PEER REVIEW HISTORY

ARTICLE DETAILS

TITLE (PROVISIONAL)	Thinking green: Modelling respirator reuse strategies to reduce cost and waste
AUTHORS	Chu, Jacqueline; Ghenand, Omkar; Collins, Joy; Byrne, James; Wentworth, Adam; Chai, Peter; Dadabhoy, Farah; Hur, Chin; Traverso, Giovanni

VERSION 1 – REVIEW

REVIEWER	Klemeš, Jiří Brno University of Technology
REVIEW RETURNED	02-Feb-2021

GENERAL COMMENTS	The reviewed manuscript has been interesting, well prepared and deserves attanetion and after updating to published as well. The primary issue that needs an urgent update is not the authors' problem, but the accelerating COVID-19 pandemics and recently especially developing new strains, which are increasing infectious and are substantially changing the requirements for the protections masks and respirators. The manuscript needs a very urgent update and fast reviewing and publishing, as we are dealing not with the traditional publishing processing flow, but racing against the development of the pandemic. For this reason, I suggest extending the covered period as the first six months, even when it is not so long time ago, has changed many issues. Please make a new check and state of the art, check recently newly developed respirators, also focusing on the implementation of nanomaterials and metals intended to increase the efficiency. They also appeared new high-tech innovative producers, which reduced the logistic demands. And I asuggest to consider also an assessment of the material, energy/emissions and plastic waste footprints. We started some work in this direction, and however, as I mentioned before, we are all just catching the fast pandemic movement; all this needs to be updated. Some formal issue, please be more specific in definition of units and symbols, e.g. billion has two versions – short 10^9 and long

	10^{12} and the paper should be precisely understood outside the US as well. Some of our thoughts had been recently published, but we are in no way pushing you to use them: Jiang, P.; Klemeš, J.J.; Fan, Y.V.; Fu, X.; Bee, Y.M. 2021, More Is Not Enough: A Deeper Understanding of the COVID-19 Impacts on Healthcare, Energy and Environment Is Crucial. Int. J. Environ. Res. Public Health, 18, 684. https://doi.org/10.3390/ijerph18020684 Klemeš, J.J., Van Fan, Y., Jiang, P., 2020. COVID-19 pandemic facilitating energy transition opportunities, International Journal of Energy Research, DOI: 10.1002/er.6007 To sum up, you are doing a good and needed work; please keep going

REVIEWER	Green, Alex Wayne State University School of Medicine
REVIEW RETURNED	17-Feb-2021

GENERAL COMMENTS	Thank you for undertaking this project. The model is thoughtfully conceived and highlights the need for resource conservation and pragmatic sustainability at a time when those topics have fallen from public discourse. This reviewer would only make a few comments concerning the study's current scope. First, the method for determining the "waste generation" of each strategy is somewhat limited, being circumscribed to the weight of one make, model, and size of N95 respirator at present. Notably, a mean/median weight of the most common N95 respirators, or a simple range between the highest and lowest weight N95 respirators, may offer greater precision. Alternatively, as a simple solution, the study's explicit examination of the standard size 3M 1860 respirator as a representative model could be cited explicitly in the study's strengths and limitations (at present it is absent). Second, in a related vein, the citation given for "Weight of one N95 Respirator" in Table #1 does not appear to match the information cited; this also applies to the citation given for "Weight of one Surgical Mask" in Table #1, and the citation for "Number of Hospitalizations due to COVID-19" in Table #2. Please double check these sources in case a numbering error occurred in the works cited. Third, it would be of immense benefit to capture the costs of UVGI or H202 vapor-decontamination in a more detailed context. Looking to H202 vapor-decontamination in particular, the number of respirators required is calculated nationally (at a reported 6,090 U.S. hospitals) but is compared to the cost ($415 million) of H202 vapor-decontamination use at only 60 sites. Without a more robust metric it is difficult to contend that true cost-saving is occurring. This would also add a unique comparison where the magnitude of waste generation may need to be weighed against cost expenditure, potentially adding further impetus for technologies better suited to low resource settings. Similar to the study's selection of a representative N95 respirator, perhaps a simple value could be derived from the experience of a

	single hospital system and extrapolated nationally to all sites included in the respirator usage calculation. These recommended edits notwithstanding, the manuscript's content is novel, and of critical salience. It was a pleasure reviewing your team's work.

REVIEWER	Salas-Vega , Sebastian London School of Economics and Political Science Health and Social Care
REVIEW RETURNED	06-Mar-2021

GENERAL COMMENTS	General Comments • Thank you for the opportunity to review this manuscript. Overall, this is a well-written study that offers a timely & important perspective on the economic and environmental impact of respirator use strategies during the COVID-19 pandemic in the US. • To "compare the impact of respirator extended use and reuse strategies with regard to cost and sustainability during the [first 6-months of the] COVID-19 pandemic" in the United States, the authors perform a model-based quantitative analysis of the usage, cost, and waste associated with several respirator use strategies. • Findings from this study have important implications for research, policy, and medical practice during the ongoing pandemic, but could also offer insights into respirator use strategies as the pandemic draws to a close and during any public health emergencies that may arise in the future. Specific Comments Introduction • Excellent overall. Minor issue: since the distinction is made, the authors should try to better characterize / define reusable vs non-reusable respirators. In other words, at least within context of the introduction, 'reusable respirators' does not include disposable respirators that are decontaminated by any method, correct? At least as currently phrased, this distinction does not seem to be wholly consistent with references to various reuse strategies throughout the rest of the paper. Methods / Results • The analysis was based on data pertaining to the 3M 1860 disposable respirator, as well as a second respirator that appears to have been developed by some of the study co-authors. Is there any reason why the authors chose to compare the respirator that they helped develop with just the 3M 1860 disposable respirator? This should be described in the paper. • Moreover, there is often only a single value for the baseline cost and waste parameters reported in Table 1. References are given, but the authors should also name the exact respirator(s) / mask(s) that correspond to the parameters given in Table 1 (also Table 4). • In addition to the HCW population, is there uncertainty or variability in any other parameter that went into the model used by the authors? If so, the authors should adjust their analysis accordingly, e.g. by giving a range of estimates where uncertainty / variability exists. For example, the authors report that H_2O_2 vapor decontamination could reduce the number of respirators

