RESPONSE TO REVIEWERS' COMMENTS

Title: "Nepal Emission Inventory (NEEMI): A high resolution technology-based bottom-up emissions inventory for Nepal 2001-2016"

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We thank both referees for their constructive comments. The scientific and editorial comments have been considered and carefully addressed through the changes detailed below. The comments from both referees have been broken down into points and subsequently answered. A point by point response is included indicating where changes appear in the revised manuscript along with the subsequent changes. The referee's comments appear in black and response to the comments follows immediately in blue color.

Note:

1. All the changes in the revised manuscript are highlighted in blue color.
2. Line numbers indicated in this text refer to the revised manuscript.

ANONYMOUS REFEREE #1

1) Page 11, line 21: Named person missing from 'personal communication' reference.

Response: Personal communication reference name, Prakash Bhave is mentioned on page 11 line 21.

2) Page 22, line 12: Like SO2, NOx is an important precursor of secondary inorganic aerosol. So if SO2 is in this list, why not NOx? Of course, NOx is also a precursor of O3 but then PM2.5 kills more people than O3. Alternatively, replace the word 'aerosols' with 'primary particulate matter' and delete the gas SO2 from this list. Perhaps a minor point - Editor to decide.

Response: The word 'aerosols' is replaced with 'primary particulate matter' on page 22 line 14. SO_2 gas is removed from the list and analysis on SO_2 has been shifted to next paragraph on page 23 line 14.

3) Page 22, lines 13-15: Issue still not addressed. If OC is not included in Fig 6 then this sentence should not imply that it is.

Response: Since OC is not included in Fig 6, description about OC emissions has been removed from line 15. Additionally a sentence is added on line 17 to describe OC emissions separately.

4) Table S1: Footnote for Kerosene lamps should say 'Assumed 50% kerosene wick lamps.....' i.e the word 'wick' is missing.

Response: Suggested changes are made in supplementary information Table S1 footnote. The word ‘wick’ is added in the footnote of Table S1 for kerosene lamps.

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ANONYMOUS REFEREE #2

I principally welcome the decision about developing two papers and clearly defining the scope of Part I and II. Personally, I'd probably choose a strategy to split the parts by addressing different pollutants since including open burning of agricultural residue and soil NOx would allow to have a complete national inventory of anthropogenic emissions for PM2.5, BC, OC, SO2, NOx, CO, and CO2 while CH4, N2O, NMVOC with large share of fugitive emissions, agriculture (possibly extended with biogenic emissions) would create Part II but also have complete coverage of sources (the combustion bits are done already and could be covered there). The advantage of that would be that for key air pollutants part I would give a complete picture of anthropogenic emissions and the whole discussion of shares/importance of particular sources that is now included in the paper could be compared easily to other work where total national emissions are presented, etc.

Still, the most important thing is to be clear about the coverage of sources and if the authors decide to go with such allocation of sources between part I and II, then I would suggest that Part II includes somewhere a summary of both Part I and Part II, i.e, national totals.

Response: We thank reviewer for constructive suggestion on strategically splitting the parts. We decide to keep the distribution of sectors in part I and II as mentioned in the manuscript. We also accept the comment to include a summary on the anthropogenic

emissions and the national totals emissions in Part-II, which will also include estimates from Part-I as well, making the emission inventory for Nepal more or less complete.

I'd like to thank the authors for responding to all the comments and considering several of them directly in the new revised version of the paper.

For most, I find the newly manuscript well written and documented, in fact some of the parts are a bit long giving account of many details which could be moved to SI. Abstract needs further work and shortening, I think.

Response: We appreciate reviewers perspective on shortening some section and moving them to SI, however since, it's one of a kind work done over Nepal that provides technical details necessary for giving reader proper orientation with brief overview of the situation and for the local and technical interest. Therefore, we would like to keep the manuscript complete in all due respect.

Here are few more specific comments:

1) TITLE: I would suggest to shorten the title a bit and remove the "technology-based" as this is the element that can be included in the keywords and so it could be: "Nepal Emission Inventory – I: A high resolution bottom up emission inventory of combustion sources (NEEMI-Tech) for 2001-2016" or even shorter "A high resolution Nepal emission inventory for 2001-2016: Part I - combustion sources"

Response: We totally agree with the reviewer and would like to shorten the title of manuscript. The title has been changed, pending approval by the editor. We propose it as:

"Nepal Emissions Inventory – I: Technologies and combustion sources (NEEMI-Tech) for 2001-2016"

The part II will have the following title:

"Nepal Emissions Inventory – II: Open burning and fugitive sources (NEEMI-Open) for 2001-2016"

2) ABSTRACT: I think the current abstract is too long and contains too many details. I think it shall address only key and not elements of the paper highlighting key results and possibly knowledge gaps. At the same time, it would be important to add one statement earlier in the abstract (e.g., around the 2nd sentence) that clearly defines the scope saying it is part I covering this and that. Part of the sentences like in line 5 after approach can be deleted, especially that I do not think the inventory is done for the purpose of understanding technologies or sectoral energy consumption. Also several statements in parenthesis (like the ones about machinery, non-renewability of biomass) can be also deleted. Suggest to simplify the part describing key sources from line 15 onwards. Somehow it is hard to see right away what are the key sources.

