste entering general waste streams (Table 2). Due to packaging requirements, the total waste accumulation from using single-use masks nationally amounts to 124,000 tonnes. If single-use filters are used in addition with reusable masks, the amount of waste is 60% less than using single-use masks. There is over 95% reduction in waste if only reusable masks are used.

Table 2: Waste arising due to face mask use in the UK for 1 year.

	S1 - Single-Use Masks	S2 - Reusable Masks, Manually Washed, w/o Filter	S3 - Reusable Masks, Manually Washed, w/ Filters	S4 - Reusable Masks, Machine Washed, w/o Filter	S5 - Reusable Masks, Machine Washed, w/ Filters
Waste Arising per FU (kt)					
Masks	66.2	1.95	1.95	3.90	3.90
Filters			29.5		29.5
Packaging	57.4	0.680	15.6	1.36	16.3
Total	**124**	**2.63**	**47.0**	**5.26**	**49.6**

Life cycle impact assessment (LCIA) results showed that Scenario 4, in which four masks are used in rotation without single-use filters and are machine-washed, has the lowest environmental impact in all of the impact categories analysed except Water Scarcity. Fig. 1 highlights the hot-spot analysis carried out on each scenario's impact on Climate Change. It shows that, for single-use masks, Mask Transport to the UK (from China – the assumed location for the production of all masks) contributes most to this impact category. Due to the higher number of masks needed for Scenario 1, the contribution of Mask Manufacture is significantly higher for this scenario than in other reusable mask scenarios. The figure also suggests that having a higher number of masks in rotation to allow for machine washing (Scenarios 4 and 5) is more environmentally beneficial than manual washing (Scenarios 2 and 3).

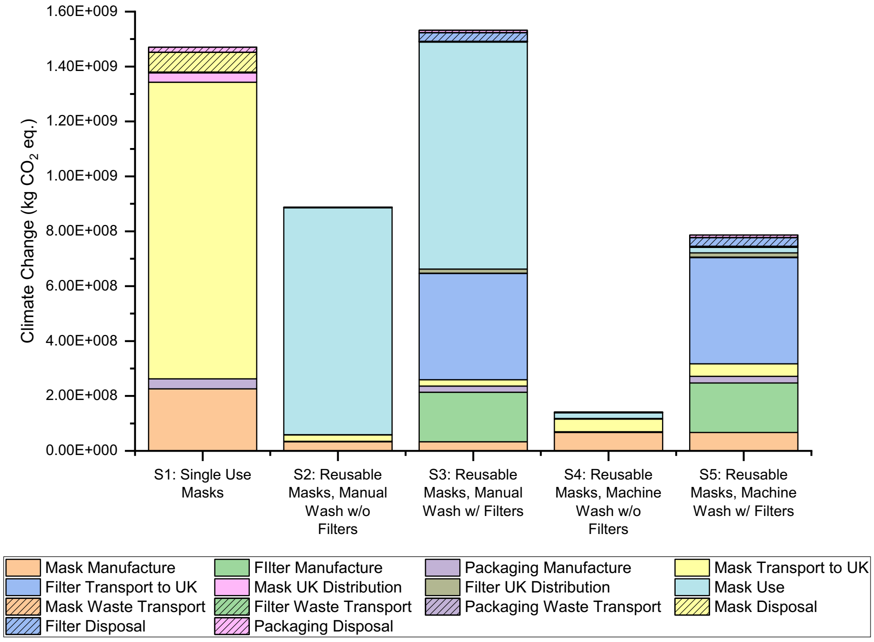

Fig. 1: Climate change results generated for each scenario of face mask use.

In Scenarios 4 and 5, each face mask requires 122 washes. However, it is understood that the products may not withstand this amount of washing. Further analysis was carried out and it was found that, if the amount of machine washes per year stays constant, up to 48 reusable masks can be used per person before Scenario 4 exceeds the impact on Climate Change, due to the use of single-use masks (Scenario 1). Here, the amount of washes per mask can be reduced to 8. This analysis was carried out on all other environmental impact categories and the average cap on the supply of reusable masks was calculated to be 25 masks per person (further details in the Appendix).

There is potential to lower the environmental impact of using single-use masks by changing the manufacturing location, and therefore reducing transport emissions. However, this depends on the supply of raw materials. For instance, cotton is typically grown in warm climates, and the UK is currently an importer of non-woven textiles (OECD, 2019). Therefore, if the UK produces its own masks in order to reduce mask transportation emissions, it will incur transport emissions from importing raw materials. Importing masks from China was deemed more realistic, owing to their manufacturing capabilities of this product.

Overall, the comparative study shows that, from an environmental perspective, using a higher number of reusable face masks in rotation to allow for machine-washing is more favourable than using single-use face masks. The use of filters with reusable face masks is discouraged, although it would generate a lower environmental impact compared to single-use face masks if machine-washed.

5. Behaviour change considerations for reusable mask use

Within the UK, the use of face masks has not yet been identified as a behavioural strategy for reducing the transmission of COVID-19 among the general population (Michie, 2020). One behavioural aspect of using face masks when in public is that they help prevent transmission *indirectly* by preventing touching of the face, particularly as this is when people are at increased risk of touching a contaminated surface and then touching a mucous membrane (i.e. nose, eyes, and mouth). As summarised in Table 3, avoiding touching the nose, eyes, and mouth is key to preventing the transmission of coronavirus among the general population. Studies have shown that individuals touch their faces an average of twenty-three times per hour, 44% of which involves touching a mucous membrane (Kwok et al., 2015). Of the mucous membranes touched, the most common was the mouth, followed by the nose and eyes. Masks may be able to prevent transmission of the disease by acting as a physical barrier against mouth and nose touching when in public, and for those most at risk of coming into contact with an infectious person. However, nothing can substitute good hand hygiene, so it is recommended that individuals always wash their hands, in accordance with WHO recommendations, after entering their homes and before and after using PPE. In general, Casanova et al. (2008) have reported that, depending on the protocols taken for hygiene, the removal of PPE could result in virus transfer to hands and clothing. Therefore, it is essential that users wash their hands and decontaminate their clothing.

Table 3: Recommended behaviours to prevent transmission of COVID-19 among the general population (taken from Michie, 2020)

Categories of recommended behaviours	Enabling behaviours
1. Maintaining hygiene	
a. Cleaning hands	• Ensure ready access to soap and water or alcohol-based (60%+) sanitiser at all times. • Carry moisturiser if you are concerned about dry hands. • Learn how to wash hands effectively for 20 seconds, soaping back of your hands, between your fingers and under your nails. • Learn when to wash hands and use clearly specified 'if-then' plans to carry this out, e.g. 'If I touch a potentially contaminated surface, I will wash my hands as soon as possible afterwards'.
b. Using and disposing of tissues	• Make sure you always clean tissues available. • Identify places to dispose of tissues immediately or as soon as possible. • Train yourself to cough or sneeze into tissues (or crook of elbow if not available), *not your hands*.
c. Cleaning surfaces	• Watch out for surfaces that could be contaminated. • Use household disinfectant to wipe at-risk surfaces.
2. Avoid touching	
a. Avoiding touching nose, mouth and eyes	• Make sure to keep hands below shoulder level except when e.g. hair brushing. • When acceptable, ask for and give feedback when you or others are touching nose/mouth eyes

b. Avoiding close contact greetings	• Develop and use alternative greetings, e.g. elbow bumping, head bowing. • Explain why you are not engaging in close contact greeting to make it normal and acceptable.
c. Avoid touching surfaces at risk of contamination	• Develop strategies for avoiding commonly touched surfaces where possible, e.g. door handles. • Avoid handling other peoples' personal objects, e.g. mobile phones.
3. Social distancing	
a. Avoiding crowds	• Plan work, travel or recreational activities that do not involve physical social gatherings e.g. online social games and events. • Develop explanations to give to people as to why you are avoiding social gatherings.
b. Maintaining personal distance	• Avoid standing or sitting close to people who are showings sings of infection.
c. Isolating (if advised to do so)	• Plan activities to minimise boredom and frustration in case of possible isolation. • Plan for practicalities of maintaining everyday life e.g. medicines, food, communications. • Plan for financial and social support during possible isolation.

Aside from whether reusable masks provide the same level of protection as single-use, the procedure for donning PPE, and the methods for decontaminating them is essential, as it is for single-use masks. The International Scientific Forum on Home Hygiene has published a report on the infection risks associated with clothing (Bloomfield et al., 2011), which states that laundering processes eliminate contamination from fabric and linen materials. Hence, as long as reusable masks are machine washable, then they should be safe to reuse. This is if hygiene protocols such as hand washing after doffing PPE are adequately followed.

A novel infectious disease outbreak presents a unique set of circumstances and challenges; understanding the capability, opportunity, and motivation-related influences on a behaviour is key to developing effective strategies to enable change. The COM-B model (Michie et al., 2011; Michie et al., 2014) is the simplest comprehensive model of behaviour in its context. COM-B posits that for behaviour to occur, people need: 1) capability, 2) opportunity, and 3) motivation. COM-B can be used to help guide strategies to ensure that the capability, opportunity, and motivation are all in place if/when the government decides to mandate reusable PPE usage when in public. Capability involves psychological (e.g. the knowledge and skill to perform an action) as well as physical (strength and stamina) capability; opportunity involves both social (e.g. norms) and physical (e.g. resources) facilitators; and motivation involves both 'reflective' (e.g. conscious decision-making) and 'automatic' (e.g. emotion and habit) processes. These behavioural influences interact as shown in Fig. 2.

