<u>Bottom-Up Inventory Base Values and Emission Factors</u>

<u>Comments on Luhar et al. (2020)</u> "Quantifying methane emissions from Queensland's coal seam gas producing Surat Basin using inventory data and an efficient regional Bayesian inversion (<u>https://doi.org/10.5194/acp-2020-337</u>)

This manuscript will make an important contribution to the ongoing scientific debate about bottom-up versus top-down greenhouse gas assessments. The authors should be congratulated for shifting the research focus in the Surat Basin, Australia, from locating methane sources to quantifying the rate of emissions from various sources. This is a valuable scientific contribution.

All my comments below relate to the bottom-up inventory which is used as a reference point for many of the discussions in Luhar et al. (2020) and as a prior for the regional Bayesian inverse model methane emission flux estimate. As documented in Luhar et al. (2020) there is a discrepancy between the top-down versus bottom-up modelling estimate for total methane emissions and apportioning to sub-areas within the domain of the study. I hope the comments below will assist in better methane source apportionment and that this will improve the alignment of the inventory with the inverse Bayesian modelling results.

As recently presented at EGU 2020 in Lu et al. (2020) UNSW researchers have developed their own bottom-up inventory in the Surat Basin for the year 2018. That presentation should convey to the authors of this manuscript that an updated bottom-up inventory for the Surat Basin will be shortly submitted for review (Kelly et al., in preparation). It would be constructive for the science of inventory collation if the inventory presented in Luhar et al. (2020) and the inventory in Kelly et al. (in preparation) converge on both workflow and methane emission estimates for the primary sources of methane. There will be a significant difference between the Luhar et al (2020) 2015 inventory and the 2018 inventory to be presented in Kelly et al. (in preparation), but those differences should be traceable (different amounts of gas produced, changes in the population of cattle etc).

From the insights in preparing the Kelly et al. (in preparation) inventory, and the airborne measurement observations in Neininger et al. (2020), I have a number of questions with respect to the inventory in Luhar et al (2020). I hope the comments will result in an improved match between the inventory and modelling in Luhar et al (2020), and the development of a common inventory template for future studies.

<u>Concerns with the lack of details provided on the inventory calculations</u>

The essential bottom-up inventory details on base quantities and emission factors for Coal Seam Gas (CSG) production and processing are not presented in Luhar et al. (2020). Nor are there any details on CSG produced water volumes or management controls. As a stand-alone reference it is not currently possible to validate the data presented in Table 2 in Luhar et al. (2020). There are more details in Luhar et al. (2018), however when I tried to access Luhar et al. (2018) at https://publications.csiro.au/rpr/pub?pid=csiro:EP185211 the link to the report was broken (access attempts 14 to 20 June 2018, none successful). This highlights the importance of putting the core information used in Luhar et al. (2020) for the inventory in the supporting information. Why is Luhar et al. (2018) not cited in Luhar et al. (2020)?

<u>Suggested manuscript revision inventory calculations</u>

In the supporting information a table needs to be presented that lists the base quantity, emission factor used, clear referencing of the document(s) for the emission factor (and for each document clear referencing of the table and row selected for the emission factor), and justification for the selection of the emission factor, especially if it is not the default value as listed in either the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (or 2019 refinement) or the Australia Government value as applied in Australia's National

Greenhouse Gas Inventory (UNFCCC classifications). This is needed for all categories, Coal Seam Gas, Grazing Cattle, Feedlot Cattle, etc.

Luhar et al. (2018) needs to be cited, as there is considerable overlap between that report and Luhar et al. (2020).

<u>Points of clarity required with the CSG bottom-up inventory estimation of emissions</u>

Because Luhar et al. (2020) does not adequately list the base CSG data I can only make a check on the inventory values presented using data in the public domain. All tallied gas volumes and produced water data for Queensland for each petroleum lease (Pel) in the Surat Basin are published online by the Queensland Government (https://www.data.qld.gov.au/dataset/petroleum-gas-production-and-reserve-statistics, accessed 18 June 2020). Luhar et al. (2018) does provide better information on most aspects of the inventory, but there are points in Luhar et al. (2020) that could be added to help all readers of the manuscript.

No listing of Pels covered is provided in Luhar et al. (2020). From the Queensland Government database in the Surat Basin gas was produced from 3519 wells in the period ending 30/06/2015 and 3768 wells in the period ending 31/12/2015. This total well number used in producing gas is actually slightly lower than reported in this manuscript (4628 wells * 0.85 = ~3934). Below I therefore use the complete production data for the Surat Basin (all from the Walloon Coal Measures).

It is well documented that there are emissions from the water management ponds in the Surat Basin: refer to Iverach et al. (2015) Figure 3, and Nisbet et al. (2020) Figure 10. There are no volumes reported for CSG produced water, nor any reference for the total emissions from produced water as an isolated category in either Luhar et al. (2018) or Luhar et al. (2020), and no reference is made to produced water control factor. There is no reference to produced water emissions due to CSG activities in Luhar et al. (2018) Table 15 Total Methane Emissions (kg/year). However, we can make a check of the likely emissions from produced water using the Queensland Government public domain data. In 2015 in the Surat Basin the volume of produced water was 48591.79 Mega litres. The API 2009 average water tank emission factor is 0.31955 tonnes CH_4 /1000 m^3 produced water (page 5-57, Table 5-10) (Also refer to NIR (2020) Volume 1 page 143 and Table 3.44, NGER Method 2 (API 2009)). Using the API 2009 emission factor, assuming a control factor of zero, up to 15,527,505 kg CH_4 / year of emissions is likely released from the "Produced Water". For the year 2015 the total gas produced in the Surat Basin was 14905.77 Mm^3. The amount flared and vented was 461 Mm^3, and 316.03 Mm^3 was used in production. Considering just total production the API (2009) Table 6.2 Facility Level Average Fugitive Emissions Factors estimate for Production (Onshore gas production) emission factor is 9.184E-01 tonnes $CH_4/10^6m^3$ produced, yielding a Surat Basin production estimate of 13,689,459 kg CH_4 / year. The API (2009) Table 6.2 Facility Level Average Fugitive Emissions Factors estimate for Gas Processing Plants is 1.032E+00 tonnes $CH_4/10^6m^3$ processed, yielding a Surat Basin processing estimate of 15,382,755 kg CH_4 / year. This tallies to 44,599,719 kg CH_4 / year for Surat Basin CSG Processing, Production and Produced Water emissions. But from the original Luhar et al. (2018) report the CSG Processing and Production tally is 16,528,838 kg CH_4.