	required by 20-fold. However, this number appears to be based on data published by the manufacturer of an H2O2 decontamination system, Batelle. Is there any reason to suspect that this may be an overestimate of reusability and, if so, how might accounting for this source of uncertainty impact study results? Similarly, the authors also elsewhere assume a "30% discard rate per day due to damaged or visibly soiled respirators after each cycle of decontamination." Wherever possible, cost analyses should provide a range of reasonable model parameters from multiple sources to help avoid introducing bias from on any single source. • Study findings pertain to the first 6-months of the COVID-19 pandemic. From a translational perspective, however, there will likely never be another scenario (emergency or non-emergency) that perfectly mirrors what was experienced over this period. In addition to base-case analyses, would the authors be able to quantify average costs & waste generated on a per patient basis? This would be helpful evidence for different readers (e.g. hospital leaders) given that e.g. "even after the pandemic, respirator and mask usage both in healthcare settings and among the general public may persist." Discussion • Thank you for including a discussion of study limitations. Among these, the authors acknowledge that they e.g. did not include installation, maintenance, distribution, or personnel costs associated with each strategy; and did not account for the environmental impact of manufacturing or decontamination processes. • Findings from this study point to clear economic and environmental benefits from respirator reuse strategies. • It's not clear to me whether policy changes regarding respirator use across the country have consistently been based on an objective, comprehensive assessment of the risks and benefits from alternative strategies. At least based on your analysis, I would have expected wider use of reusable respirator options, especially before the current pandemic. Would you the authors be able to hypothesize why there appears to be a disconnect between what the evidence (and practical experience) might suggest on potential benefits to respirator reuse and the strategies that have been adopted nationally? Would the authors be able to offer evidence-based recommendations for research or policy that could help address this disconnect? For example, individual hospital systems may not appreciate the environmental impact from use of disposable respirators to the same degree that an entire country might. Could any perceived failure to optimally change respirator use policy therefore at least in part be due to what is described in economics as negative externalities? Might there be anything to learn from how this concept has traditionally applied to e.g. pollution? And, might governments therefore have a role to play in influencing respirator use policies (e.g. subsidies during the pandemic to help hospital systems transition to reusable respirator systems, taxes as the pandemic draws to a close to help better account for any negative externalities that may be associated with use of disposable respirators)? These are particularly important questions to consider as the pandemic draws down—it's unclear whether hospitals will revert back to the

	use of disposable respirators. • As an aside, surgical N95 respirators are often not reused. That said, there are users of surgical N95 respirators that are not directly involved in surgical patient care—it would be highly usual for their masks to be exposed to bodily fluids. I find there to be some degree of inconsistency between this and initiatives (however justified) to promote the use of reusable respirators—particularly during a pandemic that has involved a novel viral strain. In other words, it seems as if we're applying two different sets of criteria for reusability of respirators. The larger question that the authors may wish to consider discussing is: from a medical and biological perspective, what criteria might justify respirator reusability in different healthcare settings? • On this point, the authors offer important insights into the use, cost, and waste associated with respirator use strategies used during the first 6 months of the pandemic. If this is to inform respirator use strategies moving forward, what other 'costs' and 'benefits' might exist? For example, are the various respirator use strategies considered in this study associated with any health risks that could lead to greater health-related costs compared to disposable respirators? It may not be within the scope of this study to systematically identify and quantify all costs and benefits associated with each respirator use strategy. However, the authors of this study should at the very least make it clear throughout that any representation of costs is not comprehensive; cost-benefit analyses are likely still needed. For example, it sounds great that assigning one respirator to each HCW over the course of the pandemic could have cut down on the number of respirators used by 99%, but would having done so contributed to health-related costs that aren't quantified / considered in this study? This is particularly important given some of the points raised in the paper, including for instance that "combining the strategies … was the least costly of all strategies"—perhaps, but only if one only counts the costs considered in this study. • The authors describe different reuse strategies throughout the paper, e.g. hydrogen peroxide, heat, steam, detergent, UVGI, as well as alcohol and bleach wipes in resource-constrained settings. I think it's important for the authors to explicitly mention that the efficacy of such reuse strategies (and thus the total cost incurred from each strategy) is not likely to be equal—e.g. alcohol wipes may be more readily available, but any decision to use this decontamination strategy in the future should (for example) also be balanced against the possibility of greater health risks. • In terms of relevance and impact, it would also be helpful for the authors to bolster their discussion of how their findings should be interpreted as the pandemic draws down—see comments above for some issues to potentially touch on.

VERSION 1 – AUTHOR RESPONSE

Peer-Reviewer #1 (comments to the author):

1. **When it is not so long time ago, has changed many issues. Please make a new check and state of the art, check recently newly developed respirators, also focusing on the implementation of nanomaterials and metals intended to increase the efficiency. They also appeared new high-tech innovative producers, which reduced the logistic demands.**

We thank the reviewer for this important suggestion. We have conducted a review of newly developed respirators, looking closely at the implementation of nanomaterials and metals to increase the efficiency of mask protection and added our appraisal of these findings in the introduction and discussion sections:

p.3 “Other types of reusable masks that aim to address barriers to communication, such as the Jelli M1 mask [16] and ClearMask, have recently been developed.[17]”

p.3 “Introducing novel mask types, such as a variety of reusable masks, presents an opportunity to diversify the market, and in turn provide more flexibility within supply chains. This has the potential to increase efficiency and reduce cost, waste, and energy consumption associated with supply chain disruption.[19]”

p. 10 “Antimicrobial agents derived from natural products (tea tree oil, grapefruit seed extract, etc.) as well as nanoparticles from different metals and metal compounds (copper, silver, zinc oxide, etc.) have also been shown to improve filtration and reduce viral load on mask surfaces.[14 ,15] There are a variety of masks now commercially available that use nanotechnology and range from disposable surgical masks, washable masks, and reusable respirators such as Innonix RespoKare (citric acid nanoparticles), Cupron Inc. (copper nanoparticles), and Argaman BioBlockX ™ (silver nanoparticles).[14 ,15 ,18]”

And I suggest to consider also an assessment of the material, energy/emissions and plastic waste footprints. We started some work in this direction, and however, as I mentioned before, we are all just catching the fast pandemic movement; all this needs to be updated.

