Response to Referee #2

We thank all referees for their constructive comments and suggestions. We respond to the specific comments below in blue color, repeating the reviewer's comments in italics for reference.

The manuscript of Lee et al. investigates the potential US air quality and climate impacts of different emission controls assumed for the future. Strictly air quality-focused controls are contrasted to the effects of CO2-focused controls. The conclusions are based on a series of simulations that aim to separate the role of different emissions reductions and of different interactions within the climate system. The manuscript is well within the scope of ACP, and it includes useful new results that will be helpful for designing future air quality and climate policy, while providing some insight into processes involved. I do not have any major concerns, except of the fact that the "Simulation setup" (3.1) section is rather confusing and needs some improvements and clarifications (see below). Furthermore, there is a range of mostly minor suggestions that I list below which I believe will improve the manuscript. Following those, I believe that it will be ready for publication.

SPECIFIC COMMENTS:
Page 31386, Line 4: Presumably, it is not just CO2 that is changed in this hypothetical scenario (as it is seen later in the abstract). This needs to be clarified early on.
Response) We understand the current sentence can be confusing. The hypothetical climate policy requires CO2 emission cut, not other species. However, cutting CO2 emissions results in changing in other species emissions, particularly SO2 emissions in our scenario. To clarify, we have modified two places in the abstract.

OLD: "a hypothetical climate mitigation policy that reduces 2050 CO_2 emissions to be 50% below 2005 emissions."
NEW: "a hypothetical climate mitigation policy that **aims to** reduce 2050 CO_2 emissions to be 50% below 2005 emissions."

OLD: "Under the hypothetical climate policy, future US energy relies less on coal and thus SO_2 emissions are noticeably reduced."
NEW: "Under the hypothetical climate policy, **CO_2 emissions reduction is achieved in part by relying less on coal,** and thus SO_2 emissions are noticeably reduced."

Page 31386, Lines 7-8: Suggest changing "and other US emissions" to "and other US emission datasets".
Response) Done.

Page 31386, Lines 10-11: By when?
Response) The emissions reduction due to the air quality regulations in 2030 are quite similar to those in 2055, because no more emission constrains are added after 2020. Thus its impacts on air quality are also similar between two time periods we considered. We have clarified this in the abstract (new parts are bolded)
"The U.S. air quality regulations are projected to have a strong beneficial impact on U.S. air

quality and public health in **year 2030 and 2055** but result in positive radiative forcing. **Under this scenario, no more emission constraints are added after 2020, and the impacts on air quality and climate change are similar between year 2030 and 2055.**"

Page 31386, Line 23: Suggest adding "simultaneously" before "target".
Response) Thanks for the suggestion. We have added it.

Page 31389, Line 8: Suggest changing "electric" to "electricity".
Response) Done.

Page 31389, Lines 16-17: Maybe intended to write "additional" instead of "additionally"?
Response) Yes. Thanks for catching the error.

Page 31389, Lines 19-20: Suggest rephrasing to "in part because of compensating effects of improved fuel efficiency and growing demands."
Response) It has been rephrased as follows: "partly because growing energy usage due to higher demand is offset by better fuel efficiency. "

Page 31390, Lines 22-24: Why is this? Worth explaining.
Response) We have clarified this in the revised manuscript. Here is the clarified sentence.

OLD: "There is also a significant delay in emission reductions when the 50% CO_2 cap is implemented without the air quality regulations."
NEW:" Without the air quality regulations, the SO_2 emission reductions result solely from the 50% CO_2 cap, and thus occur more slowly over time than in the c50 scenario (e.g., the SO_2 emission reductions reach the bs scenario level in 2040)."

Page 31391, Line 15: Suggest rephrasing to "and radiation calculations are performed every 2.5 h".
Response) Rephrased as suggested.

Page 31391, Line 20: Suggest rephrasing to "and four for silt". Also suggest substituting "with" with "for" earlier in the sentence when referring to clay.
Response) We have changed from "five size classes with clay" to "five size classes for clay" and from "and four silts" to "and "four size classes for silts".

Page 31391, Line 20: Please change "sulfuric dioxide" to "sulfur dioxide".
Response) Done.

Page 31391, Line 28: Spelling of "releaseed".
Response) Corrected.

Page 31393, Lines 3-4: Some more detail is needed here: What are the oxidation processes that affect aerosols in the model(s) (OH, H2O2, ozone, others)? How well are the oxidants simulated in the model (e.g. as found in previous papers)?

