**Reviewer A:**

Review of “Atmospheric composition, irreversible climate change, and mitigation policy” by Solomon et al.

This is a well argued review article making the case that a single basket mitigation policy is not justified by the science.  It clearly represents current literature and thinking on the subject.  It is well written and informative.

The argument is somewhat one-sided but I think this adds interest rather than distracts from the work, so I do not recommend making changes to address this.

Thank you

Any mitigation depends on the policy objective and I think they paper could benefit by clearly stating this. It comes across as if mitigation is only dependent on physical science, whereas social issues such as how much regard we put in future generations  - are just as important.

Added in the introduction

Some of the figure choices seemed odd. I didn’t really see the point of figure 1 or figure 5.

The article would be acceptable as is, but it could benefit from stronger figure choices.

**Reviewer B:**

Review of:  Atmospheric composition, irreversible climate change, and mitigation policy (Solomon, Pierrehumbert, Matthews, & Daniel)

Overall:  This is primarily a review paper; the authors also introduce their own arguments.

Technical & scientific quality:  Good.   Substantive comments below in several sections.

Relevance, importance, & clarity of identified priorities:   The authors discuss the relevance of different metrics to policy choices in a way that is directly relevant to the policy discussion and the take-away messages are clear (“avoid a single trading basket”, “beware the flaws of existing metrics”).

International coordination & integration:  Not really discussed

Readability & appeal:  Well-written. For less-informed audiences, the paper provides a nice overview of different metrics, pollutants with different lifetimes, and the implications for policy.  For well-informed audiences, most of the material will be review (it is after all a review paper).  I like the fact that the authors are bold in pointing out the widely different climate outcomes that can come from making trade-offs using the GWP metric – a fact that is not well-appreciated beyond the closely involved scientific community.

Additional comments & suggestions:  What follows below are specific suggestions, first for the text and then the figures, and lastly typos/formatting:

Specific suggestions for text:

Lines 79-81:  Figure 1 shows CO2 only.  Text should read “increase in CO2 that has taken place”

done

Lines 92-95:  This sentence leaves the reader hanging.  The point is correct, but confusing to a less-informed reader and not integral to the arguments in the paper, so the sentence could be cut without being missed.  If not cut, then clarity needs to be added about what the implications are of the relationship being “less well characterized”

Text has been edited for clarity – this makes it difficult for example to quantify land use and this is noted

Line 105:  Cut “and other important factors”;  only lifetime is covered in the table

Done

Line 106:  “uncertainties in lifetimes” would add clarity

Done

Line 117:  Worth adding a sentence here about well-mixed vs. not-well-mixed pollutants, and how “global” forcing differs between them;  the uncertainty in the global forcing of aerosols is not just due to the short lifetimes, but also due to our imperfect but improving ways of understanding & characterizing what a local forcing means on a global scale

Local versus global forcing is addressed a few sentences later but we edited the sentence to make it clearer

Line 131:  Replace “while others could represent” with “versus” to make the sentence more clear

done

Local 132:  Inserting “local” before “black carbon” would add clarity

done

Line 223:  This sentence can be read as implying a linear relationship between concentration & cumulative emissions, and that would only be correct under limited circumstances (depends on the shape of the emissions curve).  Clarification of whether linearity is implied, and under what circumstances it is true would be useful here.

Changed the wording to make this clearer – although we do not want to get into a discussion of linearity here; we replaced ‘tracks emissions’ which did indeed sound linear to ‘is linked to’ which makes clear that there is a relationship but not necessarily a linear one.