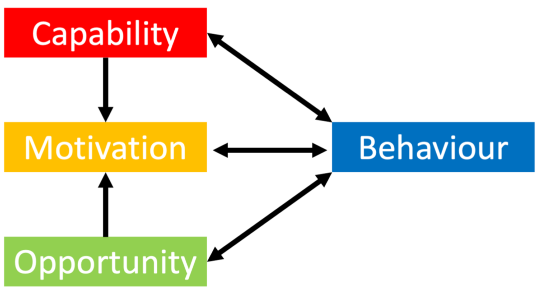

Fig. 2. Capability-Opportunity-Motivation-Behaviour model (COM-B; Michie et al., 2011; Michie e al., 2014)

6. Conclusions

If the government seeks to implement a public behaviour change intervention to reduce the wider impacts of COVID-19, a public campaign implementing reusable PPE masks should address the following:

Capability: Ensure the public knows how to don, doff, and reuse reusable PPE masks safely and practise this behaviour so that they perform it effectively. This can be implemented cost-effectively through guidelines and online video tutorials. In the case of reusable masks, the public should be clearly informed as to how to disinfect these masks through cleaning and the vital importance of doing so every time they are used.

Opportunity: Make sure the public has access to reusable PPE masks and that they are affordable. A range of reusable PPE mask solutions could be proposed, including homemade masks (access to fabrication knowledge and necessary equipment), or commercially available readymade products. As a reuse model is being proposed, an individual only needs a few masks at most to use in alternation, therefore putting less strain on the supply chain.

Motivation: Make using reusable PPE masks an attractive, or less aversive behaviour. Minimise social awkwardness by normalising the behaviour. Such challenging times are a breeding ground for public anxiety, the spread of misinformation, and fear mongering. Ensure that you communicate with the public that a reuse model does not put them at any more risk than a single-use model, and that, as tempting as it may be to let all our efforts be consumed by one prevailing issue, it is important not to neglect environmental health.

In terms of the public's engagement with reusable PPE, guidelines for correct donning and doffing of reusable PPE masks would be similar to that of single-use masks. Reusable PPE masks would, however, require a different method of 'disposal'. Instead of discarding PPE after single use, reusable masks would need to be safely stored in a separate container/laundry bag until it is put in the washing machine for laundering. These items can be safely laundered, in accordance with the manufacturer's instruction, after use. If washing items that are likely to cause illness (high-risk), the NHS recommends that they should be washed at 60°C with a bleach-based product (NHS, 2020).

There are concerns that use of masks could lead to complacency amongst the public. Masks are not an adequate replacement for good hand hygiene and distancing from others. Any public campaign should stress the importance of hand hygiene and physical distancing. It is vital that this is highlighted and communicated effectively to the public.

Single-use PPE undoubtedly has its place, particularly as an immediate measure to protect those at the greatest risk of infection. However, any wide-scale public policies that are implemented during this crisis will have serious long-term ramifications, not only for public health but the health of the natural environment. It is imperative that policies that impact on citizens are based on empirical evidence, the careful analysis of data, the advice of experts, and a holistic consideration of the possible unintended consequences, both now and in the future.

Acknowledgements

This work was funded by the EPSRC and UKRI under grant EP/S024883/1 and carried out at the UCL Plastic Waste Innovation Hub. The analysis that defines the types and anatomy of masks was carried out by Dragana Dobrijevic and Miguel Casas Arredondo. The analysis of the evidence of the effectiveness of face masks for preventing the spread of COVID-19 was carried out by Dragana Dobrijevic and Charnett Chau. The role of mask wearing in government exit strategies was carried out by Maria Bawn and Esther Ambrose-Dempster. The LCA analysis was carried out by Charnett Chau, Miguel Casas Arredondo, and Paola Lettieri. The behaviour change analysis was carried out by Ayşe Lisa Allison and Chao Liu. The whole team contributed to the writing of the report, the conclusions and the recommendations. The report was edited and compiled by Kimberley Chandler and Mark Miodownik. We would like to thank Jenny Bird and Rita Goncalves De Pinho from the Policy Unit, UCL STeAPP for their input. We would like to thank Andrea Paulillo, Fabio Grimaldi and Martina Pucciarelli from the Lettieri's LCA Group.

Declaration and Conflicts of Interest Statement

The authors declare no conflicts of interest with this work.

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Appendix 1: A LCA comparison between single-use and reusable face masks in the UK

Background

Many countries have introduced the mandatory use of face masks as a non-clinical intervention to reduce the spread of SAR-Cov-2. There is no legislation in the UK that mandates the use of such products, but a proportion of the public has already adopted this practice. However, a rise in single-use face mask littering has been observed, leading to environmental concerns over their use. A material flow analysis (MFA) analysis carried out (to complement this policy briefing) suggests that if single-use face masks were widely used by UK-citizens, then this will amount to 48kt of plastic (66kt total waste) that would need to be disposed of annually. Although the literature states that, in a clinical setting, single-use face masks are currently more effective than reusable ones; some experts have suggested that, for general use, reusable masks are just as adequate at preventing transmission when used correctly (Lai, Poon, and Cheung, 2012; MacIntyre et al., 2020). Reusable face masks can potentially reduce the amount of resultant waste, but, due to differences in material composition, and the cleaning processes necessary for reusable face masks, a trade-off in environmental impacts may arise. In addition, some reusable face masks can be complemented with single-use filters to offer greater air filtration. This may reduce the resultant waste from using single-use face masks, but equally, a high amount of waste for disposal can be foreseen. This study aims to understand the environmental impacts of both single-use and reusable face masks if they are nationally adopted in the UK.

Goal

To compare the environmental impacts of using single-use and reusable face masks nationally to prevent the transmission of infection in the UK.

Scope

Five scenarios for the public use of face masks were analysed in this comparative study:

Table A1 Summary of scenarios compared in the comparative study.

Scenario Number	Mask Type	Mask Use per Day	Number of Masks per Person per Year	Addition Filters	Number of Filters per Person per Year	Mask Treatment	Filter Treatment
1	Single-use	1	365	No	0	Disposed at the end of day.	N/A
2	Reusable	1	2	No	0	Manual washing	N/A
3	Reusable	1	2	Yes	365	Manual washing	Disposed at the end of day.
4	Reusable	1	4	No	0	Machine washing	N/A
5	Reusable	1	4	Yes	365	Machine washing	Disposed at the end of day.

The **functional unit** (FU) employed for the analysis is one year of face mask usage, and one face mask used per person per day. The number of face masks and filters required to support use in this period was calculated according to the UK's population (Table A2). The use of one face mask per day may be deemed optimistic, since the number of face masks necessary is dependent on an individual's behaviour. However, the environmental impact difference between the different scenarios remains relative. A scaling factor can be applied to the environmental impact results to reflect the actual affects if, on average, more than one face mask is used.

Table A2: Number of face masks and filters required to support face mask usage in the UK for one year. The assumed UK population was 67.8 million (Worldometer, 2020).

Scenario Number	Mask Type	Functional Unit / Time Frame	Number of Masks	Number of Filters
1	Single-use	1 year	24.7 billion	N/A
2	Reusable	1 year	136 million	N/A
3	Reusable	1 year	136 million	24.7 billion
4	Reusable	1 year	271 million	N/A
5	Reusable	1 year	271 million	24.7 billion

A cradle-to-grave study approach was used for this comparison. The scope of the study included the material sourcing of the face masks, transport to the manufacture facility, the manufacture of face masks, transport to the UK, face mask distribution nation-wide, and face mask use and final disposal (Figure A1).

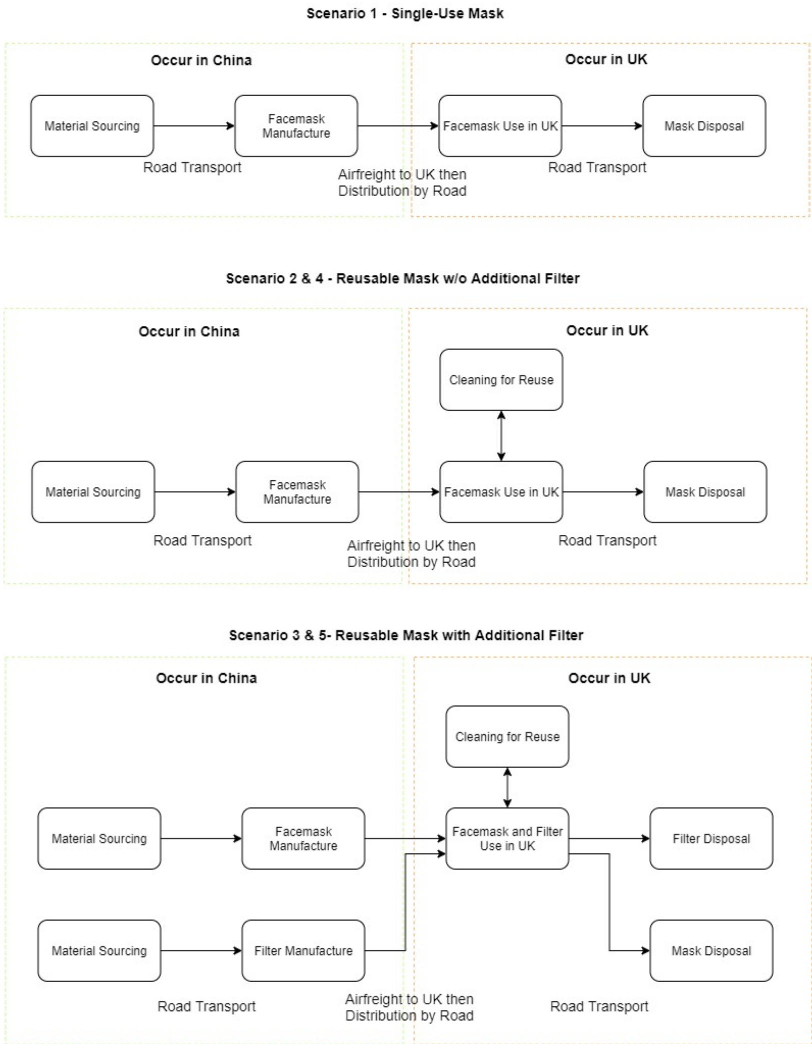

Figure A1: Cradle-to-grave system boundary for each facemask use scenario.