Response) Our model computes sulfur chemistry using online H_2O_2, OH, and NO_3. The detailed sulfur chemistry reactions are available in Koch et al. (1999) and the impact of using online oxidant fields is presented in Bell et al. (2006). As described in our response to reviewer 1, we added additional description regarding previously published model evaluation, including results related to OH and ozone (see our response to the reviewer 1). We also have added the following information in the manuscript.
"(e.g., H_2O_2, OH, and NO_3 for sulfur aerosol; see Bell et al., 2006)"

Page 31393, Lines 6-9: Some mention of model performance in capturing aerosols would be helpful here (for both aerosol modules).
Response) There was a similar comment from the other reviewer, so we have added the following statements in the Section 3 to provide a short summary of model evaluation and differences.
"The detailed description and evaluation of ModelE2-TOMAS and the difference between OMA and TOMAS is available in Lee et al. (2014). In brief, the ModelE2-TOMAS and ModelE2-OMA models capture the observed sulfur species and other aerosol species as well as aerosol optical depth mostly within a factor of two. However, anthropogenic aerosols in both models differ from each other by a few percent to a factor of 2 regionally due to differences in aerosol processes such as deposition, cloud processing, and emission parameterizations. "

Page 31393, Line 11: Suggest rephrasing to "ModelE2, except for CO2 RF".
Response) We have changed the sentence as suggested.

Page 31393, Line 13: "utilize" -> "utilizes".
Response) Corrected.

Page 31393, Line 14: "timescale" -> "timescales".
Response) Corrected.

Section 3.1: I am not entirely convinced that there is a good reason for the FIXMET/FUTURE simulations and INTERACT to have different lengths (3 vs 20). The reason why in fixed-SST ERF estimates we perform multi-year simulations (typically 20 or 30) is not that the rapid atmospheric adjustments take that long to occur, but that we need a higher signal-to-noise ratio, which is an issue even if the SSTs/sea ice are fixed. In that sense, I cannot see why the FIXMET/FUTURE cases would not similarly warrant 20-year simulations. Please explain.
Response) First of all, we agree with the reviewer that the fixed-SST approach requires longer simulations to smooth out the internal noise. In case the reviewer missed this, we explicitly stated this in the end of Section 3.1. This is the exact reason we perform 20 years for INTERACT runs. As we explained in Section 3.1, the INTERACT simulations have the model internal noise because aerosols/gases affect meteorology via interaction with radiation and clouds. However, the FIXMET and FUTURE simulations do not account for such aerosols/gas interaction, so the model meteorology is not perturbed by changing emissions. In other words, the model meteorology is identical in all simulations under the FIXMET and FUTURE cases, a case that is thus far more tightly constrained than a fixed-SST/sea-ice simulation, and 3 year-long simulations are sufficient.

Page 31393, Line 24: For it to be entirely "CTM-like", the atmosphere should be constrained to observations as well (e.g. via nudging). I would avoid this characterization here, as it is somewhat misleading.

Page 31393, Lines 26-28: Similar to above: The prescribed SSTs and sea-ice will not lead to exactly identical meteorology. I suggest adding "approximately" before "the same".

Responses to the two comments) We have removed "CTM-like". We agree with the reviewer that the prescribed SSTs and SICE will not lead to identical meteorology. In the model setup, the same meteorology is achieved by 1) turning off the aerosols/gases interaction with radiation and clouds and 2) prescribing the same observed SSTs and SICE in the all simulations. To avoid any confusion, we have revised the sentences.

OLD:" In order to assess the impact of each emission scenario on air quality and climate, we ran "CTM (Chemical Transport Model)-like" simulations using our climate model. In this run, aerosols and gases do not affect model radiation and clouds thus model meteorology is not disrupted. We denote these simulations as FIXMET. In order to keep the same meteorology, we prescribed observed monthly mean sea surface temperatures (SST) and sea ice coverage averaged from 2001 to 2010 in all FIXMET runs. "

NEW:" In order to assess the impact of each emission scenario on air quality and climate, we set our climate model to have identical meteorology among all emission scenarios by 1) disabling the influence of aerosols and gases on radiation and clouds in the model (i.e., turning off aerosols-climate and gases-climate interactions) and 2) prescribing observed monthly mean sea surface temperatures (SST) and sea ice (SICE) coverage averaged from 2001 to 2010 in all FIXMET runs."

