March 11, 2021

Comments from the Royal Swedish Academy of Agriculture and Forestry

on Working Group III contribution to the IPCC Sixth Assessment Report, Second Order Draft

The comments below are extracted from the sheet provided by the IPCC. Only minor copyedit has been made.

On the Entire Report:

1. The shortcoming of the metric GWP-100 for methane is recognized in the report and that other metrics, such as GWP* may better represent the actual warming caused by methane emissions. Still, the report concludes that GWP 100 shall be used but that ”this choice does not constitute a recommendation to use GWP100 for any specific policy application as the most appropriate choice depends on the policy goal and implementation of the metric” (p26 1–3). While this might be a valid choice all things considered it becomes problematic when many of the conclusions in the report regarding food and agriculture are based on research using GWP 100, and that these conclusions are used for policy recommendations in the report. In particular, the results of lifecycle analysis for agriculture products and diets are heavily influenced by the metric used. The report concludes ”rapidly declining CH4 emissions are given a negative CO2 -equivalent value based on GWP* but a positive CO2 -equivalent value based on GWP” (p 25, 25–27). In the case of diet scenarios this means, for example, that a diet with just a 10% reduction in ruminant meat or dairy will reduce warming using GWP* while using GWP 100 it still cause considerable warming. For further elaboration see John Lynch et al 2020 Environ. Res. Lett. 15 044023. This needs to be reflected in the texts about diets in chapter 7 and 12 (possible also in other places).

2. Agriculture is and can become an even bigger part of the solution. This is especially true for LU. This needs to be highlighted in the report. To increase that insight, the carbon cycle and soil carbon pools needs to be better described in future reports. Carbon sequestration is dependent on nitrogen supply. Although nitrogen gives rise to emissions it also is a prerequisite for using photosynthesis for increased carbon binding. Much of the carbon bound by agriculture is not made visible in the report. The carbon is also treated too standardized, not least taking into account what is stable carbon versus easily decomposable carbon. Stable carbon is protected in the soil. If the possibilities with photosynthesis are not highlighted, few outside the sector can understand how much of the potential available solution within AFOL: U. Within the EU, the sector is a net contributor with is a promising fact. Johnson, J.M.-F., Allmaras, R.R., Reicosky, D.C., 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. Agron. J. 98, 622–636. Kätterer, T., Bolinder, M.A., Andrén, O., Kirchmann, H., Menichetti, L., 2011. Roots contribute more to refractory soil organic matter than above-ground crop residues, as revealed by a long-term field experiment. Agric. Ecosyst. Environ. 141, 184–192. Rasse, D.P., Rumpel, C., Dignac, M.-F., 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilization. Plant Soil 269, 341–356.

3. The report use the expression ”plant-based diet”. The term is poorly defined and therefore unscientific. It is often used in the meaning of food without animal products and could be understood as such (which was visible in media reports from the SRCCL). If it, instead, means a diet constituting predominantly plants it becomes meaningless as almost all people eat a diet where plants contribute most volume, weight and energy (global average is 18 % of calories from animal products). Diets needs to be regionalized.

On the Summary for Policymakers:

4. The main task of agriculture is to produce food. The share of GHG emissions by agriculture in food production cannot result in zero emissions. Therefore, agriculture needs a tolerance for continued emissions. Based on how the reporting system is structured, it is easy to misunderstand the fundamental conditions of food production.

5. The image of agriculture is given by the fact that the report focuses on emissions. Large emissions are attributed to “foodsystems” where agriculture is a subset. Some of agriculture emissions can be reduced by using BAT (Best Available Technology), an important part of BAT includes measures that enable high productivity. High productivity enables unnecessary land use to produce food. How much emissions must be tolerated to produce the food? Perhaps the next IPCC report can calculate such a "base-line".

6. (page 2, line 3–26) The focus of Working group III is “mitigation of climate change”. Theoretically such mitigation can be about both emissions and “capturing” of greenhouse gases. Moreover, the term “greenhouse gases” seems not to be defined in Annex B but in theory greenhouse gases could be defined as both positive gases and negative gases as seen from the perspective “mitigation of climate change”. Regarding “positive gases” I have in mind the gas oxygen that is produced by plants and then emitted to the atmosphere which leads to a change in the concentration of negative vs. positive gases in the atmosphere. In the summary, as well as the whole material, I miss a comment that the focus on emissions instead of capturing as well as focus on negative vs positive gases in fact is a kind of chosen focus (or perspective) of the Working Group III.