Manufacturing assumptions

It was assumed that the face masks (both single-use and reusable) and filters were manufactured in China before being transported by airfreight to the UK. The materials and energy assumed to be required for the major manufacturing process of face masks and filters are summarised in Table A3 and Table A4. For all five scenarios, the arising waste and treatment of waste from manufacturing was not modelled due to limited data. Their impact was also assumed to be relative amongst the scenarios. The emissions associated with the life cycle of factory machines were also not modelled. This was because installed equipment is assumed to have a long lifespan, thirty years on average (Erumban, 2008). The emissions and environmental impacts associated with the fabrication and decommission of equipment would be allocated proportionally over their lifespan, and was, therefore, assumed to be negligible.

Table A3: Material of construction and mass used to model each product.

Product / Component	Material	Area (m2)	Length (m)	Mass (g)	Source / Reference
(S1) Single-Use Mask					
Layer 1	PP (non-woven)	0.029	-	0.638	95mask, (2020) and Thomasnet (2020) provided the components and dimensions of a surgical mask.
Layer 2	Cellulosic fabric	0.029	-	0.725	
Layer 3	PP (non-woven)	0.029	-	0.638	
Nose Wire	HDPE	-	0.098	0.231	
Ear Loops	Polyetherimide (elastic material)	-	0.185 (each)	0.444	
Total				2.68	
(S2) Reusable Mask					
Layer 1	Cotton fabric	0.039	-	6.98	CDC, (2020) provided the dimensions of fabric required.
Layer 2	N/A	-	-	-	
Layer 3	Cotton fabric	0.039	-	6.98	
Nose Wire	N/A	-	-	-	
Ear Loops	Polyetherimide (elastic material)	-	0.185	0.444	
Total				14.4	
(S3) Single-Use Filters					
Layer 1	PP (non-woven)	0.0096	-	0.211	Product dimensions taken from product specification from Amazon.co.uk. Materials assumed similar to single-use masks.
Layer 2	Cellulosic fabric	0.0096	-	0.241	
Layer 3	Carbon filter (activated carbon)	0.0096	-	0.288	
Layer 4	Cellulosic fabric	0.0096	-	0.241	
Layer 5	PP (non-woven)	0.0096	-	0.211	
Total				1.19	

Table A4: Electricity assumptions for the manufacture of masks and filters

Product / Component	Electricity Consumption (kWh/1000mask)	Reference Values	Assumption / Reference
Single-Use Mask			
Mask Body Forming	0.556	4 kW, 110 – 160 pcs/min	Reference values were taken from Testex, (no date) website on surgical mask production line. It was assumed the thorough put of mask was 120pc/min (240pc/min of ear loops)
Ear Loops Cutting	0.694	0.5 kW, 120 – 240 pcs/min	
Ultrasonic Welding	0.167	1.2 kW	
Total	0.792		
(Total per FU)	(19.6GWh)		
Reusable Mask			
Laying, Cutting and Sewing	34.2	2.38 kWh/kg	(Moazzem *et al.*, 2018)
Total	34.2		
(Total per FU)	(4.64GWh)		

Single-Use Filters **Filter Body Forming** **Total** **(Total per FU)**	 0.556 0.556 (13.7GWh)	 4 kW, 110 – 160 pcs/min	 Assumed similar production to single-use masks (above)

Packaging assumptions

Packaging configurations were assumed based on product specifications shown on retailers' websites (Amazon, 2020; LANS Grupo, 2020). Table A5 details the assumptions made in calculating the packaging weight of each packaging component.

Table A5: Packaging assumptions for each scenario.

	Packaging Configuration	Component / Material	Component Weight (kg)	Total Mass per FU (kt)	Assumptions / Reference
S1 – Single-Use Facemask	50pcs/box 40boxes/carton (2000pcs/carton)	Box – Cardboard Carton – Cardboard	0.0535 2.50	1060 30.9	LANS Grupo, (2020) provided dimensions and weight of each packaging component.
S2 – Reusable Facemasks, Manually Washed (2 masks per person)	Individually wrapped 1500pcs/carton	Wrap – LDPE Carton - Cardboard	0.00335 2.50	0.454 0.226	0.09m^2 surface area and 40 micron thickness of LDPE sheet was assumed to provide the weight per component. Assumed same size carton used, number of pcs per carton was calculated based on facemask surface area differences.
S3 – Reusable Facemasks, Manually Washed, with Single-Use Filters (2 masks per person)	Masks individually wrapped 1500pcs/carton Filter wraps in packs of 10 6000pcs/carton	Wrap – LDPE Carton - Cardboard Wrap – LDPE Carton – Cardboard	0.00335 2.50 0.00186 2.50	0.454 0.226 4.6 10.3	0.05m^2 surface area and 40 micron thickness of LDPE sheet was assumed to provide the weight per component. Assumed same size carton used, number of pcs per carton was calculated based on facemask surface area differences.
S4 – Reusable Facemasks, Machine Washed (4 masks per person)	Individually wrapped 1500pcs/carton	Wrap – LDPE Carton - Cardboard	0.00335 2.50	0.454 0.226	(As Scenario 2)
S5 – Reusable Facemasks, Machine Washed, with Single-Use Filters (4 masks per person)	Masks individually wrapped 1500pcs/carton Filter wraps in packs of 10 6000pcs/carton	Wrap – LDPE Carton - Cardboard Wrap – LDPE Carton – Cardboard	0.00335 2.50 0.00186 2.50	0.908 0.452 4.6 10.3	(As Scenario 3)

Transport assumptions

Both face mask types were assumed to have been manufactured in China before being distributed in the UK, with transport assumptions shown in Table A6.

Table A6: Transport assumptions for masks and filters for all scenarios.

	Mode of Transport	Distance (km)	Notes
Materials to Manufacturing Facility & Facility to Terminal	Truck	100	Assumed materials sourced locally
China to UK	Air Freight	7800	(Entfernungsrechner, 2020)
Mask Distribution	Truck	1000	Assumed distribution start from one UK Terminal
Mask and Filters to Disposal Sites	Truck	100	Assumed local authority collection for disposal

Reuse assumptions

MacIntyre et al., (2020) have recommended using at least two face masks in rotation to allow for adequate cleaning and drying before use. It is acknowledged that the number of reusable masks used in rotation per person depends on personal preference and economic feasibility. Hence, scenarios where two and four face masks are employed per person were both modelled. Due to the frequency of washing necessary, it was assumed that, with two face masks, manual washing is necessary. With four masks, it was assumed that households could bulk wash their face masks with the usual laundry, and therefore machine washing is possible (explanation of assumptions below).

The International Scientific Forum on Home Hygiene has published a report on the infection risks associated with clothing (Bloomfield et al., 2011). It states that laundering processes will eliminate contamination from fabric and linen materials. For this study, an average household soap/detergent was assumed sufficient for cleaning face masks.

Manual washing (Scenarios 2 and 3): The study assumed that each face mask is washed every two days, due to being used in rotation. Hence, each reusable face mask is modelled to be washed 183 times per FU (one-year timeframe). Because frequent washing would be required, manual washing of face mask was assumed. Ariel's guide on hand washing recommends using a teaspoon (approximately 6ml (6.24g)) of liquid detergent in a tub of slightly warm water. Once the garment has been cleaned with the mixture, it should be rinsed in a tub of detergent-free water (Ariel, 2020). The tub volume was not mentioned, but this was assumed to be a 5L-washing bowl filled to 3L level.

The Office for National Statistics (2017) states that an average household comprises 2.4 people. Therefore, it was assumed that 2.4 masks could be washed together. Hence, each mask requires 2.6g of detergent and 2.5L of water per wash. It was assumed that hot water from household taps is typically heated up to 60°C by gas boilers (Energy Saving Trust, 2013). The total requirements for mask cleaning are shown in Table A7.

Table A7: Requirements for the manual washing of face masks for Scenarios 2 and 3.

Cleaning Components	Per Mask Per Wash	Per Mask Per Year (183 Washes)	Total per FU
Soap	2.6g	476g	62.1kt
Water	2.5L	458L	6.21×10^{10}L
Steam	407kJ (Q = mcdT = 2.5kg x 4.186kJ/kg x (60°C -21°C))	74.5MJ	10.1PJ

Machine washing (Scenarios 4 and 5): This study assumed that, within an average household comprising 2.4 people, there would be sufficient laundry for a full machine wash every three days (if garments from each household member were pooled). One wash every three days means that each face mask is washed 122 times in one year (FU). Walser et al.

(2011) evaluated the environmental impact of t-shirts, with consideration for the "low", "medium," and "high" environmental awareness of their wearers, which influences the choice of washing machine category, the quantity of detergent used, and the temperature of the wash. Acknowledging that the ability to own a highly efficient washing machine is also dependent on household income, it was assumed that the "medium" scenario is more probable for the UK public. Hence, this study used the parameters assumed by Walser et al. (2011) in their "medium" scenario (Table A8), a 40°C full-load wash, to allocate the amount of cleaning resources required to clean each face mask.

Table A8: Requirements for the machine-washing of facemasks for Scenario 4 and 5.

