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

Summary

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 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.

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Key points

- As pressure mounts on the UK government to define 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).

Outline

1. Types and anatomy of masks

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

3. Role of mask wearing in exit strategies for COVID-19

4. Environmental impact of masks

5. Behaviour change considerations for reusable mask use

6. Public campaign

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 studies that evaluate the effectiveness of reusable masks compared to single-use masks. Davies et al. (2013) report that these types of masks are only 15% less efficient than surgical masks in blocking the transmission of particles, and cloth masks may be five times more effective for this purpose than wearing no face mask at all.

Another study indicates that cloth masks (typically made of cotton and gauze) have poorer filtration capacities than surgical masks, and concludes that, due to higher moisture retention, the reuse of this type of mask may increase the risk of infection (MacIntyre et al., 2015). However, the authors stated that there were limitations to the study, which included not measuring the compliance with personal hygiene, and the relative quality of paper and cloth masks. It is also unclear what type of single-use and reusable masks were studied. Most single-use face masks have an inbuilt filter, whereas reusable masks typically do not; however, some do allow for the insertion of a filter, which may well increase protection. Gauze is shown to offer greater protection than a cotton mask, due to the fineness of the material and the greater number of layers (MacIntyre et al., 2015).

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 128,000 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.

Table 2: Waste arising due to facemask 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**

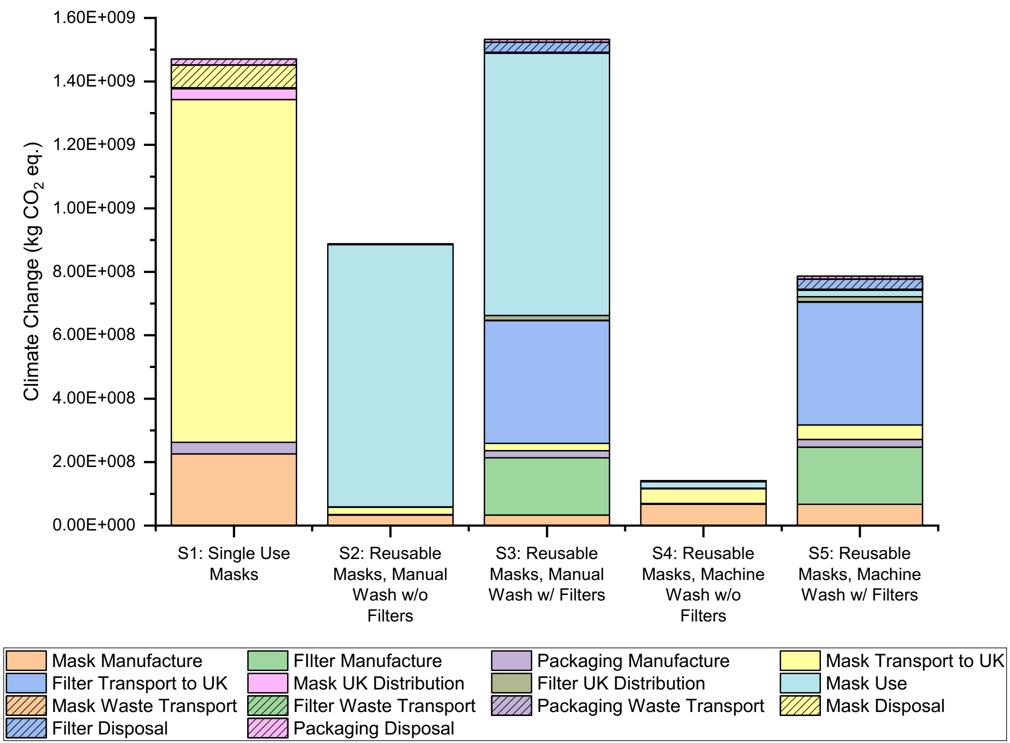
This study assumed the use of one mask per person per day, which is deemed optimistic since the number of masks necessarily depends on an individual's behaviour. However, the difference in environmental impact between the different scenarios is relative. A scaling factor can be applied to the environmental 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.

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).

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).

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



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.