We thank the reviewer for this important suggestion. We have conducted an updated assessment of the literature regarding the material, energy/emissions and plastic waste footprints during the COVID-19 pandemic. We have added our findings to both the Introduction and ‘Limitations’ section in the Discussion.

p.3 “The global increase in the use of plastics for mask and PPE production has drastically increased medical waste, with countries such as Spain and China reporting increases of 350% and 370%, respectively.[20] As of February 2020, the production rate of face masks in China alone increased by 12 fold.[20]”

p. 10 “In addition, our analysis measured only the waste generated by masks themselves and did not study the environmental impact of manufacturing, packaging or waste generation from decontamination processes, which some studies estimate could generate up to 90% of greenhouse gas emissions.[19] Furthermore, the environmental impact of single-use plastics generated from packaging related to mask use, estimated to have increased by up to 40% during the pandemic, may contribute a significant amount of additional environmental waste.[64] These aspects were not included in our analyses and require further quantification.”

Some formal issue, please be more specific in definition of units and symbols, e.g. billion has two versions – short 109 and long 1012 and the paper should be precisely understood outside the US as well.

We thank the reviewer for this important comment. In order to make this more widely understood outside of the United States, we have included the parameter costs in both Euro and Pound Sterling in Table 1.

4. **Some of our thoughts had been recently published, but we are in no way pushing you to use them:**

Jiang, P.; Klemeš, J.J.; Fan, Y.V.; Fu, X.; Bee, Y.M. 2021, More Is Not Enough: A Deeper Understanding of the COVID-19 Impacts on Healthcare, Energy and Environment Is Crucial. Int. J. Environ. Res. Public Health, 18, 684. https://secure-web.cisco.com/1x9FnV1k_WNls3d5bPAyX-AIK6fo8GoCo8wPHBHhAIVnPPTiFTyjYqlOcRxFigtUNAdy3MpeyDXXNmR8-IvsqDcmt8SAOYpaBAvn52aFoZSuMffBPz5Yi_Vo6nbRjKhD8ogokIEJIy9BDkAnQ88-uPe_yRpIvOVOxhPs4w_KDMJ9AFBsMpQJqpqbiWoW_p8QbiBr-1_isshDpLKlbu8DPFGjZCZn3JomuDhZqqlaFuL9Y8ZtAIWQRulyqYywR0qJK/https%3A%2F%2Fdoi.org%2F10.3390%2Fijerph18020684

Klemeš, J.J., Van Fan, Y., Jiang, P., 2020. COVID-19 pandemic facilitating energy transition opportunities, International Journal of Energy Research, DOI: 10.1002/er.6007

To sum up, you are doing good and needed work; please keep going

We thank the reviewer for sharing these published works which were extremely helpful in guiding our literature search. We have cited these in the manuscript on p.3 of the Introduction section and p.10 in the Limitations section of the Discussion where we discussed the amount of cost, waste, and energy consumption as well as the increase in plastic use on a global scale due to the use of face masks and other PPE during COVID-19.

p.3 "Introducing novel mask types, such as a variety of reusable masks, presents an opportunity to diversify the market, and in turn provide more flexibility within supply chains. This has the potential to increase efficiency and reduce cost, waste, and energy consumption associated with supply chain disruption.[19]"

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Some formal issue, please be more specific in definition of units and symbols, e.g. billion has two versions – short 109 and long 1012 and the paper should be precisely understood outside the US as well.

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Some of our thoughts had been recently published, but we are in no way pushing you to use them:

Jiang, P.; Klemeš, J.J.; Fan, Y.V.; Fu, X.; Bee, Y.M. 2021, More Is Not Enough: A Deeper Understanding of the COVID-19 Impacts on Healthcare, Energy and Environment Is Crucial. Int. J. Environ. Res. Public Health, 18, 684. https://secure-web.cisco.com/1x9FnV1k_WNls3d5bPAyX-AlK6fo8GoCo8wPHBHhAlVnPPTiFTyjYqlOcRxFigtUNAdy3MpeyDXXNmR8-IvsqDcmt8SAOYpaBAvn52aFoZSuMffBPz5Yi_Vo6nbRjKhD8ogokIEJIy9BDkAnQ88-uPe_yRpIvOVOxhPs4w_KDMJ9AFBsMpQJqpqbiWoW_p8QbiBr-1_isshDpLKlbu8DPFGjZCZn3JomuDhZqqlaFuL9Y8ZtAIWQRulyqYywR0qJK/https%3A%2F%2Fdoi.org%2F10.3390%2Fijerph18020684

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p.3 "Introducing novel mask types, such as a variety of reusable masks, presents an opportunity to diversify the market, and in turn provide more flexibility within supply chains. This has the potential to increase efficiency and reduce cost, waste, and energy consumption associated with supply chain disruption.[19]"

p.3 "The global increase in the use of plastics for mask and PPE production has drastically increased medical waste, with countries such as Spain and China reporting increases of 350% and 370%, respectively.[20] As of February 2020, the production rate of face masks in China alone increased by 12 fold.[20]"

p. 10 "In addition, our analysis measured only the waste generated by masks themselves and did not study the environmental impact of manufacturing, packaging or waste generation from decontamination processes, which some studies estimate could generate up to 90% of greenhouse gas emissions.[19]"

<u>Peer Reviewer #2 (comments to the author):</u>

1.Thank you for undertaking this project. The model is thoughtfully conceived and highlights the need for resource conservation and pragmatic sustainability at a time when those topics have fallen from public discourse. This reviewer would only make a few comments concerning the study's current scope. First, the method for determining the "waste generation" of each strategy is somewhat limited, being circumscribed to the weight of one make, model, and size of N95

respirator at present. Notably, a mean/median weight of the most common N95 respirators, or a simple range between the highest and lowest weight N95 respirators, may offer greater precision. Alternatively, as a simple solution, the study's explicit examination of the standard size 3M 1860 respirator as a representative model could be cited explicitly in the study's strengths and limitations (at present it is absent).

We thank the reviewer for this important comment. In order to provider a wider scope of the “waste generation” for each strategy, we have conducted a sensitivity analysis to provide a range of the lowest and highest weight of commonly used N95 respirators in healthcare: 3M’s 1860 N95 Respirator and Gerson’s 1730 N95 Respirator. The 3M model has a weight of 11.3 grams, whereas the Gerson model’s weight was estimated to be 17.0 grams. Although there are various other respirators used in the healthcare system, these two models, and their differences in weight, provide a representative range for the waste accumulated from respirator use. Estimates using the Gerson model respirator are included in Supplementary Table 2. Additionally, we perform an estimate using a commercially available reusable elastomeric respirator with results listed in Supplementary Table 3.