Cleaning Components	**Per Machine Wash of 6 Kg Load** (Walser *et al.*, 2011)	**Per Mask Per Wash**	**Per Mask Per Year (122 Washes)**	**Total per FU**
Soap	67.5g	0.162g	19.7g	5.34kt
Water	49L	0.117L	14.3L	3.88 x10^9 L
Electricity	0.66kWh	1.58Wh	0.192kWh	52.2GWh

Disposal assumptions

All waste arising from the use of face masks was modelled for disposal through landfill and/or incineration: 43% landfill, 41% incineration with energy recovery, and 16% incineration only. This was based on UK statistics on waste supplied by the Department for Environment, Food & Rural Affairs [Defra] (2019). Landfill and incineration were chosen as the disposal methods, because these are the typical waste destinations for household waste. Single-use face masks and filters are not currently recycled, while textiles are currently unlikely to be recycled. Although packaging can be recycled, plastic film packing, modelled as wrapping for reusable and single-use filters, is not conventionally recycled. Cardboard is widely recycled; however, this was not modelled due to insufficient data from GaBi (PE International, 2006) and EcoInvent databases (Ecoinvent, 2019).

For Scenarios 2 to 5, all face masks were modelled for disposal after one year of use. There is no data available on how long each reusable face mask can last; data is required to understand the usability of face masks after frequent washes. It was assumed that the life of each face mask would be similar. In Scenarios 2 and 3, the face masks are washed more frequently than in Scenarios 4 and 5; however, manual washing is typically recommended for delicate garments, because it is more gentle on the fabric.

Results

The comparative study was modelled on GaBi Software (Thinkstep, 2019), the life cycle impact assessment (LCIA) method used to assess each scenario's environmental impact was the Environmental Footprint (EF) 3.0 methodology (Zampori and Pant, 2019). Both the life cycle inventory (LCI) analysis and LCIA were carried out, and compared across the different scenarios. The LCI analysis showed that the use of reusable face masks significantly reduces the amount of waste entering the general waste stream (Table A9). Due to packaging requirements, the total waste accumulated from using single-use face masks nationally amounts to 124,000 tonnes. If single-use filters are used in addition to reusable face masks, then the amount of waste is 60% less than using single-use face masks. There is over 95% reduction in waste if only reusable face masks are used.

Table A9: Waste arising due to face mask use in the UK for one year.

	S1 - Single-Use Masks	S2 - Reusable Masks, Manually Washed, w/o Filter	S3 - Reusable Masks, Manually Washed, w/ Filters	S4 - Reusable Masks, Machine Washed, w/o Filter	S5 - Reusable Masks, Machine Washed, w/ Filters
Waste Arising per FU (kt)					
Masks	66.2	1.95	1.95	3.90	3.90
Filters			29.5		29.5
Packaging	57.4	0.680	15.6	1.36	16.3
Total	**124**	**2.63**	**47.0**	**5.26**	**49.6**

A summary of environmental impact results is presented in Table A10. The results show that Scenario 4, in which four face masks are employed per person (without single-use filters) and are machine-washed, generated the lowest environmental impact in all impact categories, except the impact associated with water usage. The results also showed that when reusable face masks are employed without the additional use of single-use filters, whether they are washed manually or by machine, a lower environmental impact is generated overall. The use of single-use filters with reusable face masks is observed to be environmentally beneficial when compared to single-use face masks, if the masks are machined washed (Scenario 5).

Table A10: Overall environmental impact results for each face mask scenario. Green indicates the lowest results generated; red indicates the highest results generated.

	Scenario 1 - Single-Use Masks	Scenario 2 - Reusable Masks (Manual Washing)	Scenario 3 Reusable Mask with Single-Use Filters	Scenario 4 - Reusable Masks (Machine Washing)	Scenario 5 - Reusable Masks with Single-Use Filters (Machine Washing)
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	6.27E+06	1.95E+06	4.37E+06	1.00E+06	3.43E+06
EF 3.0 Cancer human health effects [CTUh]	6.10E-01	3.88E-01	6.27E-01	1.39E-01	3.78E-01
EF 3.0 Climate Change [kg CO2 eq.]	1.47E+09	8.88E+08	1.53E+09	1.71E+08	8.16E+08
EF 3.0 Ecotoxicity freshwater [CTUe]	1.56E+10	9.35E+09	1.50E+10	3.35E+09	9.00E+09
EF 3.0 Eutrophication freshwater [kg P eq.]	4.94E+04	5.53E+04	7.23E+04	1.53E+04	3.23E+04
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	8.05E+07	1.60E+07	5.19E+07	1.28E+07	4.87E+07
EF 3.0 Land Use [Pt]	4.68E+09	8.19E+09	1.01E+10	3.16E+09	5.08E+09
EF 3.0 Non-cancer human health effects [CTUh]	7.63E+00	8.88E+00	1.24E+01	5.85E+00	9.42E+00
EF 3.0 Ozone depletion [kg CFC-11 eq.]	2.60E+02	1.92E+01	1.13E+02	1.41E+01	1.08E+02
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	6.10E+06	1.25E+06	3.62E+06	5.57E+05	2.93E+06
EF 3.0 Resource use, energy carriers [MJ]	2.15E+10	1.29E+10	2.23E+10	2.26E+09	1.17E+10
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	4.87E+02	7.04E+02	9.50E+02	2.14E+02	4.60E+02

EF 3.0 Respiratory inorganics [Disease incidences]	3.23E+01	2.77E+01	4.02E+01	1.66E+01	2.92E+01
EF 3.0 Water scarcity [m³ world equiv.]	1.40E+08	3.26E+09	3.31E+09	7.53E+08	8.04E+08

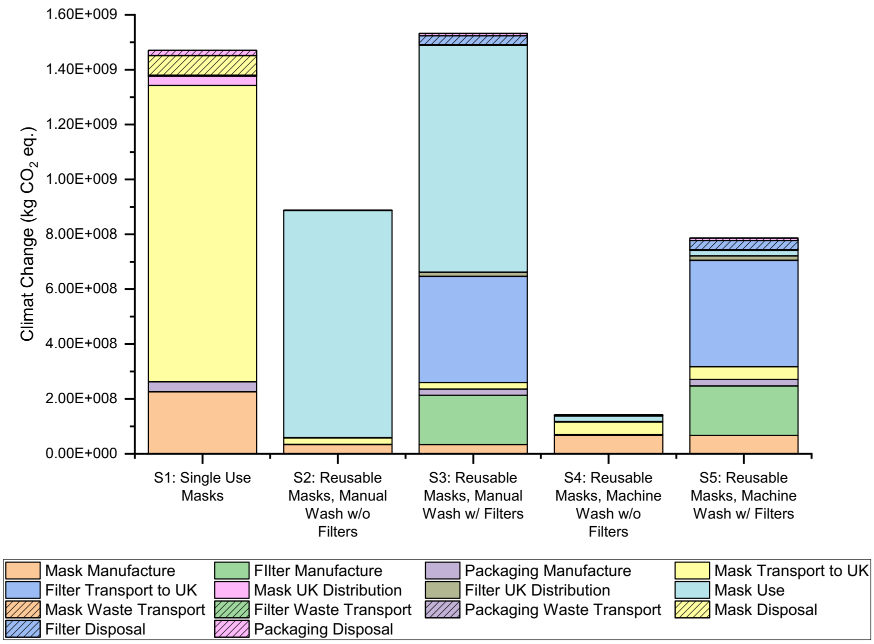

Figure A2: Climate change results generated for each scenario of facemask use.

Figure A2 highlights the hot-spot analysis carried out on the Climate Change results generated by each scenario. It shows that the transportation of single-use face masks (Scenario 1) contributed most to this impact category. This is attributed to the large number of face masks required, and, therefore, an increased level of transportation is necessary, when compared to reusable face masks, to supply to the whole UK population for a year. The contribution of Mask Manufacture is also significantly higher in Scenario 1, due to the higher quantity of masks required. For Scenarios 2 and 3, the highest contributor to Climate Change is the cleaning of masks for reuse; the thermal energy required to supply hot tap water represents over 70% of Scenario 2’s impact. In Scenario 4, it generated the lowest impact overall, even though a higher number of masks is required than in Scenarios 2 and 3. This suggests that having a higher number of masks in rotation, to allow for machine washing (Scenarios 4 and 5), is more environmentally beneficial than manual washing (Scenarios 2 and 3).

The results show that the use of reusable face masks can be environmentally beneficial when compared to using single-use face masks (Table A9); however, all reusable face mask scenarios are associated with substantial amounts of water usage. Figure A4 illustrates the processes that contribute to Water Scarcity. Reusable face mask manufacture (Scenarios 2-5) contributed highly to this impact category, when compared to the manufacture of single-use face masks. This is attributed to the high water requirements of the textile industry for producing cotton fabric. The most significant impact on water scarcity is manual washing of face masks (Scenarios 2 and 3). This caused the value generated by S2 and S3 to be two orders of magnitude larger than S1.

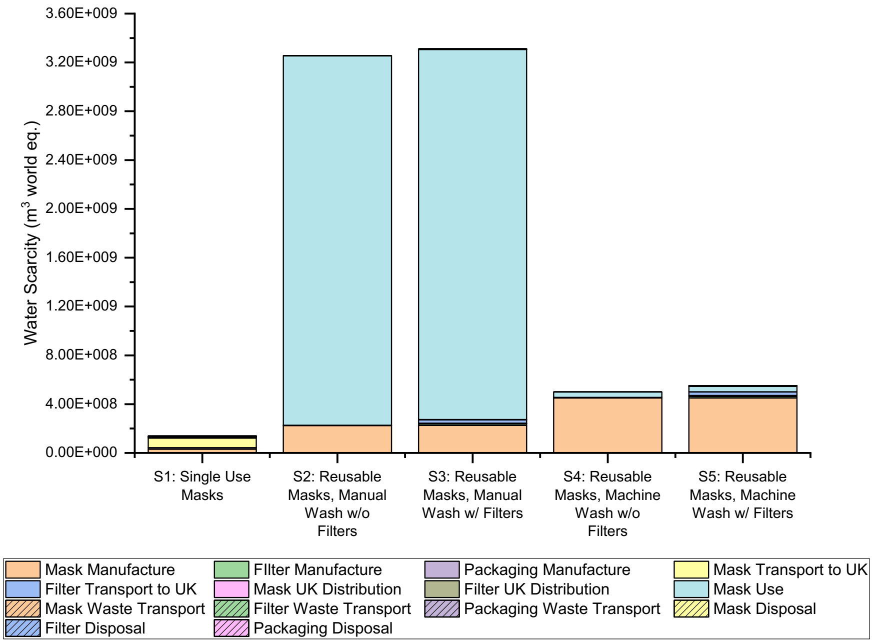

Figure A3: Water Scarcity results generated by each facemask scenario.