Page 31394, Line 3: For radiative forcing, and especially for climate response (not studied here), I expect that indeed the signal will be partly obscured by internal noise. But for air quality, the differences in emissions between 2005, 2030 and 2055 are so large, that it is hard to imagine that the signal would not exceed the noise. In a nutshell, I think this statement is too strong when it comes to air quality signals.

Response) We agree with the reviewer and have changed the phrase.
OLD: "impact on air quality and climate"
NEW: "impact on radiative forcing"

Page 31394, Line 15: I suggest removing "overall" here, as that implies full ocean-atmosphere simulations.

Response) "overall" has been removed.

Page 31394, Line 18: Suggest rephrasing to ": : :can estimate the radiative response following "rapid" adjustments in the atmosphere : : :"

Response) It has been changed as suggested.

Page 31394, Line 20: Suggest adding "in the same model" after "estimate aerosol effective forcing".

Response) The method we employed here has been used to estimate aerosol effective

forcing in other studies (e.g., ACCMIP studies presented in Shindell et al. (2013a)). ModelE2 participated the ACCMIP studies, but there are many other GCMs. Having said that, adding "in the same model" is not appropriate here. We believe this suggestion came because of the error in the reference, which is explained just below.

Page 31394, Line 20: It is not clear from the reference list which is 2013a.
Response) Thanks for catching the error. We failed to notice that "2013a" was changed to "2013" during producing the discussion paper. We will correct this in the final version.

Page 31394, Line 22: Is "cloud" mentioned intentionally here? Perhaps just stating "the resulting radiative forcing is not identical to aerosol effective radiative forcing" would be more accurate.
Response) The resulting cloud radiative forcing is the aerosol effective forcing, if the aerosol emissions are the only changes between two runs. However, as we mentioned in the main text, our simulations include gas emissions changes, so the resulting cloud radiative forcing is not aerosol effective forcing. Nevertheless, we have modified the sentence to clarify (new part is in bold).
"In this study, both aerosol and gas emissions are changed from the reference period (i.e., 2005), and the resulting cloud radiative forcing is also **influenced by gas forcing. Thus it cannot be used to estimate aerosol effective forcing.**"

Table 1: The title of the last column is a bit confusing – for example, for FIXMET, it gives the impression that aerosols and non-CO2 gas emissions impact climate. Also, I suggest changing the caption to "Summary of simulation categories used in this study".
Response) We have changed the caption from "Air quality and climate impact by" to "Air quality and radiative forcing due to".

Table 2: The table could be made substantially simpler if all the 05 simulations could be named "bs05". Given that for 05 the conditions are the same in all cases (noaq05, c50nq05, bs05, c5030-c5005), it would make sense to substitute all of them with bs05, in which case all of the bs05 occurrences would cancel, and the table would be much simpler and easier to comprehend.
Response) bs05, noaq05, c50nq05, and c50 are not identical, although it appears the same in Figure 1. The air quality regulations and/or climate policy have an impact in year 2005. We've clarified this in Section 2.4 in the revised manuscript.
"Note that the US emission scenarios are not same in year 2005, even though they may appear so in Fig. 1. For instance, the bs emissions are not identical to the c50 emissions in year 2005."

Furthermore for Table 2: I suggest reminding the reader in the caption what the different notations mean in the "Simulations" column. It would help so as to avoid having to refer back to Fig. 1 or to the text in order to recall.
Response) We have added the following in the caption.
"In the "Simulations" column, the first letters represent the US emission scenarios and the last two numbers represent the emission year ("bs" for the baseline, "noaq" for the no air quality regulations, "c50" for the 50% CO_2 cap in the baseline, and "c50nq" for the 50% CO_2

cap in the noaq scenario)."

Table 2 is referenced after Table 3 in the text.
Response) We have changed the order.

Page 31397, Line 16: "PM related" -> "PM-related".
Response) Changed.

Page 31397, Line 25 onwards: It is somewhat hard to follow what the difference is between CO230/CO255 and BOTH30/BOTH55. It is stated that the former is "for the impact of CO2 reduction policy under the air quality regulations", so why is it not equivalent to both? It may become clearer later on, but it is worth making it clearer here too.
Response) The reference simulations are different between $CO_2 30$/$CO_2 55$ and BOTH30/BOTH55. For instance, $CO_2 30$ is computed using the "c50" and "bs" simulations, so the difference is only climate policy (air quality is present in both simulations), while BOTH30 is computed using the "c50" and "noaq" simulations, so the difference is both air quality regulations and climate policy. Since Table 3 clearly presents the difference, we've added a short note (shown in bold), followed by the statement:
" .. for the impact of both air quality regulation and CO_2 reduction policy as BOTH30 and BOTH55 **(see Table 3 for the exact pair of simulations used for each case)**."