2.Second, in a related vein, the citation given for "Weight of one N95 Respirator" in Table #1 does not appear to match the information cited; this also applies to the citation given for "Weight of one Surgical Mask" in Table #1, and the citation for "Number of Hospitalizations due to COVID-19" in Table #2. Please double check these sources in case a numbering error occurred in the works cited.

We thank the reviewer for identifying these citation errors. We have addressed this by updating the citations to reflect the appropriate parameters in Table 1 on p.4. For the citation referring to “Weight of one N95 respirator”, we have referenced the manufacturer website for 3M, where the weight of one surgical N95 respirator is noted as 11.3 grams. For the citation referring to “Weight of one Surgical Mask” we have revised our source to reference the product distributor Adesso and the weight of their ‘3 Ply Disposable Personal Protective Face Mask’, 8.5 grams. For the citation referring to the “Number of Hospitalizations due to COVID-19” in Table 2 on p.5, upon investigation we found that the citation for “Number of Hospitalizations due to COVID-19” on the COVID Tracking Project’s Cumulative hospitalizations page had been removed as of November 16th due to the fact that it was an under-representation of the total hospitalizations in the United States, as only two-thirds of states and territories reported this data. We have addressed this in the “Limitations” section in the Discussion on p. 10.

p. 10 “Additionally, the number of COVID-19 hospitalizations were likely underestimated in this study, as only two-thirds of states and territories in the United States have reported this data during the COVID-19 pandemic; however, we suspect that this therefore underestimates the potential impact of mask reuse strategies.[46]”

3.Third, it would be of immense benefit to capture the costs of UVGI or H202 vapor-decontamination in a more detailed context. Looking to H202 vapor-decontamination in particular, the number of respirators required is calculated nationally (at a reported 6,090 U.S. hospitals) but is compared to the cost ($415 million) of H202 vapor-decontamination use at only 60 sites. Without a more robust metric it is difficult to contend that true cost-saving is occurring. This would also add a unique comparison where the magnitude of waste generation may need to be weighed against cost expenditure, potentially adding further impetus for technologies better suited to low resource settings. Similar to the study's selection of a representative N95 respirator,

perhaps a simple value could be derived from the experience of a single hospital system and extrapolated nationally to all sites included in the respirator usage calculation. These recommended edits notwithstanding, the manuscript's content is novel, and of critical salience. It was a pleasure reviewing your team's work.

We thank the reviewer for this important and helpful suggestion. In order to provide a more in-depth cost analysis of the H_2O_2 decontamination systems, we conducted a literature review to estimate the lower and upper bound costs based on the decontamination capacity of the facilities and the number of hospitals in the United States. We used the example of a large academic teaching hospital here in Boston, MA and the Battelle decontamination center in close proximity located in Somerville, Massachusetts. We described our findings in the "Cost Estimate" section of the Methods on p. 6 and further described in Supplementary Table 1, as well as the "Cost Estimate" section in Results on p. 7.

p. 6 Methods (Cost estimate): "Due to variation in implementation and maintenance costs for Battelle H_2O_2 vapor decontamination systems across sites, it was difficult to estimate exact costs.[51] We performed a sensitivity analysis to estimate lower and upper-bound costs based on data from the Battelle decontamination center in Somerville, MA and added them to the total cost of the respirators themselves. This decontamination center is capable of decontaminating 80,000 respirators per day and servicing up to roughly 157 hospitals. There are currently 6,090 hospitals across the United States.[47] For the lower bound, we estimated that if each site were able to service 157 hospitals, this would require approximately 39 decontamination centers and only 65% of the 415 million dollars to fund 60 sites across the United States. For the upper bound, we used a decontamination cost per respirator of $3.25 and multiplied that by the respirator usage required for the first 6 months of the pandemic.[52] In addition, we estimated the shipping costs from a large academic hospital here in Boston, MA (Massachusetts General Hospital) to the local Battelle decontamination center in Somerville, MA. The shipping costs for one day per each hospital were estimated to be $114 to and from the site (for a total of $228 in shipping costs; based on the estimated weight of 25 lbs. for shipping 1000 masks over a distance of roughly 3.5 miles).[53] We scaled this cost by the number of hospitals and Battelle sites across the United States over the course of the first 6 months of the pandemic and added this to the overall costs for lower, base-case, and upper bound costs (Supplementary Table 1). For the cost of the UVGI system, we assumed the base-case cost of the UVGI system to only include the cost of the respirators required. The literature suggests that UV systems are more readily available on site in many hospitals in comparison to H_2O_2 vapor decontamination systems. [39] This may be because UV systems require significantly less space and personnel than H2O2 vapor decontamination systems.[40]"

p. 7 Results (Cost Estimate): "The cost for the H_2O_2 vapor decontamination strategy would reduce cost to $1.65 billion ($4.17k per patient), saving approximately 1.18 billion, though sensitivity analyses estimated the cost of the H_2O_2 decontamination system could vary between $1.51-$4.98 billion (Supplementary Table 1)."

<u>Peer-Reviewer #3 (comments to the author):</u> Thank you for the opportunity to review this manuscript. Overall, this is a well-written study that offers a timely & important perspective on the economic and environmental impact of respirator use strategies during the COVID-19 pandemic in the US.

1.To "compare the impact of respirator extended use and reuse strategies with regard to cost and sustainability during the [first 6-months of the] COVID-19 pandemic" in the United States, the

authors perform a model-based quantitative analysis of the usage, cost, and waste associated with several respirator use strategies.

Findings from this study have important implications for research, policy, and medical practice during the ongoing pandemic, but could also offer insights into respirator use strategies as the pandemic draws to a close and during any public health emergencies that may arise in the future.

Introduction: Excellent overall. Minor issue: since the distinction is made, the authors should try to better characterize / define reusable vs non-reusable respirators. In other words, at least within context of the introduction, 'reusable respirators' does not include disposable respirators that are decontaminated by any method, correct? At least as currently phrased, this distinction does not seem to be wholly consistent with references to various reuse strategies throughout the rest of the paper.

We thank the reviewer for this important comment. In order to provide a better distinction between the different reuse strategies that are referred to throughout the paper, we formally introduced each term on p. 3 of the Introduction in order to more clearly define and characterize them for consistency.

p. 3 "For the purpose of this study, we used the following terms to describe the different respirator use and reuse strategies: single use refers to the use of one disposable respirator per patient encounter, followed by disposal; extended use refers extended use of a disposable respirator to an entire day, followed by disposal; and reuse refers to strategies to decontaminate respirators or use of non-disposable respirators longer-term."