Further study on single-use mask manufacture

The hot-spot analysis showed that for Scenario 1 (Single-use face mask), the largest contributor to the environmental impact categories was Mask Transport. This suggests that if the manufacture of single-use face mask is relocated, then the overall impact associated with single-use face masks will be reduced. China was modelled as the manufacturing location for single-use face masks, because it is the biggest supplier of this product. The study therefore presents a realistic representation of the environmental impacts, if single-use face masks are to be employed for everyday use in the UK. However, to combat the shortage of single-use face mask supply, textile companies have begun to convert their production lines to enable the production of face masks. This means the supply chain of face masks may change in the future.

Table 3: Further modelling of Scenario 1 with changes made to production location and hence, supply distances.

Scenarios	Materials Sourcing	Mode of Transport to Plant / Distance	Model of Transport to UK Terminal / Distance	Justifications / Reference
S1a- Single-use Masks Manufacture in Turkey	For Mask & Packaging : Turkey	Truck / 100km	Truck / 3500km	Distance from Turkey to UK, assumed production plant situate in Istanbul and delivered to Dover (approx. 3000km (Google, 2019)). Addition 500km was added to reflect transport to a distribution point.
S1b Single-use Masks Manufacture in UK (1)	For Masks: China For Packaging: UK	Airfreight / 7800km Truck / 500km Truck / 100km	N/A	Transport distance from China assumed as Table 6. Addition 500km was added to reflect transport to a distribution point.
S1c - Single-use Masks	For Masks: Turkey For Packaging: UK	Truck / 3500km Truck / 100km	N/A	Transport distance from Turkey assumed as above.

Manufacture in UK (2)				

Scenario 1 was further modelled to stipulate future supplies of single-use face masks (Table 11). Two manufacturing locations were modelled: Turkey (Scenario S1a), and the UK (Scenarios S1b and S1c). Turkey was assumed to be a viable location for the production of single-use face masks, because it is the second biggest supplier of textiles after China (Euratex, 2018), and one of the biggest producers of non-woven products in Europe (Edana, 2019). Furthermore, Triton Market Research (2020) showed that major companies that produce polypropylene (PP) non-woven products include those manufactured in Turkey. Hence, the material required to produce face masks in Turkey was assumed to have been locally sourced.

According to market data from the Organisation for Economic Co-operation and Development (OCED, 2019) and Edana (2019), the UK is one of the main importers of non-woven textiles. Hence, it is deemed likely that the UK will need to import these materials in order to manufacture single-use face masks. Thus, if face mask production is relocated to the UK, then although the emissions associated with importing the product are eliminated, there will be emissions associated with importing raw materials. Since China and Turkey are the largest suppliers of textiles (Euratex, 2018), it was assumed that the UK will import the materials necessary for face mask production from either countries. Scenarios S1b and S1c were modelled to explore the potential range of environmental impacts associated with producing in the UK (Table 11).

For Scenarios S1a to S1c, it was assumed that packaging for face masks is manufactured locally. This is because cardboard is largely produced in both Turkey and the UK (FEFCO, 2018).

Further results

A summary of the environmental impact results generated from modelling single-use face mask production (from Scenario 1) in Turkey and the UK are highlighted in Table 12. The results were compared to the impacts generated by Scenario 1, where single-use face masks are manufactured in China, and Scenario 4, where reusable face masks (manufactured in China) are used in rotation and machine-washed. Results show that, by relocating single-use face mask production from China to Turkey and the UK, the environmental impacts will reduce by 39.4%, if the UK manufactures face masks but imports materials from China. In addition, over 81% reduction can be generated if materials are sourced from Turkey, and manufactured in either Turkey or the UK. However, Scenario 4 continues to have the lowest impact towards most environmental impact categories; this includes Climate Change, Ecotoxicity, and Resource Use.

Table 4: Overall environmental impact results for the new single-use facemasks supply scenarios compared to Scenario 4 (Use of 4 Reusable Masks in Rotation & Machine-washed). Green indicates the lowest results generated; red indicates the highest results generated.

	S1 - Single-Use Masks, Manufactured China	S4 - Reusable Masks, Machine-Washed, Manufactured in China	S1a - Single-Use Masks, Manufactured in Turkey	S1b - Single-Use Masks, Manufactured in UK (Materials from China)	S1c - Single-Use Masks, Manufactured in UK (Materials from Turkey)
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	6.27E+06	1.00E+06	1.18E+06	3.80E+06	1.02E+06
EF 3.0 Cancer human health effects [CTUh]	6.10E-01	1.39E-01	1.16E-01	3.74E-01	1.15E-01
EF 3.0 Climate Change [kg CO2 eq.]	1.47E+09	1.71E+08	4.04E+08	9.68E+08	4.08E+08
EF 3.0 Ecotoxicity freshwater [CTUe]	1.56E+10	3.35E+09	8.05E+09	1.47E+10	1.07E+10
EF 3.0 Eutrophication freshwater [kg P eq.]	4.94E+04	1.53E+04	2.59E+04	4.93E+04	3.72E+04
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	8.05E+07	1.28E+07	9.10E+06	5.34E+07	1.59E+07
EF 3.0 Land Use [Pt]	4.68E+09	3.16E+09	3.08E+09	4.45E+09	3.71E+09
EF 3.0 Non-cancer human health effects [CTUh]	7.63E+00	5.85E+00	4.28E+00	6.06E+00	4.44E+00
EF 3.0 Ozone depletion [kg CFC-11 eq.]	2.60E+02	1.41E+01	1.64E+01	1.49E+02	1.97E+01
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	6.10E+06	5.57E+05	8.37E+05	3.64E+06	8.45E+05
EF 3.0 Resource use, energy carriers [MJ]	2.15E+10	2.26E+09	6.43E+09	1.46E+10	6.68E+09
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	4.87E+02	2.14E+02	4.17E+02	4.77E+02	4.52E+02
EF 3.0 Respiratory inorganics [Disease incidences]	3.23E+01	1.66E+01	1.39E+01	2.06E+01	1.27E+01
EF 3.0 Water scarcity [m³ world equiv.]	1.40E+08	7.53E+08	7.02E+07	1.03E+08	6.27E+07

Hot-spot analyses were carried out on the Climate Change results for Scenario 1a to 1c, and were compared with all the other face mask use scenarios. Figure 4 shows that the emissions associated with Mask Transport to the UK iare significantly reduced by relocating single-use face mask manufacturing to Turkey. It also illustrates that the impacts generated from Mask Manufacture for Scenarios 1, 1a, and 1c are similar, and are lower than in Scenario 1b. Further analysis showed that the difference in Mask Manufacture results (for Scenario 1 and the sub-scenarios) is dependent on the delivery of materials for face mask production. Scenario 1b assumed that the materials would be sourced and imported from China. This showed that the transportation of materials to the UK by airfreight contributes 71.3% towards the Mask Manufacture Climate Change value (57.9% of total impact). The materials transport for face mask manufacture contributed 0.193%, 0.201%, and 8.98% towards the Mask Manufacture Climate Change results for Scenarios 1, 1a, and 1c respectively.

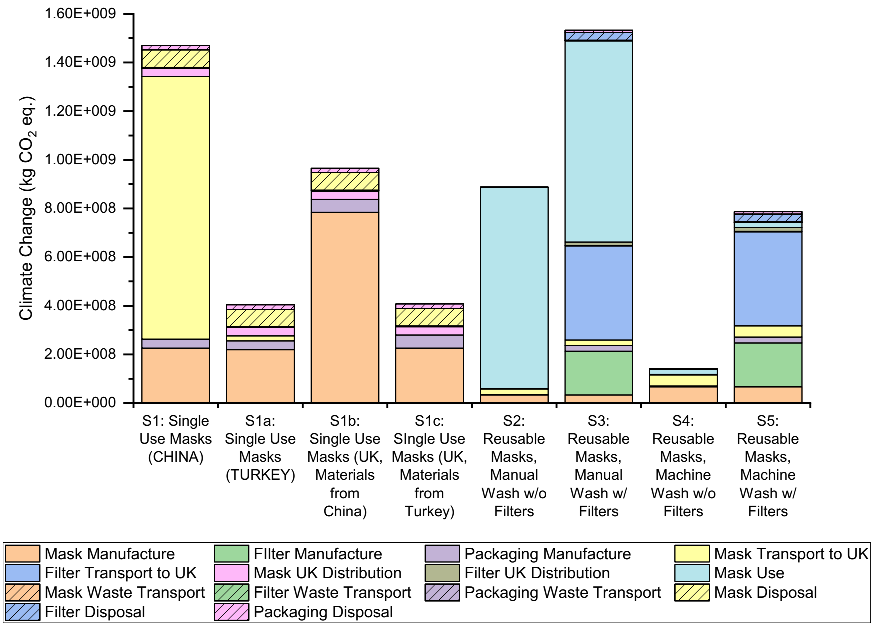

Figure 2: Climate change results generated for each scenario of facemask use and single-use facemask supply.