Line 227:  Replacing “one-time reduction” with “step-change permanent reduction” would be more accurate

done

Line 228:  This sentence is not technically correct as written.  A reduction in the emission rate of a long-lived gas does not yield a reduction of RF.  It yields a reduction in the annual increase of RF, and the difference between the mitigation RF and the counterfactual RF grows over time.

corrected

Line 255:  This sentence can be mis-read as implying that the height of the pulse is different between short- and long-lived pollutants.  I’m pretty sure that the authors mean that the rate of post-peak decline in concentration is more rapid for short-lived pollutants.  Re-wording would help here.

done

Line 327:  Worth noting here that short-term warming could also be significant if it had a material impact on increasing feedbacks, acknowledging that our understanding of feedbacks is still incomplete.  Those feedbacks would outlive the direct effects of the short-lived pollutants.

It is not clear to us what feedbacks would be more likely to be more non-linear for a short-term warming as opposed to longer-term warming. Reviewer’s comment isn’t clear to us. Left as is.

Line 326:  Also worth mentioning that whether short-term warming is considered “significant” is in itself a value judgment, and one that is made in a political context in which there is a natural human inclination to care most about the next 20-100 years that decision-makers hope to be alive.

The values issues have been addressed briefly elsewhere in response to the comment by another reviewer. Here we are focusing on the physical and chemical responses. Text not changed.

Line 377:  Value judgment is buried here in the word “quickly”.  In this case, quickly refers to over 100 years.  People differ on whether 100+ years is fast or slow.  “Quickly drops” can be replaced with “drops over 100+ years”.

changed

Lines 366-379 and Fig 3c:

A subset of these authors makes a stronger, more nuanced argument on the CO2 vs. CH4 trade-off in Daniel et al, Climatic Change 2011.  In that paper in Fig. 2, they very effectively show the results of achieving the GWP goals of RCP 2.6 and RCP 4.5 via CO2 only vs. CH4 only.  The methane-only scenario in that paper has a lower temperature until ~2085 in the RCP2.6 scenario and until ~2135 in the RCP 4.5 scenario; after those dates, the CO2-only scenario has a lower temperature.  The reader is allowed to evaluate which outcome is better – to this paper’s earlier point of eliminating any value judgment from the authors.

If possible, it would be great to include the Climatic Change figure in this review paper to make the argument about “methane first” vs. “CO2 first”.  The strength of Fig. 3c in the paper at hand is the point about “trimming the peak”.  That argument would be much stronger if the top 2 lines on Fig. 3c were eliminated, leaving only “Methane + 640 GtC” (aka, CO2 reductions only) and “640 GtC, No Methane” (aka, Simultaneous CO2 and CH4 reductions).  These 2 lines would very clearly illustrate “trimming the peak”.

Figure 3 has been modified to address these points; the shaded region in the bottom panel is similar to that shown in Daniel et al. However, we disagree that eliminating the top two curves would make the point of Figure 3c clearer – in fact it would obscure our main point and lead to a very misleading comparison. The lower two curves alone do indeed illustrate peak trimming, but by themselves they frame the policy alternative in an incomplete way. One always will get more cooling from doing two things rather than doing one thing. The correct question to ask, however, is whether we could get an even better outcome if methane abatement were deferred and the extra resources put into additional reductions in CO2. The peak trimming comparison becomes relevant only if we get the methane reductions essentially for free, or if the situation is such that additional reductions of CO2 are essentially impossible, for technical or political reasons. We have added a few sentences to point out these issues, and also put in a sentence in connection with the discussion of Fig. 6 referring back to this point.

Line 386:  Contrast should be stated more precisely.  Authors showed in Fig 3b that warming persists for several hundred years after short-lived pollutant emissions end.  The difference between short- and long-lived pollutants is not that the warming of long-lived pollutants “persists long after emissions are eliminated”, but the magnitude at which the warming persists – which is much higher for long-lived pollutants.

Wording changed

Line 397:  Would add accuracy to say “gases and its abundance relative to other long-lived pollutants” (since the other long-lived pollutants would also be important if present in large quantities)

Disagree. The reference to ‘major gases’ means that we are talking only about gases that are present in large amounts. We are not talking here about e.g. perfluorocarbons, which are not among the major gases. The focus here is on major gases and their time scales.