2.Methods/Results: The analysis was based on data pertaining to the 3M 1860 disposable respirator, as well as a second respirator that appears to have been developed by some of the study co-authors. Is there any reason why the authors chose to compare the respirator that they helped develop with just the 3M 1860 disposable respirator? This should be described in the paper.

We thank the reviewer for this helpful comment. We studied the 3M 1860 respirator since we found it to be the most common respirator used in the US. Furthermore, we decided to study a reusable respirator recently developed by our co-authors as it was the most inexpensive currently developed; therefore, we believe this would be a useful estimate of the potential cost-savings from the use of reusable respirators. However, to address these considerations, we've also performed a sensitivity analysis using Gerson's 1730 N95 Respirator as well as 3M's reusable respirators with P100 filters included in the "Sensitivity analysis" section of the results on pp. 7-8.

pp.7-8 "A sensitivity analysis of a larger commonly used disposable respirator (Gerson 1730) did not significantly change the estimated cost of the strategies or relative amounts of waste generation (Supplementary Table 2). Cost and waste estimates for commercially available reusable half-facepiece elastomeric respirators (3M 7500 series) with P100 filters (assuming that each HCW uses one pair of filters per week) were also explored (Supplementary Table 3).[27 ,28 ,34 ,57] Low and high cost estimates of $2.02 and $2.26 billion were calculated using sources from the commercial manufacturer 3M,[28] with reusable respirator costs ranging from $25 to $45 per respirator with a single disposable P100 filter cost of $7.00.[27 ,28] These cost estimates of $2.02-$2.26 billion were lower than the one respirator per day reuse strategy, but higher than the H_2O_2 decontamination, UVGI decontamination, reusable respirator, reusable respirator with decontaminated filters, and surgical mask strategies (Table 4, Supplementary Table 3). Low and high waste estimates of 3.22 million kg and 3.59 million kg were calculated using a respirator weight of 135 grams and filter weight of 4.54 grams (Supplementary Table 3). These waste estimates were lower than the one per day reuse strategy, H_2O_2 decontamination, UVGI, reusable respirator, and surgical mask strategies, but higher than the reusable respirator with decontaminated filters strategy (Table 4, Supplementary Table 3)."

3.**Methods/Results: Moreover, there is often only a single value for the baseline cost and waste parameters reported in Table 1. References are given, but the authors should also name the exact respirator(s) / mask(s) that correspond to the parameters given in Table 1 (also Table 4).**

We thank the reviewer for this important clarification. In order to make the types of respirators/masks used in the analysis more clear and explicit, we provided the names of each mask type in correspondence to the parameters in Table 1 on p. 4 and in the results in Table 4.

4.In addition to the HCW population, is there uncertainty or variability in any other parameter that went into the model used by the authors? If so, the authors should adjust their analysis accordingly, e.g. by giving a range of estimates where uncertainty / variability exists. For example, the authors report that H2O2 vapor decontamination could reduce the number of respirators required by 20-fold. However, this number appears to be based on data published by the manufacturer of an H2O2 decontamination system, Battelle. Is there any reason to suspect that this may be an overestimate of reusability and, if so, how might accounting for this source of uncertainty impact study results? Similarly, the authors also elsewhere assume a "30% discard rate per day due to damaged or visibly soiled respirators after each cycle of decontamination." Wherever possible, cost analyses should provide a range of reasonable model parameters from multiple sources to help avoid introducing bias from any single source.

We thank the reviewer for this important feedback. In order to provide a more thorough analysis for cost and waste estimates and to add to the base values provided in Table 1, we conducted sensitivity analyses of the number of decontamination cycles required per strategy (UVGI and H2O2) as well as the discard rates. We have added the results of our sensitivity analyses to Supplementary Tables 4-8 and provided additional clarification in the text:

p. 8 "Sensitivity analyses of respirator discard rates and maximum cycles of H_2O_2 decontamination found that a 10% discard rate lowered respirator usage, cost, and waste generation by 657 million respirators, $601 million, and 7.45 million kg, respectively. A 50% discard rate would increase respirator usage, cost and waste generation by 660 million respirators, $570 million, and 7.44 million kg, respectively. Lowering maximum decontamination to 10 cycles increased respirator usage, cost and waste generation to 160 million respirators, $155 million, and 1.86 million kg, respectively (Supplementary Tables 4-5)."

p.8 "A sensitivity analysis of the UVGI decontamination system costs estimated a range of $1.41-1.42 billion, even accounting for variations in sophistication of technology installed (Supplementary Table 6). Sensitivity analyses of respirator discard rates and maximum cycles of UVGI decontamination found that a 10% discard rate reduced respirator usage, cost, and waste generation by 654 million respirators, $562 million, and 7.44 million kg, respectively. A 50% discard rate increased respirator usage, cost and waste generation by 660 million respirators, $570 million, and 7.44 million kg, respectively. Lowering maximum decontamination to 2 cycles increased respirator usage, cost, and waste generation by 990 million respirators, $850 million, and 11.17 million kg, respectively (Supplementary Tables 7-8)."

5.Study findings pertain to the first 6-months of the COVID-19 pandemic. From a translational perspective, however, there will likely never be another scenario (emergency or non-emergency) that perfectly mirrors what was experienced over this period. In addition to base-case analyses, would the authors be able to quantify average costs & waste generated on a per patient basis? This would be helpful evidence for different readers (e.g. hospital leaders) given that e.g. "even after the pandemic, respirator and mask usage both in healthcare settings and among the general public may persist."

We thank the reviewer for this important comment. In order to quantify the average cost and waste on a per patient basis, we divided our cost and waste results per each respirator strategy by the total number of hospitalized COVID-19 patients and added additional columns entitled, "Cost accumulated per patient" and, "Waste generated per patient" to Table 4 in Results on p.8. Due to the underestimation of total COVID-19 hospitalizations (only two-thirds of US states and territories report total number of hospitalization data) brought to our attention in section 3.2 of the Peer-Reviewer #2's comment, the impact of mask reuse strategies is likely much greater than reported in this analysis, which we have included in the Limitations section of our Discussion on p. 10.

6.Thank you for including a discussion of study limitations. Among these, the authors acknowledge that they e.g. did not include installation, maintenance, distribution, or personnel costs associated with each strategy; and did not account for the environmental impact of manufacturing or decontamination processes.