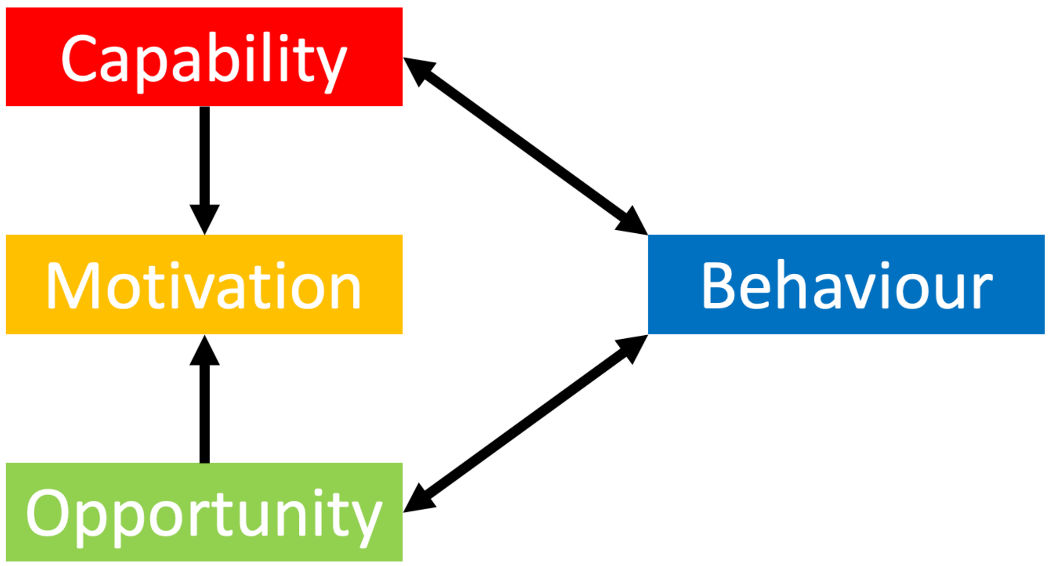
Table 3: Behaviours to prevent transmission of COVID-19 among the general population (taken from Michie, 2020)

2. Avoiding 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 people's personal objects, e.g. mobile phones.

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. Public campaign

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.

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Appendix 1: A LCA Comparison between Single-Use and Reusable Facemasks Use in the UK

Background

Many countries have introduced the mandatory use of facemasks as a non-clinical intervention to reduce the spread of SAR-Cov-2. There are no legislations in the UK to mandate the use of such products but a portion of the general public has adopted already this practice. However, a rise in single-use facemask littering has been observed and has led to environmental concerns over their use. A Material Flow Analysis (MFA) analysis carried out (to complement this policy briefing) suggests that if the use of single-use facemasks were widely used by all UK-citizens then this will amount to 48kt of plastic (66kt total waste) that requires disposing annually. Although reviews in the literature states that in a clinically setting single-use masks are currently more effective than reusable; for general use, some experts have suggested that reusable masks are as adequate in preventing transmission when they are used correctly (Lai, Poon and Cheung, 2012; MacIntyre *et al.*, 2020). Reusable facemasks have the potential to reduce the amount of waste arising but due to differences in materials of construction and the addition of cleaning processes for reusable facemasks, a trade-off in environmental impacts may arise. In addition, some reusable masks can be complemented with single-use filters to offer greater air filtration, this may reduce waste arising from single-use mask but high amount of waste for disposal can equally be foreseen. This study aimed to understand the environmental impacts of both single-use and reusable masks if they are adopted for use nationally in the UK.

Goal

Compare the environmental impacts of using single-use facemasks and reusable facemasks nationally to prevent the transmission of infection in the UK.

Scope

Five scenarios of public use of facemasks 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 1 year of facemask use and assumed one mask use per person per day. The number of facemasks and filters required to support use in this period were calculated according to the population within the UK (Table A2). One mask per day may be deemed optimistic since the number of masks necessary is dependent on an individual's behaviour. However, the environmental impact difference between the different scenarios will remain relative. A scaling factor can be applied to environmental impact results to reflect the actual affects if, on average more than one mask are used.

Table A2: Number of mask and filters required to support facemask use in the UK for 1 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 approached was used for this comparison. The scope of the study included the material sourcing of the masks, transport to manufacture facility, manufacture of masks, transport to the UK, mask distribution nation-wide, mask use and final disposal (Figure A1).