Figure 4 also suggests that if single-use face masks are manufactured in Turkey and the UK (with materials sourced in Turkey), then machine washing reusable face masks (Scenario 4) is the only scenario where reusable masks are environmentally preferable for UK-wide use. The manual washing of face masks without the use of single-use filters (Scenario 2) and the machine-washing of face masks with the use of single-use filters (Scenario 5) are only preferable to single-use face masks if the materials are supplied from China.

Limitations & discussion

The comparative study explored the environmental impact differences between using a face mask that designed to be disposed of after one use with different scenarios in which face masks are designed to be washed and reused. The reusing of single-use face masks was not analysed. This is because there are currently no protocols for reusing face masks designed to be used once. Hence, not all face mask use scenarios were explored as part of this study. Equally, a limitation of this comparative study is the washing of face masks. Different techniques may be employed at individual households; for instance, cold washing and other machine-washing techniques. It is acknowledged that cold washing will reduce the thermal energy use to heat water in Scenarios 2 and 3; however, the current guidelines for eliminating viruses suggest the use of hot water and soap. More data is needed about the effectiveness of using cold water and soap for removing viruses before this recommendation can be made.

In Scenarios 2 to 5, each face mask requires over 120 washes during one year of use. It is acknowledged that the products may not withstand this amount of washing. Walser et al. (2011) discussed the life of t-shirts and stated that if a garment is washed with low efficacy then its life is twenty washes, fifty washes for medium efficacy, and 100 washes for high efficacy. If a face mask has a life of 20 washes, then 18 masks are necessary for one full year of face mask use.

Further analysis was carried out on Scenario 4 to understand the environmental impact of additional supplies of masks. Assuming that the total amount of machine washes per year stays constant and filters continue to not be used, then up to forty-eight reusable face masks (forty-four additional masks) can be supplied per person before the impact on Climate Change exceeds the generated value for Scenario 1. Table A11 highlights the maximum number of reusable masks per person for all other environmental impact categories, and the average limit is calculated to be twenty-five. Thus, depending on which impact category is of most interest, an additional twenty-one masks can be supplied over one year of mask use, such that Scenario 4 retains its environmental superiority over Scenario 1 (single-mask use). With twenty-five masks, this reduces the amount of washing per mask to fifteen washes, which is below the lower bound of a t-shirt life stated by Walser et al. (2011).

Table A11: The maximum number of reusable masks in use per person per year (without additional filter-use) before the environmental impact exceeds the generated value of using single-use masks (Scenario 1)

Impact Category	Number of Reusable Masks per Person
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	30
EF 3.0 Cancer human health effects [CTUh]	24
EF 3.0 Climate Change [kg CO2 eq.]	48
EF 3.0 Ecotoxicity freshwater [CTUe]	30
EF 3.0 Eutrophication freshwater [kg P eq.]	20
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	59
EF 3.0 Land Use [Pt]	8
EF 3.0 Non-cancer human health effects [CTUh]	5
EF 3.0 Ozone depletion [kg CFC-11 eq.]	82
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	53
EF 3.0 Resource use, energy carriers [MJ]	54
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	14
EF 3.0 Respiratory inorganics [Disease incidences]	8
EF 3.0 Water scarcity [m^3 world equiv.]	N/A
Average	**25**

Single-use face masks were modelled as being manufactured in China, Turkey, and the UK, in order to explore the potential reduction in environmental impacts if production was relocated away from China. Reusable face masks (Scenario 2 to 5) were also assumed to be imported from China, but their production in Turkey or the UK was not modelled. This was because the environmental impact results for reusable Mask Manufacture and Mask Transport to the UK were over 70% lower than those generated for single-use face masks (Scenario 1) for most impact categories. However, there is advice available on how to make reusable face masks at home, and therefore the manufacture of face masks in China may not be necessary. This can reduce the overall environmental impact of all reusable face mask scenarios, especially if masks are made with waste clothing.

The manufacturing waste that would arise and the associated waste disposal treatments were not modelled in this comparative study, due to the limited data available. However, the percentage contribution of mask waste disposal towards each impact category is low for all scenarios (average percentage contribution <1%) (Appendix). From this, it was inferred that the percentage contribution from manufacturing waste treatment should be negligible.

Lastly, this study assumes that every face mask scenario has an equal functionality in preventing the transmission of infection. The effectiveness of face mask use cannot be evaluated using life cycle assessment. A highly developed review by MacIntyre and Chugtai (2015) suggests that the effectiveness of face masks in providing protection against infections is subject to compliance, complementary interventions, and early use. Thus, although reusable face masks are said to be less effective in a high-risk setting, when used as a precautionary intervention in conjunction with social distancing and regular hand washing, it should have the same effect as single-use face masks.

Conclusion

The comparative study results show that using a higher number of reusable face masks, in rotation to allow for machine washing, is the most favourable method of using face masks from an environmental perspective. The use of filters with reusable face masks is discouraged, but can generate a lower environmental impact when compared to single-use face masks, if face masks are machine-washed.

Currently, sourcing materials and face masks from China is deemed the most realistic option. However, analyses show that if the manufacture of single-use face masks can be relocated to Turkey and the UK, then the environment impact of using of single-use masks in the UK will reduce, but using reusable face masks in rotation and machine washing them (Scenario 4) is still preferable for the environment.

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Appendix 2: Supplementary Information on the Process Contribution of Different Facemask Scenarios

Table A15: Stage contribution to each environmental impact category for Scenario 1 – Using Single-Use Masks in the UK (Manufactured in China)

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	11.35%	0.00%	2.68%	84.31%	0.00%	1.59%	0.00%	0.00%	0.02%	0.00%	0.02%	0.03%	0.00%	0.10%
EF 3.0 Cancer human health effects [CTUh]	12.52%	0.00%	4.39%	80.79%	0.00%	2.44%	0.00%	0.00%	0.01%	0.00%	0.01%	-0.17%	0.00%	-0.01%
EF 3.0 Climate Change [kg CO2 eq.]	15.56%	0.00%	2.53%	74.38%	0.00%	2.34%	0.00%	0.00%	0.12%	0.00%	0.11%	4.96%	0.00%	1.28%
EF 3.0 Ecotoxicity freshwater [CTUe]	17.81%	0.00%	30.38%	50.16%	0.00%	2.56%	0.00%	0.00%	0.02%	0.00%	0.02%	-0.94%	0.00%	-0.27%
EF 3.0 Eutrophication freshwater [kg P eq.]	10.21%	0.00%	30.25%	51.15%	0.00%	7.63%	0.00%	0.00%	0.00%	0.00%	0.00%	0.76%	0.00%	0.40%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	11.18%	0.00%	2.14%	88.63%	0.00%	2.97%	0.00%	0.00%	0.00%	0.00%	0.00%	-4.92%	0.00%	-1.83%
EF 3.0 Land Use [Pt]	12.29%	0.00%	41.54%	41.96%	0.00%	5.11%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.90%	0.00%	-0.30%
EF 3.0 Non-cancer human health effects [CTUh]	41.32%	0.00%	7.98%	45.32%	0.00%	5.17%	0.00%	0.00%	0.04%	0.00%	0.03%	0.15%	0.00%	1.67%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	0.37%	0.00%	1.21%	95.62%	0.00%	2.80%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	9.45%	0.00%	1.89%	87.41%	0.00%	1.21%	0.00%	0.00%	0.02%	0.00%	0.02%	0.01%	0.00%	0.29%
EF 3.0 Resource use, energy carriers [MJ]	25.51%	0.00%	2.31%	70.92%	0.00%	2.35%	0.00%	0.00%	0.11%	0.00%	0.10%	-1.30%	0.00%	-0.82%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	26.80%	0.00%	14.07%	22.30%	0.00%	37.64%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.82%	0.00%	-0.32%
EF 3.0 Respiratory inorganics [Disease incidences]	30.34%	0.00%	10.11%	54.60%	0.00%	5.12%	0.00%	0.00%	0.02%	0.00%	0.02%	-0.21%	0.00%	0.01%
EF 3.0 Water scarcity [m^3 world equiv.]	23.68%	0.00%	8.24%	58.86%	0.00%	3.15%	0.00%	0.00%	0.00%	0.00%	0.00%	6.08%	0.00%	4.16%

Table A16: Stage contribution to each environmental impact category for Scenario 2 – Using Reusable Masks, Manually Washed in the UK

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	14.98%	0.00%	0.14%	5.75%	0.00%	0.15%	0.00%	78.92%	0.00%	0.00%	0.00%	0.06%	0.00%	0.00%
EF 3.0 Cancer human health effects [CTUh]	9.64%	0.00%	0.11%	2.71%	0.00%	0.11%	0.00%	87.42%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%
EF 3.0 Climate Change [kg CO2 eq.]	3.76%	0.00%	0.18%	2.58%	0.00%	0.11%	0.00%	93.24%	0.01%	0.00%	0.00%	0.12%	0.00%	0.06%
EF 3.0 Ecotoxicity freshwater [CTUe]	8.31%	0.00%	0.38%	1.78%	0.00%	0.13%	0.00%	89.40%	0.00%	0.00%	0.00%	-0.01%	0.00%	-0.01%
EF 3.0 Eutrophication freshwater [kg P eq.]	7.33%	0.00%	0.11%	0.97%	0.00%	0.20%	0.00%	91.38%	0.00%	0.00%	0.00%	0.02%	0.00%	0.01%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	6.87%	0.00%	0.31%	9.62%	0.00%	0.45%	0.00%	83.20%	0.00%	0.00%	0.00%	-0.45%	0.00%	-0.21%
EF 3.0 Land Use [Pt]	12.70%	0.00%	0.10%	0.51%	0.00%	0.09%	0.00%	86.61%	0.00%	0.00%	0.00%	-0.01%	0.00%	0.00%
EF 3.0 Non-cancer human health effects [CTUh]	26.13%	0.00%	0.14%	0.81%	0.00%	0.13%	0.00%	72.69%	0.00%	0.00%	0.00%	0.09%	0.00%	0.01%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	3.98%	0.00%	0.06%	27.58%	0.00%	1.12%	0.00%	67.26%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	8.51%	0.00%	0.21%	9.07%	0.00%	0.17%	0.00%	81.88%	0.00%	0.00%	0.00%	0.15%	0.00%	0.01%
EF 3.0 Resource use, energy carriers [MJ]	3.10%	0.00%	0.33%	2.53%	0.00%	0.12%	0.00%	93.98%	0.01%	0.00%	0.00%	-0.07%	0.00%	-0.02%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	8.02%	0.00%	0.15%	0.33%	0.00%	0.77%	0.00%	90.75%	0.00%	0.00%	0.00%	-0.01%	0.00%	0.00%
EF 3.0 Respiratory inorganics [Disease incidences]	24.35%	0.00%	0.11%	1.35%	0.00%	0.18%	0.00%	74.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Water scarcity [m³ world equiv.]	6.91%	0.00%	0.01%	0.05%	0.00%	0.00%	0.00%	93.02%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%