We thank the reviewer for this helpful comment. In order to adequately summarize the updates to the study limitations in the Discussion, we further acknowledged that installation, maintenance, distribution, and personnel costs associated with each strategy were not included in our analysis as well as the impact of manufacturing or decontamination on pp. 9-10.

p. 9 "though additional studies are needed to estimate the impact of additional costs, such as shipping to shared decontamination sites, installation costs, and time associated with decontamination or cleaning methods. Additional investigation is needed to capture other potential costs and benefits related to each mask-reuse strategy."

p. 10 "In addition, our analysis measured only the waste generated by masks themselves and did not study the environmental impact of manufacturing, packaging or waste generation from decontamination processes, which some studies estimate could generate up to 90% of greenhouse gas emissions.[19] Furthermore, the environmental impact of single-use plastics generated from packaging related to mask use, estimated to have increased by up to 40% during the pandemic, may contribute a significant amount of additional environmental waste.[64] These aspects were not included in our analyses and require further quantification."

7.Findings from this study point to clear economic and environmental benefits from respirator reuse strategies. It's not clear to me whether policy changes regarding respirator use across the country have consistently been based on an objective, comprehensive assessment of the risks and benefits from alternative strategies. At least based on your analysis, I would have expected wider use of reusable respirator options, especially before the current pandemic. Would you the authors be able to hypothesize why there appears to be a disconnect between what the evidence (and practical experience) might suggest on potential benefits to respirator reuse and the strategies that have been adopted nationally? Would the authors be able to offer evidence-based

recommendations for research or policy that could help address this disconnect? For example, individual hospital systems may not appreciate the environmental impact from use of disposable respirators to the same degree that an entire country might. Could any perceived failure to optimally change respirator use policy therefore at least in part be due to what is described in economics as negative externalities? Might there be anything to learn from how this concept has traditionally applied to e.g. pollution? And, might governments therefore have a role to play in influencing respirator use policies (e.g. subsidies during the pandemic to help hospital systems transition to reusable respirator systems, taxes as the pandemic draws to a close to help better account for any negative externalities that may be associated with use of disposable respirators)? These are particularly important questions to consider as the pandemic draws down—it's unclear whether hospitals will revert back to the use of disposable respirators.

We thank the reviewer for this very thoughtful and important point. We have incorporated these concerns into our Discussion section on pp.10-11 below:

pp. 10-11"Our analysis raises key questions for stakeholders regarding the optimal strategy to both provide sufficient protection for healthcare workers and patients while also ensuring equitable access to PPE and reducing environmental harm. Given our findings that reusable respirator strategies greatly reduce the number of respirators required and medical waste generated, it is interesting that reusable respirators or decontamination strategies have largely not been adopted in the US prior to the COVID-19 pandemic. We hypothesize that this could be due to a number of reasons including cost and availability of reusable respirators, lack of recognition of the scale of medical waste and its impact on the environment, and individual healthcare systems' lack of accountability with regard to medical waste. We have reason to believe that the first two reasons will be addressed over the course of the pandemic. Given renewed interest in new technologies for PPE, we expect options and availability for reusable respirators to continue to expand.[15] We believe our study as well as others will increase public awareness of the environmental impact of disposable PPE, particularly masks.[22 ,38 ,64] In order to improve hospital system accountability over medical waste, however, we may need to turn to policymakers to consider nationwide incentives such as subsidies to transition to reusable PPE, taxes to offset medical waste generation, and other incentives as has been used to promote transition to green technologies in other fields.[66-68]"

8.As an aside, surgical N95 respirators are often not reused. That said, there are users of surgical N95 respirators that are not directly involved in surgical patient care—it would be highly usual for their masks to be exposed to bodily fluids. I find there to be some degree of inconsistency between this and initiatives (however justified) to promote the use of reusable respirators—particularly during a pandemic that has involved a novel viral strain. In other words, it seems as if we're applying two different sets of criteria for reusability of respirators. The larger question that the authors may wish to consider discussing is: from a medical and biological perspective, what criteria might justify respirator reusability in different healthcare settings?

We thank the reviewer for this helpful suggestion and have included this in the Limitations section of our Discussion.

pp. 9-10 "An additional limitation of our study is that we modelled one strategy for all HCWs, regardless of frequency and type of patient contact. For HCWs at low risk of contact with bodily fluids (including respiratory droplets), it may be possible to deploy alternate strategies such as extended use of disposable respirators or less frequent decontamination. This could potentially further reduce cost and waste and increase respirator availability without sacrificing protection."

9.On this point, the authors offer important insights into the use, cost, and waste associated with respirator use strategies used during the first 6 months of the pandemic. If this is to inform respirator use strategies moving forward, what other 'costs' and 'benefits' might exist? For example, are the various respirator use strategies considered in this study associated with any health risks that could lead to greater health-related costs compared to disposable respirators? It may not be within the scope of this study to systematically identify and quantify all costs and benefits associated with each respirator use strategy. However, the authors of this study should at the very least make it clear throughout that any representation of costs is not comprehensive; cost-benefit analyses are likely still needed. For example, it sounds great that assigning one respirator to each HCW over the course of the pandemic could have cut down on the number of respirators used by 99%, but would having done so contributed to health-related costs that aren't quantified / considered in this study? This is particularly important given some of the points raised in the paper, including for instance that "combining the strategies … was the least costly of all strategies"—perhaps, but only if one only counts the costs considered in thistudy.

We thank the reviewer for this important feedback. In order to highlight that the representation of costs in this study is not comprehensive and that future cost-benefit analyses are still needed we reiterated the hidden costs such as those associated with installation, personnel, and maintenance in the Principal Findings section of the Discussion on p. 9. We also highlighted the differences in efficacy across respirator use and reuse strategies and incorporated studies that looked at the effects of mask reuse on mask fit and filtration in the Limitations section of the Discussion.

p.9 "additional studies are needed to estimate the impact of additional costs, such as shipping to shared decontamination sites, installation costs, and time associated with decontamination or cleaning methods. Additional investigation is needed to capture other potential costs and benefits related to each mask-reuse strategy."

p.9 "The decision to employ decontamination methods for reuse should be weighed against the possibility for greater health risks incurred by incomplete decontamination or lowered respirator efficacy, which may incur additional costs. The CDC recommended extended respirator use and reuse strategies for N95 respirators if respirators maintained their fit and function after decontamination.[61] Several studies have evaluated the effect of extended use and re-use strategies that require multiple donning on the fit and efficacy of N95 respirators independent of decontamination. One study found that 48% of subjects failed a fit test after only one redonning of an N95 respirator. Additionally, another study found that among test subjects experienced in respirator donning, consecutively donning the same respirator 5 times was the threshold before mask-fit dropped below 100%.[62] Furthermore, both UVGI and H_2O_2 decontamination methods have shown to reduce filtration and mask performance after 3 rounds of decontamination in some studies.[63] Therefore, it is important to note that the efficacy of each reuse strategy may not be not equal and should be considered prior to implementation. Potential costs related to unequal respirator efficiency and protection were not estimated in our analysis."