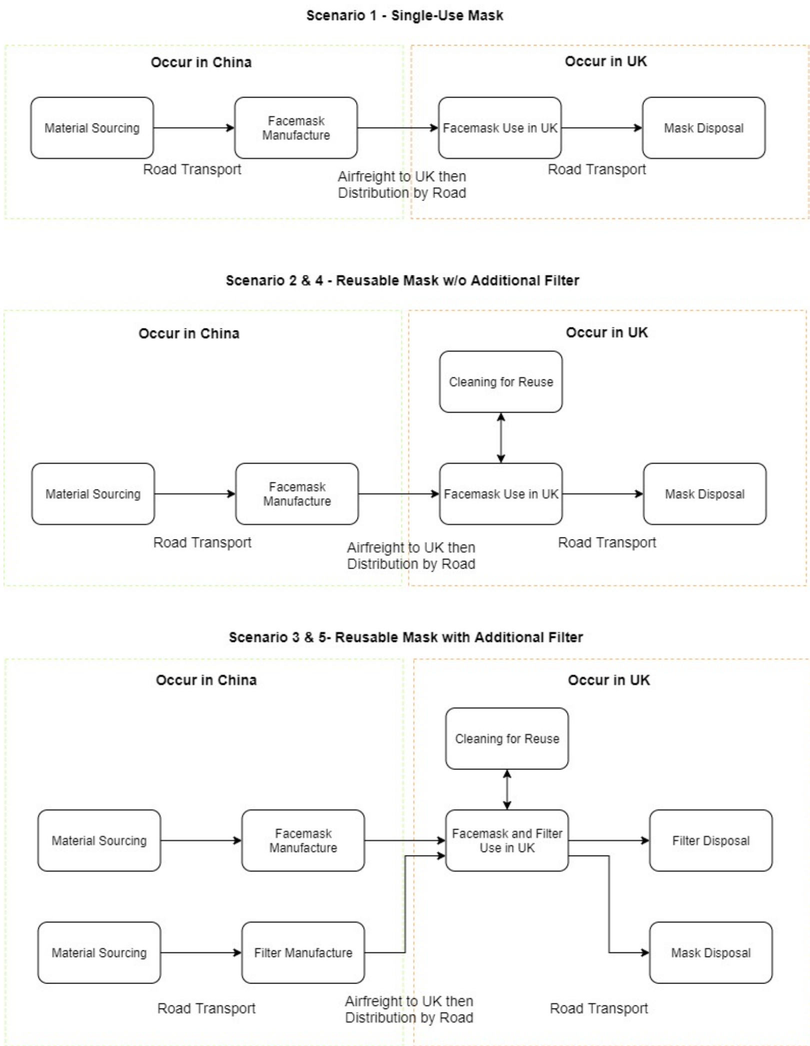

Figure A1: Cradle-to-grave system boundary for each facemask use scenario.

MANUFACTURING ASSUMPTIONS

The manufacturing of masks (single-use and reusable) and filters were assumed to be manufactured in China before transported by airfreight to the UK. The material of construction and the energy requirement for the major manufacturing process assumed for each face and filter are summarised in Table A3 and Table A4. For all scenarios, the waste arising and treatment of waste arising from manufacturing was not modelled this study.

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

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** **Ear Loops Cutting** **Ultrasonic Welding** **Total** **(Total per FU)**	 0.556 0.694 0.167 0.792 (19.6GWh)	 4 kW, 110 – 160 pcs/min 0.5 kW, 120 – 240 pcs/min 1.2 kW	 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)
Reusable Mask **Laying, Cutting and Sewing** **Total** **(Total per FU)**	 34.2 34.2 (4.64GWh)	 2.38 kWh/kg	 (Moazzem *et al.*, 2018)
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 mask types were assumed to be manufactured in China before distribution in the UK, transport assumptions are 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 the use of at least two masks in rotation to allow adequate cleaning and drying of masks before use. It is acknowledged that the number of reusable masks used in rotation per person is dependent on personal preference and economic feasibility. Hence, scenarios where two and four masks are employed per person were both modelled. Due to the frequency of washing necessary, it was assumed that with two masks, manual washing is necessary. With four masks, it was assumed that households can bulk wash masks with 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, average household soap / detergent was assumed sufficient to clean facemasks.

Manual Washing (Scenarios 2 and 3): The study assumed that each facemask is washed every 2 days due to being used in rotation. Hence, each reusable facemask is modelled to be washed 183 times per FU (one year time frame). Because frequent washing would be required, manual washing of facemask was assumed. According to Ariel's guide on hand washing, it stated to use a teaspoon (approximately 6ml (6.24g)) of liquid detergent in a tub slightly warm water, once the garment has been cleaned with the mixture, it should then 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.