7. (page 2, line 27–29) I just want to say that I like the additions of demand, innovation etc. as stated in this sentence: “chapters dedicated to demand, services and social aspects of mitigation {5}, and innovation, technology development and transfer {16}.”

8. (page 18, line 19–24) This statement might not be correct. Starting in 1970s there is a large body of literature on integrated assessment climate models on consumer (demand) and producer (supply) behaviour. This progress was awarded the Nobel prize in 2018.

9. (page 24, line 24–26) Here is stated this: “The Agriculture, Forestry and Other Land Use (AFOLU) sector can provide large-scale GHG emission reductions and land-based CDR at relatively low-cost measure but cannot compensate for slow mitigation in other sectors. ”A comment is missing that AFOLU also has a carbon capturing function (and by the way also oxygen production function) so this sector can contribute to climate not only through lowering emissions of negative gases but also by expanding the capturing of carbon in for example soil and crops (and part of the crops has long life – compare isolation material produced by straw).

10. (page 25, line 1–2) The challenge is not the diversity in ownership etc. since a results-based and common incentive would guide the land-owners. Instead, the problem is to find the correct incentive and assure additionality and permanence.

On Chapter 2 Emissions trends and drivers:

11. (page 66, line 13–15) There are very few countries where traditional diets have included a big consumption of vegetables, instead increased vegetable consumption is an indicator of affluence and goes in tandem with increase in meat consumption (Pradhan P, Reusser DE, Kropp JP (2016) Embodied Greenhouse Gas Emissions in Diets. PLOS ONE 11(7)). The global increase in consumption of vegetables has been more rapid than the total increase of consumption of animal foods (FAOSTAT). Consumption is a crucial driver for food systems and thus emissions from agriculture. But on consumption, few measures are highlighted in the report. This could be developed more and perhaps discussed in preparation work for the next report.

On Chapter 6 Energy systems:

12. (page 66, line 13–15) “The hard-to-decarbonise-sectors, i.e. agriculture”; even if land was not used for farming there would still be emissions.

On Chapter 7 Agriculture, Forestry, and Other Land Uses (AFOLU):

13. On one hand the agriculture sector accounts for 23% of global anthropogenic Greenhouse Gas (GHG) emissions. On the other the hand land and biomass are also an important sink estimated to absorb around 31% of anthropogenic CO2 emissions. Agriculture is and can become an even bigger part of the solution. This is especially true for LU. This needs to be highlighted in the report. To increase that insight, the carbon cycle and soil carbon pools needs to be better described in future reports. Carbon sequestration is dependent on nitrogen supply. Although nitrogen gives rise to emissions it also is a prerequisite for using photosynthesis for increased carbon binding. Much of the carbon bound by agriculture is not made visible in the report (Bolinder et al., 2020). The carbon is also treated too standardized, not least taking into account what is stable carbon versus easily decomposable carbon (Guenet et al, 2020). Stable carbon is protected in the soil. If the possibilities with photosynthesis are not highlighted, few outside the sector can understand how much of the potential available solution within AFOLU. Within the EU, the sector is a net contributor with is a promising fact. Bolinder M.A., Crotty F., Elsen A., Frac M., Kismanyoky T., Lipiec J., Tits M., Toth Z., Kätterer T. 2020. The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: A synthesis of reviews. Mitigation and Adaptation Strategies for Global Change 25: 929–952. Guenet et al. 2020. Can N2O emissions offset the benefits from soil organic carbon storage? Global Change Biology 27: 237 –256.

14. General comment. An overall view of the entire chapter 7, is that it is unfortunate that agriculture and forestry, at least from a boreal perspective, are in the same chapter. The assessment of the existing research will be very brief when these two sectors, that have such different conditions in different parts of the world, are to be dealt with in the same chapter.

15. Many of the measures presented are focused on agriculture. Measures for agriculture needs to be regionalized. In highly productive agriculture, the potential for action is often largely exploited. Perhaps therefore it is best to present measures as part of a "Tool-Box". Measures that is not regionally limited is plant breeding, new technology, digitalization and innovation in general. These measures are

also strongly correlated with increased productivity and therefore needs to be raised significantly more.

16. Knowledge Gaps 1: Regional and national implementations; Europe already has a negative net CO2-emission calculation on AFOLU. What will be the effects of implementing more measures or measures strongly put forwards by IPCC on a global scale, such as Agroforestry, use of biochar. There is urgent need for developing and implementing regionally adapted tool boxes.

17. Knowledge Gaps 2: What is the potential of successful use of modern plant breeding technologies on AFOLU emissions and sequestration?