Response: Abstract is trimmed down and rewritten to highlight key results of the paper. A sentence citing the second part of the complete study is now mentioned on line 5 of the

abstract. The part of the sentence in line 5 "the purpose of understanding technologies or sectoral energy consumption" is now deleted. Several short statements like the ones about machinery, non-renewability of biomass in parenthesis are deleted.
The new abstract now reads as follows:

The lack of a comprehensive, up-to-date emissions inventory for the Himalayan region is a major challenge to understanding the extensive regional air pollution, including its causes, impacts, and mitigation pathways. This study describes a high resolution (1 km × 1 km) present-day emission inventory for Nepal, developed with a higher-tier approach. The complete study is divided into two parts; this paper covers technologies and combustion sources in residential, industry, commercial, agricultural diesel-use and transport sectors as part-I (NEEMI-Tech), while emissions from open burning of municipal waste and agricultural residue in fields, and fugitive emissions from waste management, paddy fields, enteric fermentation and manure management for the period 2001–2016 will be covered in part-II (NEEMI-Open). The national total energy consumption estimated in the base year 2011 was 374 PJ, with the residential sector being the largest energy consumer (79 %) followed by industry (11 %) and the transport sector (7 %). Biomass is the dominant energy source, contributing 88 % to the national total energy consumption, while the rest is from fossil fuel. A total of 8.9 Tg CO2, 110 Gg CH4, 2.1 Gg N2O, 64 Gg NOX, 1714 Gg CO, 407 Gg NMVOC, 195 Gg PM2.5, 23 Gg BC, 83 Gg OC and 24 Gg SO2 emissions were estimated in 2011 from the five energy-use sectors considered in NEEMI-Tech. NEEMI provides for the first time temporal trends of fuel and energy consumption and associated emissions in Nepal for a long period, 2001-2016. The energy consumption showed an increase by a factor of 1.6 in 2016 compared to 2001, while the emissions of various species increased by a factor of 1.2–2.4. An assessment of the top polluting technologies shows particularly high emissions from traditional cookstoves and space heating practices using biomass. In addition, high emissions were also computed from fixed chimney Bull's Trench kilns in brick production, cement kilns, two-wheeler gasoline vehicles, heavy diesel freight vehicles and kerosene lamps. The monthly analysis shows December, January and February as periods of high PM2.5 emissions from the technical sources considered in this study. Once the full inventory including open burning and fugitive sources (part-II) is available, a more complete picture of the strength and temporal variability of the emissions and sources will be possible. Furthermore, the large spatial variation in the emissions highlights the pockets of growing urbanization, which emphasizes the importance of the detailed knowledge about the emission sources that this study provides. These emissions will be of value for further studies, especially air quality modelling studies focused on understanding the likely effectiveness of air pollution mitigation measures in Nepal.

3) Page 10: line 2; reference to Baidaya and Borkenkleefeld…the proper name of the second author is Borken-Kleefeld

Response: We thank reviewer for bringing to our notice the following error. It's been corrected on page 10 line 2.

4) Page 10: line 22-24; here different technologies are listed and also info is given about number of different kilns. Table 1, however, lists only FCBTK. I think it might be reasonable to add all of them to table 1.

Response: We thank reviewer for pointing this out. Table 2 has been updated. Now it includes the list of combustion technologies and therefore technologies under bricks manufacturing is updated to include all the known combustion technologies like FCBTK-straight firing, zig zag firing, clamps and vertical shaft brick kilns (VSBK).

5) Page 18, line 22-26 and section 3.2 as well as other sections where reference to 'national' emissions are made; I think it would be useful to repeat few times that the presented shares refer to the combustion emissions only and not the total – just a reminder to the reader that these are not necessarily national totals.

Response: Following sentences are added to clarify the national estimates.

Page 19 line 20: *The emissions discussed henceforth refer to the estimates from the sectors and source categories described above, and do not account for the complete national totals, which will also include emissions from Part-II of this work.*

Page 20 line 21: *... from the sectors discussed in this part of the work. However the total national values will also include emissions from the second part of the study (NEEMI-Open).*

We have also replaced 'national' word in the context of emissions, with the apt information that explains the extent of emissions covered in this part of the study. Here are few changes mentioned with page and line number:

'nationally' replaced with 'From the total of five sectors' on
Page 20 line 4

'national' replaced with 'five sectors' on
Page 20 line 26; Page 23 line 9 and Page 25 line 17

'Nationally' replaced with 'A total' on
Page 2 line 13; Page 21 line 9 and Page 30 line 27

'...national emissions estimates of aerosols, ozone precursors and greenhouse gases' replaced with '...emissions estimates of aerosols, ozone precursors and greenhouse gases from the five energy-use sectors on Page 22 line 13

'...of the national estimate' replaced with '...from sources in this part of the study' on Page 23 line 6

'At the national level' replaced with 'For the five sectors considered' on
Page 26 line 3

'national' replaced with 'total' on
Page 23 line 21;
Page 24 line 6;
Page 25 line 10;
Page 26 line 12
Page 26 line 27;
Page 27 line 18;
Page 28 line 5;
Page 31 line 17

6) Section 3.4.1: In a number of places the authors refer to the argument that some differneces are there due to the difference or assumption about the sulfur retention in ash. It is not clear to me if this refers to the NEPAL inventory or the inventories which are compared like CMIP6 or EDGAR or GAINS-ECLIPSE?