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

Table A7: Requirements for the manual washing of facemasks 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 x10^{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 with an average household of 2.4, there would be sufficient laundry for a full machine wash every 3 days (if garments from each household member were pooled). A wash every 3 days equates to each mask washed 122 times in one year (FU). Walser et al., (2011) evaluated the environmental impact of t-shirts considering "low", "medium" and "high" environmental awareness of users, which influence the choice of washing machine category used, the quantity of detergent and the temperature used for the washing. 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 general 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 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	3.88×10^9 L
Electricity	0.66kWh	1.58Wh	0.192kWh	52.2GWh

Disposal Assumptions

All waste arising from the use of facemasks were modelled to be disposed by 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 Department for Environment Food & Rural Affairs [Defra], (2019). Land and incineration were chosen as the disposal method because they are the typical waste destinations for household wastes. Single-use masks and filters are currently not recycled whilst textiles are currently unlikely to be recycled. Although packaging can be recycled, plastic film packing, modelled as wrapping for reusable and single-use filters, are 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 masks were modelled to be disposed of after the year of use. There are no data available on how long each reusable masks can last, data is required to understand the usability of masks after frequent washes. It was assumed that the life of each mask could be similar. In Scenarios 2 and 3, the masks are washed more frequently than Scenarios 4 and 5, however, manual washing are 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 was the Environmental Footprint (EF) 3.0 methodology (Zampori and Pant, 2019). Both life cycle inventory (LCI) analysis and life cycle impact assessment (LCIA) were carried out and compared amongst the different scenarios. The LCI analysis showed that the use of reusable masks significantly reduces the amount of waste entering general waste streams (Table A9). 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 A9: Waste arising due to facemask 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**

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

Table A10: Overall environmental impact results for each facemask 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 [m^3 world equiv.]	1.40E+08	3.26E+09	3.31E+09	7.53E+08	8.04E+08

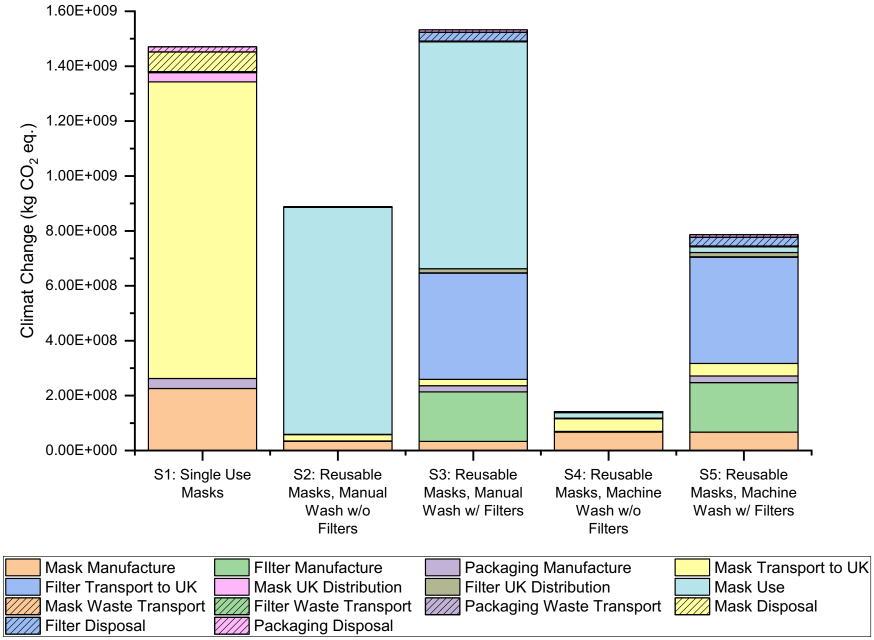

Figure A2: Climate change results generated for each scenario of facemask use.

Figure A2 highlights the hot-spot analysis carried out on Climate Change results generated by each scenario. It shows that the transport of single-use facemasks (Scenario 1) contributed the most to this impact category. This is attributed to the large number of facemasks required and therefore an increased level of transport is necessary, as compared to reusable 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; thermal energy required to supply hot tap water represents over 70% of Scenario 2 impact. In Scenario 4, it generated the lowest impact overall even though a higher number of masks are required than Scenarios 2 and 3. This suggest that having a higher numer of masks in rotation to allow machine washing (Scenarios 4 and 5) is more environmental beneficial than manual washing (Scenarios 2 and 3).

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

Limitations & Discussion

The comparative study presented explored the environmental impact differences between a mask that has been designed to be disposed after one use with difference scenarios of using masks that are designed to be washed and reused. The reusing of single-use masks was not analysed. This is because there are currently no protocols in reusing masks designed to be used once. Hence, not all facemask use scenarios were explored as part of this study. Equally, a limitation of this comparative study is the washing of facemasks. 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 current guidelines to eliminating viruses is to employ hot water and soap. Data on the effectiveness of using cold water and soap on removing viruses is required before this recommendation can be made.