Lines 399-418:  This paragraph begs for a physical explanation.  Results of several models are provided as evidence.  The reader deserves a physical explanation of the temporal dynamic of RF & ocean heat uptake that makes modelers confident in their results.  A partial explanation is provided in lines 457-460, but can be improved.  See comments below.

Addressed below where specifics are offered.

Lines 406-407:  Need to add clarity here on “the ocean”.  I’m pretty sure what the authors mean is that the increase in mixed layer temperature provided by the on-going (though decreasing) RF is almost exactly offset by the decrease in temperature of the mixed layer due to heat transport to the deep ocean – such that the mixed layer temperature stays fairly constant. The fact that these two rates are roughly the same is, I believe, coincidental.

Reviewer’s comment is muddy; first he suggests the mixed layer temperature decreases (which is not correct) then he says that it stays fairly constant. The key cancellation is between the rate of decrease of CO2 forcing and the declining rate of ocean heat uptake. The balance between the two is not entirely coincidental since both involve transport times in the ocean. Text has been modified to emphasize the basic physics of this response which adds to the fact that it occurs in a variety of types of models, and the reader is referred to Solomon et al. (2010) for a detailed analysis.

Line 449:  “ocean and land biosphere”

done

Lines 455-456:  This cited statement does not seem to be supported by observations.  So far, we have observed only the slightest rise in airborne fraction over a 50-year period of large increase in CO2 emissions; the observed AF change is probably within the range of error bars (see Global Carbon Project).

The changes in carbon so far are fairly small. This pertains to large net emissions. Wording clarified.

Lines 457-461:  This section could be presented more intuitively.  Radiative forcing increases the temperature of the mixed layer.  As RF declines, the annual rate of increase of temperature in the mixed layer is reduced.  Simultaneously, the temperature of the mixed layer decreases as heat is exchanged into the deep ocean.  The increase of mixed layer temperature from RF and the decrease of mixed layer temperature by deep ocean transport happen to offset each other, resulting in a fairly steady mixed layer temperature.  (It would be interesting to also comment on under what circumstances it is true that these rates happen to be the same, and under what circumstances they are not.)

We disagree. See above response to 406-407. Text not changed.

Lines  470 & 475:  “Instantaneous” temperature change is an incorrect description.  Matthews et al. defines climate-carbon response (CCR) as the “temperature change over some period of time, [divided]… by the total cumulative CO2 emitted over that period.”  Allen et al. defines Cumulative Warming Commitment (CWC) as “the peak warming response to a given total injection of CO2 into the atmosphere.”

Text changed.

Lines 480-483:  Not quite correct as worded, on two points.  First, “The magnitude of climate changes that occur in the coming century” will be determined by emissions to-date plus the emissions during this century, not “between now and the time by which humans are able to stop emitting CO2” (unless that time is within this century).  Second, as the authors show in Figure 6, the climate in this century will be determined by not only CO2 but also pollutants such as methane, black carbon, and (not in the figure) other aerosols such as sulfates.

Wording has been changed to address the first point. Second point is covered by the words ‘to a large extent’ since most of the warming is due to carbon dioxide increases.

Line 482:  “are able to” is something of a value judgment.  These words could be eliminated.

done

Lines 483-486:  This sentence is confusing as written.  The statement starting with “even the immediate” is true irrespective of tipping points. And tipping points themselves are often irreversible on near-term timescales even if temperature were reduced.  I’d cut this whole sentence because the main point has already been made.

Here we are emphasizing that the long time scale perturbation increases the vulnerability to a tipping point that could occur at any point in the future. Not all tipping points that are considered at present (such as in the Lenton paper referenced) are inherently irreversible in and of themselves. This point follows from previous statements but does not repeat anything said earlier, and we have retained it.

Lines 496, 517:  “shown by many authors”, “numerous studies” – would be nice to cite 2-3 examples

Done

Line 501:  Would be nice to insert a sentence here about why “trimming the peak” might be desirable.

done

Line 502:  Needs a citation – Solomon et al., PNAS 2010

Done but we chose Held et al., 2010.