Response: We thank reviewer for highlighting the confusion in the analysis. We have now reframed the sentences which now clarify the SO_2 emission factors from NEEMI on page 24 line 20.

"Also, the CMIP6 SO2 emissions from each sector vary a lot when compared to NEEMI, showcasing the shortcomings due to the coarser resolution methodologies, that lack the degree of detail present in the NEEMI inventory. Like in NEEMI, SO2 emission factors used are for a large number of technology-fuel combinations, the sulfur content of the liquid fuels changes over a period of one and half decades and the sulfur retention fraction in the ash content of coal depends on the combustion technology."

7) Page 23: line 15; I think the authors need to be more precise when they refer to the "non-renewability factor" they should explain the term, its relevance and the assumption made with respect how much of the biomass is considered non-renewable and how it affects CO2 calculation presented in the paper.

Response: We have now mentioned the importance of non-renewability factors and the details about this in the supplementary information, rather than the main manuscript, to avoid redundancy and diluting the main analysis.

Non-renewability fraction for biomass (NRB) can be defined as the imbalance between demand and supply which contributes to net-CO_2 emissions. Ghilardi et al., (2007) explains it as *"when the amount extracted and burned exceeds the growth rate of the living biomass sources"*, it contributes to net-CO_2 emissions. In simple terms, Venkataraman et al., (2010) defines NRB as *"the percent of woodfuel that is harvested on a non-renewable basis"*. The NRB factor plays a crucial role in estimating CO2 or carbon budgets. The net-CO_2 emissions from harvested fuelwood or biomass products can help identify actual carbon offsets achieved through Clean Development Mechanism (CDM) projects, although it's not the only criteria. The NRB fraction used over Nepal is 10% similar to Venkataraman et al., (2010) over India based on residential sector fuelwood supply and demand. In Nepal, residential sector consumes 79 % of the national energy during 2011 and biomass is the single largest source of energy attributing to 88 %

of the national energy. Therefore, we have used 10 % NRB in our study to calculate CO_2 emissions. In principle the % NRB is calculated as *% NRB = (fuelwood demand – fuelwood supply)/fuelwood supply* (Venkataraman et al., 2010, Ghilardi et al., 2007, 2009). Studies like Ghilardi et al., (2009) have estimated non-renewable fuelwood fraction ranging from 0 to 96 % based on demand and supply at local level in Central Mexico using GIS method. These NRB fractions can then be used to allocate the percentage of fuelwood that can be treated as non-renewable fuel and their emissions can be accounted as the net-CO_2 estimate. In our study, we have considered for 10 % NRB which means out of total fuelwood consumed, combustion of 10 % would give net-CO_2 emissions while the rest 90 % can be treated as sustainable fuelwood and doesn't contribute directly to the net-CO_2 emissions.

8) Page 25: line 12-14: As I mentioned earlier, the CMIP6 and NEI inventory might differ in source coverage and for example her the NOx from soils (agriculture) could be one of these differences. I think this can be eliminated (and shall be) for the comparison as the CEDS/CMIP6 inventory data is explicit about this particular source and so it can be subtracted for comparison.

Response: We have deleted the sentence.

9) Page 46: Figure 7 and respective text in the paper; It might be useful to add in the text a word or two about potential issues of not full compatibility of sectoral structures of different inventories and the NEPAL inventory, i.e., a source of uncertainty in the comparisons that will be different from pollutant to pollutant but in a way is unavoidable. Additionally, I am not sure if the authors used the gridded data sets to estimate the numbers from global inventories or reached out to the authors or the web sites where respective sectoral data is available. I think it would be good to say explicitly and maybe even add the web links.

Response: We have added the link to emission sources for MIX, REAS 2.1, EDGARv4.3.2, CMIP6 and ECLIPSE V5a-GAINS in parenthesis that were used for comparison with NEEMI inventory:

- MIX (emission source: Nepal emissions reported in Li et al., 2017) on page 23 line 2
- REAS 2.1 (emission source: https://www.nies.go.jp/REAS/) on page 23 line 11
- EDGARv4.3.2 (emission source: https://edgar.jrc.ec.europa.eu/overview.php?v=432_GHG&SECURE=123; https://edgar.jrc.ec.europa.eu/overview.php?v=432_AP) on page 24 line 1
- CMIP6 (emission source: https://www.geosci-model-dev.net/11/369/2018/gmd-11-369-2018-assets.html) on page 24 line 3
- ECLIPSE V5a-GAINS (emission source: Author/co-author reachout) on page 24 line 4