I acknowledge that there can be many refinements to these estimates, but the estimates presented above are more in alignment with the Bayesian inverse modelling results presented in Luhar et al. (2020). Because the base quantities for CSG gas (produced, venting, flaring, and used in production) and CSG produced water are not listed in Luhar et al. (2018) and Luhar et al. (2020) we cannot begin to understand why the CSG production and processing bottom-up inventory methane emission estimates appear to be low in Luhar et al. (2018) and Luhar et al. (2020). For the bottom-up inventory reported in Luhar et al. (2020) to have any scientific merit the base quantities and emission factors used need to be presented.

<u>Suggested manuscript revision CSG bottom-up inventory</u>

In the revised manuscript it is recommended for the CSG inventory portion of this manuscript that the inventory table using the same categories reported by the Queensland Government in the Petroleum Gas

Production and Reserves excel file be used, or a Table following the UNFCCC classifications be used. A table using either categories (classifications) would clearly separate emissions associated with Water Production. For example, a listing according to UNFCCC classifications would include:
1.B.2.b.2.i Water Production
1.B.2.b.2.ii Pipelines
1.B.2.b.2.ii Stations
1.B.2.c1 Venting
1.B.2.c2 Flaring
etc

A complete listing of petroleum leases (Pels) used in this investigation needs to be added to the supporting information.

<u>Points of clarity required with the cattle bottom-up inventory estimation of emissions</u>

The choice of using Harper et al. (1999) for cattle emission factors needs to be justified. This is a respected reference with 109 citations in Scopus. However, it is neither the IPCC nor Australian Government recommendation. The grazing cattle emission factor used is this paper was established under artificial conditions, near Canberra (a very different climate to the Surat Basin), using rather old equipment compared to modern systems.

From Luhar et al. (2018) "Methane emission factor for grazing cattle of 0.23 kg CH_4/animal/day based on direct measurements (Harper et al., 1999), which is 83.95 kg/CH_4/head/year. The use of this emission factor contradicts the statement in Luhar et al. (2020) that "Standard methodologies were generally adopted with data from various State and Federal Government Departments (e.g. (National Pollutant Inventory (NPI), National Greenhouse and Energy Reporting (NGER), and National Resource Management (NRM)). "

The choice of implied emission factor for grazing cattle has a significant impact on the inventory. The Australian Government (NIR 2017, which reports for the year 2015) uses an implied emission factor of 51 for Beef Cattle – pasture (Table 5.11 Implied emission factors – enteric fermentation). Can the authors explain why they did not use the recommended value for Australia, or the IPCC default value of 60, or the Oceania default emission factor of 63 (IPCC 2019 Volume 4, Table 10.11)?

Using the Australian Government recommendation of 51 the total estimate is only 55,389,009 kg/year (51 * 1,086,059). But the Luhar et al. (2018) emission estimate is 92,991,979 for grazing cattle (this would require an emission factor of 85.62), which appears to be an overestimate for grazing cattle of 37,602,970 kg/year. Given that the category grazing cattle is the largest source of methane reported in Figure 2 (Luhar et al 2020), some clarity on why Harper et al. (1999) was used to assign an emission factor for grazing cattle would address concerns that the grazing cattle emissions have been overestimated.

<u>Suggested manuscript revision cattle bottom-up inventory</u>

Unless locally determined emissions factors for grazing cattle and feedlots are presented, use the emission factors recommended by the Australian Government (NIR 2017), alternatively provide extensively documented justification for using Harper et al. (1999) emission factors.

<u>Closing Comments</u>

The authors of Luhar et al. (2020) have an opportunity to update the inventory used as a prior for their Bayesian modelling and provide a transparent workflow that can be a template for other regions, both within Australia and worldwide.

There is a plethora of choices to be made when collating a regional bottom-up inventory, especially for any region with extensive gas production and agricultural activities. As currently documented in Luhar et al.

(2020) the inventory cannot be validated. Thus, the prior used for the inverse Bayesian modelling cannot be validated. This distracts from the overall quality of the science that has been presented in other sections of Luhar et al. (2020), which comprehensively demonstrates the extent of coverage that can be obtained from just two greenhouse gas monitoring stations and highlights the enormous potential of similar setups for quantifying regional greenhouse gas fluxes throughout Australia.

The bottom-up inventory grazing cattle emissions may have been overestimated, and coal seam gas emissions appear to be underestimated. A number of other sources appear to have been overlooked. Redistributing the methane emissions to the correct sources and locations should improve the prior and the regional Bayesian inverse model estimates of methane emissions in the Surat Basin.

Clarity on how the bottom-up inventory emissions were estimated would greatly enhance the science outcomes reported in Luhar et al. (2020).

Regards

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