Specific suggestions for figures:

Fig. 2:  Need to quantify “very likely”.

done

Fig. 2:  Need to clarify which definition of CO2eq is being used – I think from the text that it’s the RF definition (“concentration of CO2 that would cause the same RF as a given mix of CO2 and other chemicals”)

CO2 equivalent concentration refers to RF, as is standard practice. Clarified.

Fig. 3a & b:  y axis scale is not meaningful because quantity of emissions is not provided; numbers should be removed

done

Fig. 3c:   See comments in text section above re this figure

Addressed above

Fig. 3c:  Need to provide context for how this amount of methane compares to current emissions (make it relevant to real-world policy)

done

Fig. 3c:  Should clarify that a world with “no methane” emissions is technically infeasible

As for carbon dioxide, this is a limiting case representing no added anthropogenic emissions, not a world with no methane emissions whatever. This paper is not about what may ultimately be technically feasible but rather how climate physics interacts with timescales of the gases. Recall that these are climate physics tests, not economic scenarios, and are only chosen to illustrate the different outcomes possible for identical GWP's. To add more caveats would make the points murky and we have left the text as is.

Fig. 3c:  Clarification needed  - is “cumulative” from 2000-2300?

clarified

Fig. 3c:  Labels on each line corresponding to the language from the text might improve clarity of message (e.g.,“co2 reductions only”, etc.)

done

Fig. 4:  Need to articulate assumptions made about emissions of other pollutants (also zero??)

The caption is clear that this only for CO2.

Fig. 4a:  Add comment on what the Solomon line & Lowe line represent

done

Fig. 4b:  I’d be interested in a sentence stating what is assumed about the airborne fraction over the 2000-2300 period.

We are not in a position to analyze this from the indicated studies. No change.

Fig. 5:  What scenario was modeled?  What assumptions were made about non-CO2 pollutants in 2000-2100?

See Matthews et al. (2009).

Fig. 5:  I’d be interested in knowing whether most of the uncertainty is in the numerator or denominator

The interested reader would need to go to the reference and the original model data for more information. No change.

Fig. 6:  I know this chart is copied from UNEP 2011 & Shindell 2012, but it would be a lot stronger if it were extended through 2100;  it is not customary to present charts through 2070, so the reader wonders what is missing & whether the trend lines for 2070-2100 are significantly different & why they aren’t shown

We are not in a position to change this figure here.

Fig. 6:  Need quantification here - would be nice to combine this with a chart showing the emission trajectory for each of the pollutants.  At minimum, need a comment on change in each pollutant relative to present.

Goes beyond the scope of the present work. Reader is referred to the original paper and report.

Fig. 6:  Need to identify what the “reference” scenario is

See the underlying report and paper that are referenced.

Fig.6:  Repeat the caveat from the original paper about the meaning of the likely range & how to interpret the overlap

We refer to the original paper for details.

Fig. 6:  Explain the yellow & pink shading (i.e., levels mentioned in Copenhagen Accord)

Figure now shows this.

Typos/Formatting:

Subscripts & superscripts in various places throughout

Table 1:  HFCs, “one to two decades to XXX years”

done

Fig. 1:  commas on x axis

Not practical with software used

Fig. 4:  graphs need labels “a” & “b”

Changed to clarify

Line 82: comma in 20,000 years

done

Line 106:  misplaced comma

corrected

Line 156:  “aid” not “aide”

done

Line 185:  capital letter on “Accord”

done

Line 421:  “quantity”

done

Line 500:  missing “as” in “thought of as an approach”

done

Line 562:  “basket”

done

**Reviewer C:**

I attended the talk that is written up here and this paper meets all the criteria you list below very well.  I recommend it be published as is. However, one comment is that the copy I received had highlighted text.  I assume this is to be included.  It should be.

Thank you, the highlighted text is included.