10.The authors describe different reuse strategies throughout the paper, e.g. hydrogen peroxide, heat, steam, detergent, UVGI, as well as alcohol and bleach wipes in resource-constrained settings. I think it's important for the authors to explicitly mention that the efficacy of such reuse strategies (and thus the total cost incurred from each strategy) is not likely to be equal—e.g.

alcohol wipes may be more readily available, but any decision to use this decontamination strategy in the future should (for example) also be balanced against the possibility of greater health risks.

We thank the reviewer for this important suggestion. In order to be more clear regarding the difference in efficacy among reuse strategies, we explicitly stated this in the Limitations section in the Discussion on p.9.

p.9 “The decision to employ decontamination methods for reuse should be weighed against the possibility for greater health risks incurred by incomplete decontamination or lowered respirator efficacy, which may incur additional costs. The CDC recommended extended respirator use and reuse strategies for N95 respirators if respirators maintained their fit and function after decontamination.[61] Several studies have evaluated the effect of extended use and re-use strategies that require multiple donning on the fit and efficacy of N95 respirators independent of decontamination. One study found that 48% of subjects failed a fit test after only one redonning of an N95 respirator. Additionally, another study found that among test subjects experienced in respirator donning, consecutively donning the same respirator 5 times was the threshold before mask-fit dropped below 100%.[62] Furthermore, both UVGI and H_2O_2 decontamination methods have showto reduce filtration and mask performance after 3 rounds of decontamination in some studies.[63] Therefore, it is important to note that the efficacy of each reuse strategy may not be not equal and should be considered prior to implementation. Potential costs related to unequal respirator efficiency and protection were not estimated in our analysis.”

11.In terms of relevance and impact, it would also be helpful for the authors to bolster their discussion of how their findings should be interpreted as the pandemic draws down—see comments above for some issues to potentially touch on.

We thank the reviewer for this important feedback. In order to bolster our discussion on how our findings should be interpreted moving forward as the pandemic draws down, we have discussed this in the Principal Findings and Conclusions sections in the Discussion on pp. 9 and 11.

p. 9 “Even after widespread vaccination efforts, masks will likely continue to be required due to factors such as variable vaccine uptake, incomplete vaccinations, lack of knowledge as to who has received a vaccine, the possibility of reinfection, and unclear duration of vaccination efficacy.[58 ,59] Additionally, even after the pandemic, respirator and mask usage both in healthcare settings and among the general public may persist.[60]”

p.11 “This need is emphasized by the likelihood that respirators will continue to be commonly used even after widespread vaccination and post-pandemic in certain scenarios, such as healthcare and crowded transportation areas, and such technologies can enable more sustainable use of respirators moving forward. Furthermore, these technologies can save billions of dollars that can be redistributed toward other efforts for economic and environmental recovery brought on by the pandemic. Further study is needed regarding reuse fit and filtration efficacy to minimize health risks associated with reuse strategies.”

VERSION 2 – REVIEW

REVIEWER	Green, Alex Wayne State University School of Medicine
REVIEW RETURNED	27-Apr-2021

GENERAL COMMENTS	Once again, thank you authors for undertaking this project; it has been a pleasure examining the results. Having reviewed the new submission, it is evident that many concerns highlighted in the initial draft have been addressed. The limitations imposed in selecting a representative N95 respirator model are explicitly stated, and the quantification of H2O2 costs in particular have been scaled up to better model and compare the prospective benefit of a U.S.-wide implementation. A remaining question is why the lower bound of the sensitivity analysis is based on one variable (the number of hospitals serviced by treatment sites) while the upper bound is based on another (the cost per respirator), as opposed to variations in one variable or the other. As noted before, another important remaining concern is that certain citations still appear inappropriate to the contentions they are used to support. Some of these are minor, while others bring into question the base cost assumptions used in the model. Highlighted below are a few examples: Citation #28 is used to report the weight of one 3M 1860 N95 respirator, yet the citation and link concern a different respirator (3M 6291/07002(AAD) Medium, with 3M Particulate Filters). Citation #36 (PMID 28673259) is used as the source for 3M 1860 N95 and PPE 100-50 Surgical Mask costs, yet the cited article only reports the cost for a 3M flat-fold N95 respirator (catalogue number 9132) and a 3M Standard Tie-On surgical Mask (catalogue number 1817). Additionally, the costs not only appear to be associated with different models than intended, but are also reported to be from earlier estimations; table one reports that the costs have been derived from conversations with a 3M Senior Occupational Hygienist in 2012 and 2014. Is there a way to derive these costs independently and directly from 3M in the present? Citation #38 (PMID 33519950) is used in a few instances that are beyond its scope, particularly in the "Implications and Future Research" section. On a minor note, review articles such as citations #19 and #20 are employed and interpreted broadly, when their respective, internal citations may better suit the cited material. For instance, in citation #20 (PMID 33466940), internal citation #89 is the source of the quoted 370% medical waste increase in Hubei, China, internal citation #116 is the source of the 350% increase in Catalonia, Spain, and internal citation #115 is the source of the 12-fold increase in the production of face masks containing plastic components in China between January and February 2020. As before, it is recommended that the authors reconcile the

	instances where the scope or numbering of citations do not match the intended arguments cited. Otherwise, the manuscript's content is of value and timely importance, and the new additions make for a more robust cost-benefit estimation model. Thank you for the opportunity to review your work.

VERSION 2 – AUTHOR RESPONSE

Point-by-point response:
Peer Reviewer #2 (comments to the author)

1. Once again, thank you authors for undertaking this project; it has been a pleasure examining the results. Having reviewed the new submission, it is evident that many concerns highlighted in the initial draft have been addressed. The limitations imposed in selecting a representative N95 respirator model are explicitly stated, and the quantification of H2O2 costs in particular have been scaled up to better model and compare the prospective benefit of a U.S.-wide implementation.