Table A17: Stage contribution to each environmental impact category for Scenario 3 – Using Reusable Masks with Single Use Filters, Manually Washed in the UK

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	6.68%	9.81%	1.23%	2.56%	43.40%	0.07%	1.01%	35.17%	0.00%	0.01%	0.01%	0.03%	0.02%	0.03%
EF 3.0 Cancer human health effects [CTUh]	5.97%	7.66%	1.37%	1.68%	28.16%	0.07%	1.06%	54.10%	0.00%	0.00%	0.00%	0.00%	-0.07%	-0.01%
EF 3.0 Climate Change [kg CO2 eq.]	2.19%	11.81%	1.49%	1.50%	25.41%	0.07%	0.99%	54.29%	0.00%	0.05%	0.03%	0.07%	2.10%	0.58%
EF 3.0 Ecotoxicity freshwater [CTUe]	5.18%	11.38%	7.09%	1.11%	18.72%	0.08%	1.18%	55.69%	0.00%	0.01%	0.01%	-0.01%	-0.44%	-0.13%
EF 3.0 Eutrophication freshwater [kg P eq.]	5.60%	4.68%	3.79%	0.74%	12.52%	0.15%	2.31%	69.96%	0.00%	0.00%	0.00%	0.02%	0.23%	0.09%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	2.11%	19.73%	1.52%	2.94%	49.67%	0.14%	2.06%	25.39%	0.00%	0.00%	0.00%	-0.14%	-3.41%	-1.11%
EF 3.0 Land Use [Pt]	10.31%	7.62%	3.61%	0.41%	6.98%	0.07%	1.06%	70.14%	0.00%	0.00%	0.00%	-0.01%	-0.19%	-0.06%
EF 3.0 Non-cancer human health effects [CTUh]	18.67%	15.54%	1.82%	0.58%	9.81%	0.09%	1.39%	51.99%	0.00%	0.01%	0.01%	0.07%	0.04%	0.19%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	0.68%	0.50%	0.51%	4.69%	79.12%	0.19%	2.87%	11.44%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	2.94%	10.62%	1.25%	3.13%	52.79%	0.06%	0.91%	28.23%	0.00%	0.01%	0.01%	0.05%	0.00%	0.09%
EF 3.0 Resource use, energy carriers [MJ]	1.79%	15.07%	2.41%	1.46%	24.58%	0.07%	1.01%	54.14%	0.00%	0.05%	0.03%	-0.04%	-0.56%	-0.24%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	5.94%	11.29%	2.24%	0.24%	4.10%	0.57%	8.58%	67.23%	0.00%	0.00%	0.00%	-0.01%	-0.19%	-0.06%
EF 3.0 Respiratory inorganics [Disease incidences]	16.74%	11.93%	1.96%	0.93%	15.68%	0.12%	1.82%	50.88%	0.00%	0.01%	0.00%	0.00%	-0.07%	-0.01%
EF 3.0 Water scarcity [m^3 world equiv.]	6.81%	0.37%	0.13%	0.05%	0.86%	0.00%	0.06%	91.60%	0.00%	0.00%	0.00%	0.01%	0.11%	0.05%

Table A18: Stage contribution to each environmental impact category for Scenario 4 – Using Reusable Masks, Machine-Washed in the UK

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	58.09%	0.00%	0.54%	22.37%	0.00%	0.58%	0.00%	18.17%	0.01%	0.00%	0.00%	0.23%	0.00%	0.01%
EF 3.0 Cancer human health effects [CTUh]	58.33%	0.00%	0.68%	16.33%	0.00%	0.68%	0.00%	23.93%	0.00%	0.00%	0.00%	0.04%	0.00%	-0.01%
EF 3.0 Climate Change [kg CO2 eq.]	47.55%	0.00%	2.25%	32.62%	0.00%	1.42%	0.00%	14.59%	0.07%	0.00%	0.03%	1.47%	0.00%	0.81%
EF 3.0 Ecotoxicity freshwater [CTUe]	52.54%	0.00%	2.43%	11.28%	0.00%	0.80%	0.00%	33.02%	0.01%	0.00%	0.00%	-0.08%	0.00%	-0.08%
EF 3.0 Eutrophication freshwater [kg P eq.]	59.17%	0.00%	0.87%	7.84%	0.00%	1.62%	0.00%	30.35%	0.00%	0.00%	0.00%	0.16%	0.00%	0.05%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	36.95%	0.00%	1.66%	51.64%	0.00%	2.39%	0.00%	9.77%	0.00%	0.00%	0.00%	-2.42%	0.00%	-1.12%
EF 3.0 Land Use [Pt]	67.99%	0.00%	0.54%	2.73%	0.00%	0.46%	0.00%	28.32%	0.00%	0.00%	0.00%	-0.05%	0.00%	-0.02%
EF 3.0 Non-cancer human health effects [CTUh]	85.04%	0.00%	0.47%	2.65%	0.00%	0.42%	0.00%	11.12%	0.00%	0.00%	0.00%	0.31%	0.00%	0.02%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	10.95%	0.00%	0.18%	75.95%	0.00%	3.08%	0.00%	9.84%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	41.99%	0.00%	1.03%	44.67%	0.00%	0.86%	0.00%	10.70%	0.01%	0.00%	0.00%	0.73%	0.00%	0.03%
EF 3.0 Resource use, energy carriers [MJ]	48.13%	0.00%	5.05%	39.22%	0.00%	1.80%	0.00%	6.74%	0.09%	0.00%	0.03%	-1.05%	0.00%	-0.32%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	56.46%	0.00%	1.05%	2.31%	0.00%	5.39%	0.00%	34.87%	0.00%	0.00%	0.00%	-0.08%	0.00%	-0.03%
EF 3.0 Respiratory inorganics [Disease incidences]	84.06%	0.00%	0.37%	4.67%	0.00%	0.61%	0.00%	10.29%	0.00%	0.00%	0.00%	0.01%	0.00%	-0.01%
EF 3.0 Water scarcity [m^3 world equiv.]	90.17%	0.00%	0.10%	0.67%	0.00%	0.05%	0.00%	8.92%	0.00%	0.00%	0.00%	0.09%	0.00%	0.03%

Table A19: Stage contribution to each environmental impact category for Scenario 5 – Using Reusable Masks with Single Use Filters, Machine-Washed in the UK

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	17.02%	12.54%	1.65%	6.55%	55.30%	0.17%	1.29%	5.32%	0.00%	0.02%	0.01%	0.07%	0.02%	0.04%
EF 3.0 Cancer human health effects [CTUh]	20.37%	13.07%	2.47%	5.70%	48.11%	0.24%	1.81%	8.36%	0.00%	0.01%	0.00%	0.01%	-0.12%	-0.03%
EF 3.0 Climate Change [kg CO2 eq.]	8.50%	22.93%	3.09%	5.83%	49.17%	0.25%	1.92%	2.61%	0.01%	0.10%	0.06%	0.26%	4.07%	1.21%
EF 3.0 Ecotoxicity freshwater [CTUe]	18.07%	19.82%	12.80%	3.88%	32.72%	0.27%	2.07%	11.36%	0.00%	0.02%	0.01%	-0.03%	-0.76%	-0.24%
EF 3.0 Eutrophication freshwater [kg P eq.]	26.37%	11.03%	9.12%	3.49%	29.46%	0.72%	5.44%	13.53%	0.00%	0.00%	0.00%	0.07%	0.54%	0.22%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	5.29%	24.76%	2.02%	7.39%	62.32%	0.34%	2.58%	1.40%	0.00%	0.00%	0.00%	-0.35%	-4.28%	-1.47%
EF 3.0 Land Use [Pt]	41.85%	15.46%	7.50%	1.68%	14.17%	0.28%	2.15%	17.43%	0.00%	0.00%	0.00%	-0.03%	-0.38%	-0.12%
EF 3.0 Non-cancer human health effects [CTUh]	51.42%	21.40%	2.65%	1.60%	13.51%	0.25%	1.91%	6.72%	0.00%	0.01%	0.01%	0.19%	0.05%	0.27%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	1.42%	0.52%	0.55%	9.84%	82.99%	0.40%	3.01%	1.27%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	7.39%	13.34%	1.66%	7.86%	66.30%	0.15%	1.14%	1.88%	0.00%	0.02%	0.01%	0.13%	0.01%	0.11%
EF 3.0 Resource use, energy carriers [MJ]	7.21%	30.38%	5.23%	5.88%	49.60%	0.27%	2.04%	1.03%	0.01%	0.10%	0.05%	-0.16%	-1.13%	-0.51%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	25.34%	24.07%	5.00%	1.04%	8.75%	2.42%	18.30%	15.65%	0.00%	0.00%	0.00%	-0.03%	-0.40%	-0.14%
EF 3.0 Respiratory inorganics [Disease incidences]	47.11%	16.79%	2.86%	2.61%	22.06%	0.34%	2.56%	5.77%	0.00%	0.01%	0.01%	0.00%	-0.10%	-0.02%
EF 3.0 Water scarcity [m^3 world equiv.]	81.69%	2.20%	0.84%	0.61%	5.15%	0.05%	0.34%	8.08%	0.00%	0.00%	0.00%	0.08%	0.66%	0.31%