Page 31398, Lines 5-7: Why? Briefly explain.
Response) Our health impact assessment has been done for all 50 states, so we try to make it consistent for air quality impact. However, for radiative forcing, we believe the main US continents are the main interest of policy implications as the 2 outlying states have relatively little localized forcing and the response to forcing located in such small areas is not well characterized in the literature.
"It is important to mention that all 50 states are used for air quality and public health estimates but only 48 states excluding Alaska and Hawaii for radiative forcing. "

Page 31398, Line 14: "PM related" -> "PM-related" (same for ozone).
Response) Changed.

Page 31398, Line 18: "Since no more emission constraints are added after 2020: : :": I am not sure that this has been made clear earlier in the text. Worth revisiting and maybe adding a statement on this earlier.
Response) We have added the following statement in the Abstract and Section 2.1 in the revised manuscript.

In Abstract - "Under this scenario, no more emission constraints are added after 2020, and the impacts on air quality and climate change are similar between year 2030 and 2055."

In Section 2.1 - "After 2020, there are no more emission constraints added."

Page 31399, Line 8: Worth adding ": : :due to the longer lifetime of these pollutants" at the end of this sentence.

Response) We have added the suggested phrase.

Page 31399, Lines 11-13: Why? Please briefly explain as this is quite a prominent feature.
Response) As we already mentioned, the distinct spatial pattern is due to the emissions changes. Under the CO_2 reduction policy, there is a significant change in the fuel sources used in the electricity sector as well as wind and solar power adoption. In the MARKAL model, the adoption of alterative energy production technologies and renewable technologies is determined for each region, which means the emission changes under the CO_2 policy differ regionally. For instance, the projected power usage is increased in the south central US states, but the adoption of solar power occurs after 2030. Thus the CO2 policy in 2030 has a main impact on SO4 as coal use decreases dramatically starting in 2025. We have explained some regional pattern in details in the revised manuscript (see the bold part below).

"Firstly, except for SO_4, most pollutants show a distinct spatial pattern driven by emissions, i.e., increasing concentrations over the southeastern US and decreasing concentrations over the northwestern US. For instance, **the changes in energy sources under the CO_2 policy differ by region (depending on regionally specific conditions). The increases over the south central US states can be explained by the increases in energy production. In 2030, these US states reduce their coal usage and adopt renewable energy such as solar and wind power after 2030. Thus, SO_4 is the only air pollutant strongly reduced under the CO_2 reduction policy in 2030 over the south central US.**"

Page 31399, Line 15: Suggest changing "direction" to "sign".
Response) Done.

Page 31399, Line 23: Suggest adding "reductions" after "NOx emissions".
Response) Done.

Page 31399, Line 24 onwards: This part of the text seems to be suggesting that the air quality effects of CO2 measures are more effective in the absence of measures that target air quality directly. Perhaps this is sort of obvious and not particularly informative, for the amount of attention/text that has been devoted to it, but if the authors wish to keep this discussion, there should be a correction to avoid confusion: The sentence "Lastly, impacts on air quality are larger in the absence of the air quality regulations: : :" should be rephrased to "Lastly, impacts of measures targeting CO2 on air quality are larger in the absence of the air quality regulations: : :". Otherwise, the reader may think that it is suggested that CO2 measures are more effective for tackling air quality than the air quality measures themselves (which is not the case).
Response) We have revised the sentence with the referee's suggestion.

Page 31401, Line 2: Please add "to" between "similar" and "each".
Response) Done.

Page 31401, Lines 14-15: Suggest rephrasing to "as ozone is a secondary air pollutant with a longer lifetime than aerosol constituents".

Response) We have rephrased it as suggested.

Page 31401, Line 20: And due to ozone?
Response) Yes. We have added "ozone" in the sentence;
"Unlike $CO_2 55$, $CO_2 30$ shows increasing mortality in the Southeastern US due to the increase in **O_3,** BC, OM, and NO_3 aerosols (see Fig. 3)."

Page 31401, Line 23: "direction" -> "sign".
Response) Done.

Page 31402, Lines 10-11: Suggest rephrasing to "emphasizing the importance of utilizing more than one aerosol models for estimating health benefits from pollutant emission controls".
Response) We have rephrased it as suggested.