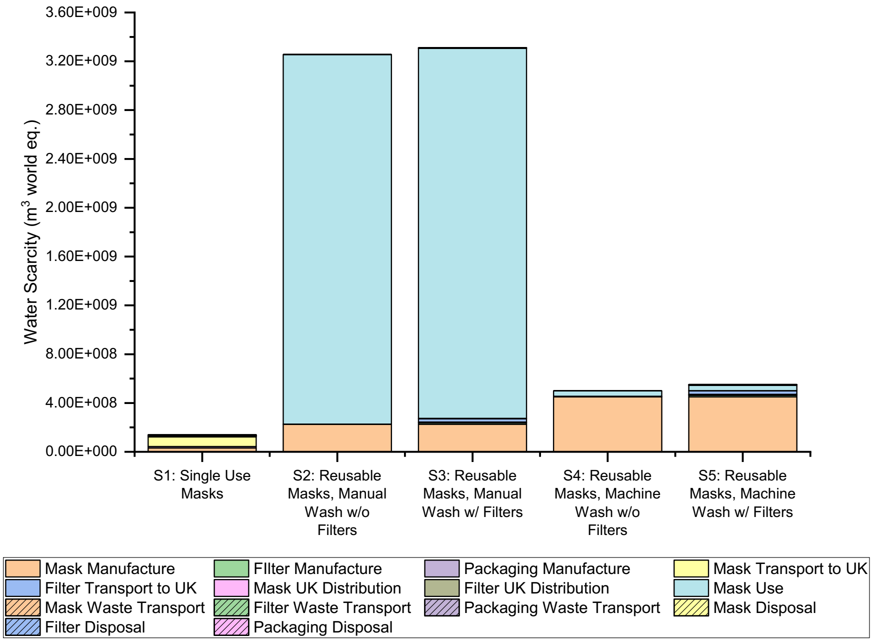

Figure A3: Water Scarcity results generated by each facemask scenario.

For Scenarios 2 to 5, each facemasks requires over 120 washes during the 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 the garment is washed with low efficacy then the life is 20 washes, 50 washes for medium efficacy and 100 washes for high efficacy. If a mask has a life of 20 washes then 18 masks are necessary to suffice a full year of 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 are continues to be not used; up to 48 reusable masks (44 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 25. Thus, depending on which impact category is of interest, an addition of 21 masks can be supplied over the year of mask use such that Scenario 4 retains its environmental superiority over Scenario 1 (single-mask use). With 25 masks this reduce the amount of washing per mask to 15 and 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**

Both single-use and reusable facemasks were assumed to be imported from China. There are advice available on making reusable facemasks at home and therefore the manufacture of facemask in China may not be necessary. This can reduce the overall environmental impact of all reusable facemask scenarios, especially if masks are made with waste clothing.

The hot-spot analysis showed that for Scenario 1 (Single-use mask) the largest contributor to most environmental impact was mask transport. This suggests that the location of single-use masks can also be repositioned to reduce the impact associated with transporting masks to the UK. According to the OCED (OECD, 2019) and Edana (Edana, 2019) market data, UK is one of the main importers of non-woven textiles. Hence, it is deemed likely that UK will require the import of these materials for it to be possible to manufacture single-use facemasks. Thus, if mask production is relocated to the UK then although the emissions associated with importing the product is eliminated there will be emissions associated with importing raw materials. As further work to this study, other manufacturing locations for masks manufacture can be explored to understand whether the use of reusable masks have environmental advantages over single-use options when both supply chains are optimised. The current study assumed China as the manufacturing location because it is the biggest exporter of non-woven textiles and have a large capacity of producing facemasks. This was deemed to be realistic for the current situation.

Manufacturing waste arising and the associated waste disposal treatments were not modelled in this comparative study due to 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 percentage contribution from manufacturing waste treatment should be negligible.

Lastly, this study assumes that every facemask scenario has an equal functionality in preventing the transmission of infection. The effectiveness of mask use cannot be evaluated using life cycle assessment. A state of the art review by MacIntyre and Chugtai, (2015) suggests that the effectiveness in providing protection against infections is subject to compliance, complementary interventions and early use. Thus, although reusable 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 masks.

Conclusion

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

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

Appendix 3 - 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

	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 [m^3 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 A19: Stage contribution to each environmental impact category for Scenario 3 – 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 [m³ 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 A18: Stage contribution to each environmental impact category for Scenario 2 – 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%