18. Knowledge Gaps 3: More knowledge is needed on the mitigation effects of the components of new management systems such as conservation agriculture, regenerative agriculture and agroecology. Presently, a lot of non-substantiated claims are being used by both protagonists and antagonists of the mentioned systems.

19. Biochar production – energy balance and alternative use of possible non-agricultural organic residues could be more discussed as I see it.

20. (page 4, line 1–page 7, line 14) Even if LUC is not included the link between reduced animal production and higher food plant production will affect the land use and the potential for arable land to work as a potential carbon sink. Should that discussion be included I Executive Summary? I believe this relevant at the same place for balance.

21. (page 4, line 9–12) The bold text should be increased to also include line 11 and 12 for better balance.

22. (page 4, line 9–page 9, line 12) Why does the IPCC see forestry and agriculture, in the global model, as man-made anthropogenic emissions, while uptake is a natural sink? Many national models do not do this.

23. (page 4, line 28–31) "Peatland drainage" should be explicitly mentioned as one of the drivers of direct land use change.

24. (page 5, line 11–15) KSLA has argued in other fora that it is unreasonable to reckon that the uptake of 1 kg of CO2 in the circular biological system can compensate for 1 kg CO2 of fossil carbon. Storage of carbon in forests or agricultural land is unsafe (due to e.g., fire, storm, insect damage). This is not accounted for in the EU "LULUCF model". For example, in New Zealand this has been accounted for by a system where 1 kg of fossil fuel CO2 corresponds to 2 kg CO2 storage in the forest ecosystem. Similar systems are used in Australia and California, USA.

25. (page 5, line 19–23) Demand-side measures related to forest products deserve to be mentioned – This involves both increasing demand for products that substitute wood for fossil carbon (such as wood in buildings), but also the quality of what is demanded. Using the example wood buildings, the strength of the substitution effect can vary several fold depending on how wood is utilized in building.

26. (page 6, line 20–22) During the same period the production of Food, fibers and energy from the sector has increased and this productive development to support the demands could be argued as contribution in producing more with less GHG impact/kg.

27. (page 6, line 27–30) The evidence of the following sentence: “Although from bio-physical and ecological perspective, the mitigation potential of AFOLU measures is large, its feasibility is mainly hampered by lack of public acceptance of some measures, uncertainty over long term additionality, and lack of institutional capacity and long-term continuation of certain measures {7.6}. ”needs to be substantiated – in particular the aspect on public acceptance.

28. (page 6, line 32–43) Mention the importance of creating incentives for forest owners to invest in sustainable forestry with high climate benefits. A summary of an international conference where active use versus leaving forests for free development is published in: KSLA, 2018: 6, Forests and the climate – KSLAT nr 6-2018. ISSN 0023-5350, ISBN printed edition 978-91-88567-21-5 digital edition 978-91-88567-22-2. https://www.ksla.se/wp-content/uploads/2018/12/KSLAT-6-2018-Forests-and-the-climate.pdf.

29. (page 6, line 38–43) The following statement and associated section (7.6) needs to be further substantiated with evidence to give more advice to policy-makers: “Successful policies and measures include establishing tenure rights and community forestry, agriculture improvement and sustainable intensification, conservation, payments for ecosystem services, forest management improvement and certification, voluntary supply chain management efforts, private funding and regulatory efforts. The success of different policies, however, will depend on numerous region-specific factors in addition to funding, including governance, institutions, long term consistent execution of measures, and the specific policy setting {7.6}.”

30. (page 10, line 7–10) Figure 7.2 The length, size and, in some cases, colour of the arrows do not appear to be related to what they should represent! Photosynthesis should be much more prominent. We also question having the same brown colour for CO2 released from fossil sources and biofuels.

31. (page 11, line 37–page 15, line 16) As said also in the summary; The modelling is not complete and is under development, yet the conclusions have weighed the potential for improvement with regard to the need for increased food production for a growing population with a changed diet where people who receive increasing income switch from rice diet to a more animal-based diet. This leads to greater land requirements for food production and demands for improved efficiency and forms of cultivation that increase the earth’s long-term production capacity, create biodiversity and reduce the need for fossil fuels. The modelling is done with boundaries that for Agriculture mean that an important carbon sink is omitted and means an unnecessary disqualification of N-fertilizer use. In several places in the report, it is considered that the "synthetic N-fertilizer application" has negative effects. This is true if one only takes into account the emissions of greenhouse gases that are released into the soil and does not take into account the harvest increase that takes place in crops and at the same time the improved root development. This leads to a reduced need for land and increased organic C content in the soil that stores C. The net effect of this is positive and should be credited to agriculture's share of greenhouse gases. This carbon sink in the soil, which means increased carbon content, is not included in the calculations. If I, as farmer, were to apply the same method in my accounting and not include all income, I would be convicted of tax offenses. In the report, no value for what a mulch build-up in the soil would entail.