Page 31402, Lines 13-15: Are all RFs referenced at the tropopause?
Response) Only ozone RF is at the tropopause, while the others are at top of atmosphere. To clarify, we have added the following sentence.
"Note that the ozone RFs are referenced at the tropopause, where they provide a better indicator of global temperature response, while the others are at the top of atmosphere."

Figure 9: Suggest removing "F" from "ADF" and "AIF", or, for consistency, it would need to be added to all components (i.e. OzoneF, CO2F etc).
Response) We've modified other components name: e.g., O_3 to O_3_RF; CO_2 to CO_2_RF.

Page 31402, Lines 17-18: Why are some RFs calculated from FIXMET and some from INTERACTIVE? Does this create inconsistencies?
Response) Using the model setup used in FIXMET (i.e., turning off chemistry-radiation interaction), our model can still compute aerosols and gases RFs based on the simulated values, but not for CH_4. In the current version, CH_4 RF is computed with simulated methane concentrations only when the simulated CH_4 influences model radiation. Taking CH_4 RF from INTERACT simulations introduces inconsistency, but the overall RF would be little affected by this because CH_4 RF is small. We have added the following into the Section 3.1.

"The ModelE2 version used in this study does not compute CH_4 RF with simulated concentrations, if the CH_4-radiation interactions are turned off, which is the case in the FIXMET and FUTURE simulations. Thus, we use CH_4 RF from the INTERACT simulations and other RFs from the FIXMET simulations in Section 4.3. This inconsistency would little influence to overall RFs, since the CH_4 RF signal is small compared to other RFs."

Page 31404, Lines 10-16: These conclusions come from comparing to Fig. 9, right? Worth stating it in this paragraph.
Response) We have added "(shown in Fig. 9)" after "the FIXMET runs".

"As shown in Fig. 13, ADF averaged over the US (including BC-albedo RF, which is much weaker than ADF) is generally less positive than that in the FIXMET runs **(shown in Fig.**

9)"

Page 31404, Lines 22-23: "that closely follows NOx changes" – how do we know this? And is this due to lightning NOx, impacted by the warmer climate? Does the changing STE play some role? Some insight would be useful here.
Response) Yes. We found that lightning NOx source is increased in the FUTRE simulations (10-14% higher lightning source in 2030 and 2055), which affects NOx changes in mid and upper troposphere. We have added the following information (shown in bold).
"... that closely follows NO_X changes, **which might be explained by the fact that the lightning NO_X sources are increased by 10-14% in 2030 and 2055, compared to 2005.**"

Page 31405, Line 8: "Significant" can be misleading here. "Large" would be more appropriate.
Response) We have replaced to "large".

Page 31405, Line 9: Suggest changing "with" to "by".
Response) Changed.

Page 31405, Lines 13-15: As for the FUTURE results, some insight into what may be causing these changes in ozone would be useful.
Response) We believe the reviewer is asking the INTERACT results here, not FUTURE. Relatively larger changes in O_3 RF (compared to ADF) are also shown in the FUTURE simulations, and we have added the following sentence to explain the cause (shown in bold).
"Nevertheless, we observe some systematic changes such as a) the impact of the atmospheric rapid adjustments on O_3 RF is relatively large under the CO_2 reduction policy (i.e., $CO_2$30. $CO_2$55, CO_2NQ30, and CO_2NQ55), and b) the relative changes are larger in O_3 RF than ADF. **The latter is also shown in the FUTURE simulations, and this might be due to the fact that O_3 is a greenhouse gas that interacts with the outgoing longwave radiation which depends on temperature whereas the aerosols interact with only solar radiation via aerosol direct effects in our forcing calculation.**"

Page 31406, Line 17: Suggest adding "reflective" before "aerosols".
Response) Added.

Page 31406, Line 24: ":" -> ";".
Response) Changed.

Page 31407, Lines 3-5: Some rephrasing is needed (e.g. "but" appears twice).
Response) Thanks for catching the error. The first "but" was wrongly inserted during the file production. With removing the first "but", the sentence is fine.
"In our study, the CO_2 reduction policy results in a net cooling on a global-scale due to the loss of cooling aerosols, but the policy leads to a net positive forcing over the U.S. on a regional scale."

Page 31407, Line 17: Suggest changing "shows" to "reinforce".

Response) Changed.

Page 31408, Line 4: "lead a considerable" -> "lead to a considerable".
Response) "to" is added.