A remaining question is why the lower bound of the sensitivity analysis is based on one variable (the number of hospitals serviced by treatment sites) while the upper bound is based on another (the cost per respirator), as opposed to variations in one variable or the other.

We thank the reviewer for this important clarification. For the H2O2 decontamination cost sensitivity analysis, we chose to use two different variables for the lower and upper bound estimates due to the variation in implementation and maintenance costs for H2O2 decontamination across the country in order to capture the largest range of cost estimates for the H2O2 system. Since H2O2 decontamination methods were not universal across the United States throughout the first 6 months of the pandemic (every hospital in the United States did not have access to a Battelle Decontamination Center, facility decontamination efficiency may vary across centers, sophistication of decontamination systems may vary, etc.), we thought it would be beneficial to demonstrate the costs utilizing different variables and include those that generated the lowest and highest total cost for the H2O2 system in order to generate the broadest sensitivity analysis (p 6 Methods “Cost Estimate”). The lower bound cost was a conservative estimate using the assumption that all hospitals in the United States had access to a Battelle decontamination center, with each decontamination center servicing 157 hospitals per day. The upper bound cost was calculated using the individual cost of H2O2 decontamination ($3.25/respirator) per respirator and multiplying that by respirator usage required for the first 6 months of the pandemic. This resulted in a higher cost estimate than changing the number of hospitals that Battelle decontamination centers were capable of servicing per day, and therefore was a more stringent test of H2O2 strategy’s cost effectiveness. Please see the in-text description on p 6 Methods “Cost Estimate” and p 8 Results “Cost Estimate”. Both the lower and upper bound costs included the cost of the respirators themselves as well as shipping costs (p 6 Methods “cost estimate”).

P 6 Methods “Cost Estimate”: “We performed the sensitivity analysis varying different parameters for the upper and lower bounds in order to test the widest range for the cost of the H2O2 decontamination strategy.”

2. As noted before, another important remaining concern is that certain citations still appear inappropriate to the contentions they are used to support. Some of these are minor, while others bring into question the base cost assumptions used in the model. Highlighted below are a few examples:

Citation #28 is used to report the weight of one 3M 1860 N95 respirator, yet the citation and link concern a different respirator (3M 6291/07002(AAD) Medium, with 3M Particulate Filters).

We thank the reviewer for noticing this important citation error. We have updated citation #28 on p 13 to reflect the correct respirator (3M 1860) that was used throughout our model. This is now citation #29 and is found in text and in Table 1 on p 4 (please see citation 29 below).

“3M. Science. Applied to Life. 3M™ Disposable Respirator 1860, 1860S, N95. Products 2021 [Available from https://multimedia.3m.com/mws/media/1538979O/3m-disposable-respirator-1860-1860s-technical-data-sheet.pdf.]”

Citation #36 (PMID 28673259) is used as the source for 3M 1860 N95 and PPE 100-50 Surgical Mask costs, yet the cited article only reports the cost for a 3M flat-fold N95 respirator (catalogue number 9132) and a 3M Standard Tie-On surgical Mask (catalogue number 1817). Additionally, the costs not only appear to be associated with different models than intended, but are also reported to be from earlier estimations; table one reports that the costs have been derived from conversations with a 3M Senior Occupational Hygienist in 2012 and 2014. Is there a way to derive these costs independently and directly from 3M in the present?

We thank the reviewer for this important comment. We reached out directly to 3M on Tuesday, June 23, 2021. The representative declined to give us the cost data for their N95 respirators. We searched the literature as well as online manufacturers/distributors and found variable market costs. We found a unit cost of $1.27/respirator from 3M (citation #57). 3M noted that costs were likely to be negotiated to a lower price when bought in bulk. For this reason, we used the base case cost of $0.86 (converted from $0.79 USD 2014 to 2020 USD; Mukerji et al, 2017; citation #36 p 13) and conducted a sensitivity analysis to compare it to the cost of $1.27 (Supplementary Table 3). We found that even at a cost of $1.27 per respirator, which is an overestimate given lack of wholesale discount, the relative rankings of the reuse strategies did not change. We also found an updated 2020 cost for a 3-ply surgical mask (Fluidshield Level 1 Sensitive Skin) of $0.14, which was comparable to our original cost estimate found in the literature. Please see Table 1 p 4 and Table 4 pp 8-9, as well as citations 35 and 36.

Pp 8-9 Results “Sensitivity Analyses”: “An additional sensitivity analysis was conducted looking at a different 3M disposable respirator cost found from the commercial manufacturer 3M to account for variability in market costs ($1.27/respirator). The cost variation did not change the relative rankings of the reuse strategies (Supplementary Table 3).[36 ,57]”

3. Citation #38 (PMID 33519950) is used in a few instances that are beyond its scope, particularly in the "Implications and Future Research" section.

We thank the reviewer for this important comment. We have removed citation #38 from the “Implications and Future Research” section in the Discussion on p 11 and agree that the other citations (#38 and #69) are sufficient in support of our discussion point.

P 11: “We believe our study as well as others will increase public awareness of the environmental impact of disposable PPE, particularly masks.[38 , 69]”

4. On a minor note, review articles such as citations #19 and #20 are employed and interpreted broadly, when their respective, internal citations may better suit the cited material. For instance, in citation #20 (PMID 33466940), internal citation #89 is the source of the quoted 370% medical waste increase in Hubei, China, internal citation #116 is the source of the 350% increase in Catalonia, Spain, and internal citation #115 is the source of the 12-fold increase in the production of face masks containing plastic components in China between January and February 2020.

We thank the reviewer for this important comment. We have added the internal citations #89, #116, and #115 from the original citation #20 to our article in the introduction section on p 3. These are now citations #20 for the quoted 350% increase of medical waste in Catalonia, Spain; #21 for the 370% increase of medical waste in Hubei, China; #22 for the 12-fold increase in production of face masks containing plastic components in China between January and February 2020 (References, p 13). The original citation #20 is now citation #21 in the introduction on p 3 and also found in references on p 13.

After reviewing the use and context for citation #19, we felt that it should be cited as it is referencing interpretation of data and conclusions drawn by the authors in Klemes et al, 2020 (citation #19, References, p 12). We have also included the original citation for the reference regarding 90% of greenhouse gas emissions coming from medical sterilization/decontamination (citation #68, References, p 15). We thank the reviewer for the opportunity to rereview this citation and ensure it is being used appropriately.