32. (page 12, line 12–14) Table 7.1. Not being able to further separate the lump sum of CO2-emissions from FOLU indicates a great insecurity in the model and that it needs to be further investigated. Since 1990 the total emissions have increased 15,6 pc land use changes being the most important. At the same time, the globally fed population has increased with at least 2 billion.

33. (page 13, line 8–9) Figure 7.3. It should be transparent how the CO_2 equivalents for CH_4 are estimated. The GWP100 is under debate and other alternatives are presented. F.i. GWP* https://www.nature.com/articles/s41612-019-0086-4 The difference between CH_4 as a flow gas and CO_2 as a stock gas is ignored in these comparisons.

34. (page 14, line 4–5) The AFOLU sector is an emission source, accounting for 23% of global anthropogenic Greenhous Gas (GHG) emissions. In Chapter 12 (below).

35. (page 17, line 31) The statement that the fluxes are close to 0 has not data – no reference – and cannot be put forward in this way. The statement is wrong. As comes later in the report, grasslands mitigate a large amount of carbon.

36. (page 18, line 10–12) In Figure 7.6, add net figures for Europe.

37. (page 20, line 2–10) As Tian et al. (2020) demonstrate there are substantial emissions of nitrous oxide from natural terrestrial systems. Per area unit they appear to be almost on par with those from the agriculture system (including grasslands). Therefore, it is misleading that all nitrous oxide emissions from agriculture lands are classified as antropogenic. It should rather be emission over and above ”natural” emissions from the same kind of land not used for agriculture purposes. This would also include emissions from manure in extensively grazed lands (where livestock gets no feed and which is not fertilized) where there is no logic in that nitrous oxide emissions from manure from a sheep is considered antropogenic, but the manure from a deer grazing the same land is called natural. The same reasoning could also be used for methane emissions from ruminants on extensive grazing.

38. (page 26, line 9–page 27, line 17) As for the ruminants, the negative effects of their ruminants are described, but no account is taken of the fact that they use their digestive system to convert indigestible plant fiber into essential proteins for us. In addition, they also create the biodiversity that is included in the environmental goals. This should also be taken into account when calculating possible improvement potential and dietary changes. Conclusion: possibilities in shifting diets from animal-based food is overestimated because of growing population and when people getting better economy in developing countries ask for more meat instead of rice.

39. (page 29, line 10–15) Here it is stated that there is robust evidence and high confidence in the importance of biophysical effects on climate – and that is high confidence that these can have effect long distance – but then there is very low confidence in such. The whole paragraph is contradictory. The references for the statements in this paragraph are some old – and others very specific. It seems strange not to refer to comprehensive references here like Bonan’s Ecological Climatology: Concepts and applications (2016) and more recent papers on the subject. Bonan, G. 2016. Ecological Climatology: Concepts and Applications (3.eds). Cambridge University Press. 436 p.

40. (page 30, line 5–11) The first sentence in this paragraph is strange – land conditions to mitigate GHG-induced climate change as this section is on Biophysical forces – not GHG. Further, the last sentence in this paragraph (i.e. ”low agreement on the impact of .. tillage .. grazing”) – stated without citations in wrong. Grazing keeps the land open and snow covered in the winter and lighter in the summer (grass vs. trees) – tillage leaves the land open and dark – heating the land. This paragraph is recommended to be rewritten.

41. (page 30, line 12–21) Here again it seems that bold statements are made with very little effort to find new studies and references. The three citations used here are either very old (Betts 2000) or very

specific. With the statement “Studies of biophysical effects have increased since AR5 and confirmed the importance of accounting for biophysical effects including albedo (Betts 2000)...”. AR5 Synthesis Report is from 2014. Citing a publication from 2000 after saying studies have increased since 2014 is not acceptable. There is comprehensive later work, like Bonan 2016 and Bonan 2019. Bonan, G. 2016. Ecological Climatology: Concepts and Applications (3.eds). Cambridge University Press. 436 p. Bonan, G. 2019. Climate Change and Terrestrial Ecosystem Modeling. Cambridge University Press. 692 p.