Table A20: Stage contribution to each environmental impact category for Scenario 1a – Using Single-Use Masks in the UK (Mask Manufactured in Turkey)

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	70.96%	0.00%	14.19%	5.56%	0.00%	8.41%	0.00%	0.00%	0.12%	0.00%	0.10%	0.14%	0.00%	0.53%
EF 3.0 Cancer human health effects [CTUh]	59.80%	0.00%	23.04%	5.16%	0.00%	12.86%	0.00%	0.00%	0.06%	0.00%	0.05%	-0.89%	0.00%	-0.07%
EF 3.0 Climate Change [kg CO2 eq.]	54.22%	0.00%	9.09%	5.03%	0.00%	8.42%	0.00%	0.00%	0.44%	0.00%	0.38%	17.82%	0.00%	4.60%
EF 3.0 Ecotoxicity freshwater [CTUe]	35.28%	0.00%	59.01%	3.02%	0.00%	4.98%	0.00%	0.00%	0.04%	0.00%	0.04%	-1.84%	0.00%	-0.53%
EF 3.0 Eutrophication freshwater [kg P eq.]	19.46%	0.00%	57.48%	6.34%	0.00%	14.53%	0.00%	0.00%	0.00%	0.00%	0.00%	1.44%	0.00%	0.76%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	97.11%	0.00%	19.25%	17.71%	0.00%	26.73%	0.00%	0.00%	0.03%	0.00%	0.03%	-44.33%	0.00%	-16.53%
EF 3.0 Land Use [Pt]	18.38%	0.00%	63.61%	12.05%	0.00%	7.79%	0.00%	0.00%	0.00%	0.00%	0.00%	-1.38%	0.00%	-0.45%
EF 3.0 Non-cancer human health effects [CTUh]	67.96%	0.00%	14.08%	5.60%	0.00%	9.06%	0.00%	0.00%	0.06%	0.00%	0.05%	0.26%	0.00%	2.92%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	5.84%	0.00%	19.10%	30.66%	0.00%	44.41%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	67.84%	0.00%	13.78%	7.19%	0.00%	8.81%	0.00%	0.00%	0.14%	0.00%	0.12%	0.04%	0.00%	2.08%
EF 3.0 Resource use, energy carriers [MJ]	85.48%	0.00%	7.78%	5.24%	0.00%	7.94%	0.00%	0.00%	0.38%	0.00%	0.33%	-4.41%	0.00%	-2.75%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	31.33%	0.00%	16.52%	9.35%	0.00%	44.13%	0.00%	0.00%	0.01%	0.00%	0.00%	-0.96%	0.00%	-0.38%
EF 3.0 Respiratory inorganics [Disease incidences]	52.41%	0.00%	23.40%	12.70%	0.00%	11.84%	0.00%	0.00%	0.05%	0.00%	0.05%	-0.48%	0.00%	0.03%
EF 3.0 Water scarcity [m^3 world equiv.]	54.49%	0.00%	15.79%	4.02%	0.00%	6.04%	0.00%	0.00%	0.00%	0.00%	0.00%	11.67%	0.00%	7.98%

Table A21: Stage contribution to each environmental impact category for Scenario 1b – Using Single-Use Masks in the UK (Mask Manufactured in UK, Materials Imported from China)

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	90.21%	0.00%	6.89%	0.00%	0.00%	2.62%	0.00%	0.00%	0.04%	0.00%	0.03%	0.04%	0.00%	0.16%
EF 3.0 Cancer human health effects [CTUh]	88.79%	0.00%	7.49%	0.00%	0.00%	3.98%	0.00%	0.00%	0.02%	0.00%	0.02%	-0.28%	0.00%	-0.02%
EF 3.0 Climate Change [kg CO2 eq.]	81.26%	0.00%	5.53%	0.00%	0.00%	3.51%	0.00%	0.00%	0.18%	0.00%	0.16%	7.43%	0.00%	1.92%
EF 3.0 Ecotoxicity freshwater [CTUe]	48.41%	0.00%	50.12%	0.00%	0.00%	2.73%	0.00%	0.00%	0.02%	0.00%	0.02%	-1.01%	0.00%	-0.29%
EF 3.0 Eutrophication freshwater [kg P eq.]	38.11%	0.00%	53.11%	0.00%	0.00%	7.62%	0.00%	0.00%	0.00%	0.00%	0.00%	0.75%	0.00%	0.40%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	93.98%	0.00%	11.81%	0.00%	0.00%	4.55%	0.00%	0.00%	0.01%	0.00%	0.00%	-7.54%	0.00%	-2.81%
EF 3.0 Land Use [Pt]	37.95%	0.00%	57.93%	0.00%	0.00%	5.39%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.95%	0.00%	-0.31%
EF 3.0 Non-cancer human health effects [CTUh]	77.80%	0.00%	13.46%	0.00%	0.00%	6.41%	0.00%	0.00%	0.04%	0.00%	0.04%	0.18%	0.00%	2.06%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	90.81%	0.00%	4.28%	0.00%	0.00%	4.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	92.59%	0.00%	4.84%	0.00%	0.00%	2.02%	0.00%	0.00%	0.03%	0.00%	0.03%	0.01%	0.00%	0.48%
EF 3.0 Resource use, energy carriers [MJ]	93.75%	0.00%	5.59%	0.00%	0.00%	3.50%	0.00%	0.00%	0.17%	0.00%	0.15%	-1.94%	0.00%	-1.21%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	41.05%	0.00%	21.57%	0.00%	0.00%	38.54%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.84%	0.00%	-0.33%
EF 3.0 Respiratory inorganics [Disease incidences]	71.53%	0.00%	20.68%	0.00%	0.00%	8.03%	0.00%	0.00%	0.04%	0.00%	0.03%	-0.33%	0.00%	0.02%
EF 3.0 Water scarcity [m^3 world equiv.]	63.76%	0.00%	18.69%	0.00%	0.00%	4.13%	0.00%	0.00%	0.00%	0.00%	0.00%	7.97%	0.00%	5.45%

Table A22: Stage contribution to each environmental impact category for Scenario 1c – Using Single-Use Masks in the UK (Mask Manufactured in UK, Materials Imported from Turkey)

	Mask Manufacture	Filter Manufacture	Mask Packaging Manufacture	Mask Transport to UK	Filter Transport to UK	Mask UK Distribution	Filter UK Distribution	Mask Use	Mask Waste Transport	Filter Waste Transport	Packaging Waste Transport	Mask Disposal	Filter Disposal	Packaging Waste Disposal
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	63.67%	0.00%	25.59%	0.00%	0.00%	9.73%	0.00%	0.00%	0.13%	0.00%	0.12%	0.16%	0.00%	0.61%
EF 3.0 Cancer human health effects [CTUh]	63.65%	0.00%	24.28%	0.00%	0.00%	12.92%	0.00%	0.00%	0.06%	0.00%	0.05%	-0.89%	0.00%	-0.07%
EF 3.0 Climate Change [kg CO2 eq.]	55.46%	0.00%	13.15%	0.00%	0.00%	8.34%	0.00%	0.00%	0.44%	0.00%	0.38%	17.67%	0.00%	4.56%
EF 3.0 Ecotoxicity freshwater [CTUe]	29.06%	0.00%	68.91%	0.00%	0.00%	3.76%	0.00%	0.00%	0.03%	0.00%	0.03%	-1.39%	0.00%	-0.40%
EF 3.0 Eutrophication freshwater [kg P eq.]	17.93%	0.00%	70.43%	0.00%	0.00%	10.11%	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	0.00%	0.53%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	79.67%	0.00%	39.90%	0.00%	0.00%	15.37%	0.00%	0.00%	0.02%	0.00%	0.02%	-25.48%	0.00%	-9.48%
EF 3.0 Land Use [Pt]	25.62%	0.00%	69.43%	0.00%	0.00%	6.46%	0.00%	0.00%	0.00%	0.00%	0.00%	-1.14%	0.00%	-0.38%
EF 3.0 Non-cancer human health effects [CTUh]	69.76%	0.00%	18.34%	0.00%	0.00%	8.73%	0.00%	0.00%	0.06%	0.00%	0.05%	0.25%	0.00%	2.81%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	30.52%	0.00%	32.35%	0.00%	0.00%	37.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	68.12%	0.00%	20.81%	0.00%	0.00%	8.72%	0.00%	0.00%	0.14%	0.00%	0.12%	0.04%	0.00%	2.06%
EF 3.0 Resource use, energy carriers [MJ]	86.33%	0.00%	12.22%	0.00%	0.00%	7.65%	0.00%	0.00%	0.37%	0.00%	0.32%	-4.23%	0.00%	-2.65%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	37.80%	0.00%	22.77%	0.00%	0.00%	40.67%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.89%	0.00%	-0.35%
EF 3.0 Respiratory inorganics [Disease incidences]	53.75%	0.00%	33.59%	0.00%	0.00%	13.04%	0.00%	0.00%	0.06%	0.00%	0.05%	-0.53%	0.00%	0.03%
EF 3.0 Water scarcity [m^3 world equiv.]	40.55%	0.00%	30.65%	0.00%	0.00%	6.77%	0.00%	0.00%	0.00%	0.00%	0.00%	13.08%	0.00%	8.94%