42. (page 31, line 23–page 32, line 20) Here land use change is identified as an important driver of emissions and that the trend has been intensification with less grazing land and more arable land use for crops for livestock feed. This important change is not put in context in the whole report and in most cases grassland, savannah, cropland, meadow and pasture is put under the same roof (i.e. table 7.5). There is no division made between permanent grassland and annual (arable) land and natural and managed (seeded-perennial) grassland – i.e. permanent meadow and pasture, cropland and pasture. There is a fundamental difference between natural grasslands and managed grasslands, both in soil stability, soil depth, root depth and species composition and biodiversity. There is no difference made between grassland, cropland, meadow, pasture, savannah. The fact that arable agricultural land (crops) on old grassland soil (i.e. USA) has lost much SOC is well known (i.e. Thaler et al. 2021) and shows clearly that these cannot be put in the same category. In the whole report – there has to be made a clear difference between cropland and grassland on one side and what kind of grassland – natural, permanent, seeded or cultivated. The carbon cycle is very different in these – and how these are acting in relation to climate. Natural grasslands and permanent pastures have, in general, high biodiversity, plants with deep root systems and accumulate SOC. Croplands and annual transitional pastures have, in general, low biodiversity, plants with shallow root system and more aboveground tissue. Further, these are usually seeded on regular basis and plowed, tilled or harrowed, leaving the soil open for SOC oxidation and carbon emissions. Thaler, E. A., Larsen, I. J. & Q. Yu. 2021. The extent of soil loss across the US Corn Belt. Proceedings of the National Academy of Sciences, 118 (8) e1922375118.

43. (page 35, line 6–15) Although FAO 2020 is cited for the statement ”About 98 Mha of forest are estimated to have been affected by fire in 2015” – the data seems old (2015). Major forest fires have been since 2015. It has been pointed out that with increasing global temperatures increasing forest fires is to be expected (see line 14 –15). As the main carbon source in forests is aboveground, these will release increasing amounts of forest carbon into the atmosphere while carbon stored belowground will, for the most, be protected. Therefore, grasslands that store carbon belowground should be considered – not only afforestation and reforestation – for long term carbon storage (Dass et.al 2018 – cited elsewhere in the report). Dass, P., Houlton, B.Z. Wang, Y. & Warlind, D. 2018. Grasslands may be more reliable carbon sinks than forests in California. Environ.Res.Lett. 13 (7): 074027.

44. (page 34, line 45–48) Whether soils are a net source or sink for methane depends on the balance between methanogenesis (methane production) and methanotrophy (methane consumption) (Conrad, 2009; Praeg et al. 2014). Grasslands are, in general, an important methane sink (Mosier et al. 1991; Saggar et al. 2007; Holst et al. 2008; Wang et al. 2014). However, the relative abundance and community composition of methanotrophs is strongly affected by different environmental factors like land use, e.g. grazing and tillage (Abell et al. 2009; Jacinthe et al. 2014; Deng et al. 2019), water availability (Gao et al. 2018), and nutrient availability (Bodelier et al. 2004). Soil moisture is the major driver of temporal dynamics of methane fluxes (Rong et al. 2015; Shrestha et al. 2012; Praeg et al. 2014; Bai et al. 2018; Thomas et al. 2018). Ma et al. (2016) found that non-grazing (enclosures)

changed the methanotrophic community structure with time, resulting in less abundance and activity and less methane uptake. Methane produced by grazers is taken up by the methanotrophs in the grassland. In industrial operations, with wet/muddy conditions, methanogens dominate and in the absence of methanotrophs, methane is released. Rong, Y.P., Ma, L., Johnson, D.A., 2015. Methane uptake by four land-use types in the agro-pastoral region of northern China. Atmos. Environ. 116:12–21. Shrestha, P.M., Kammann, C., Lenhart, K., Dam, B. & W. Liesack. 2012. Linking activity, composition and seasonal dynamics of atmospheric methane oxidizers in a meadow soil. The ISME International Society for Microbial Ecology Journal 6: 1115–1126. Praeg, N., Wagner, A.O. & P. Illmer. 2014. Effects of fertilisation, temperature and water content on microbial properties and methane production and methane oxidation in subalpine soils. European Journal of Soil Biology 65: 96–106. Bai, X., Li, X., Wen, W., Mi, X., Li, R., Huang, Q. & M. Zhang. 2018. CO2, CH4 and N2O flux changes in degraded grassland soil of Inner Mongolia, China. J Arid Land, 10(3):347–361. Ma, T., Chen, H., Wang, Y., Kang, X., Tian, J., Zhou, X., Zhu, Q., Peng, C., Liu, L., Hu, J., Zhan, W. & E. Zhu. 2016. Effects of enclosure time on the community composition of methanotrophs in the soils of the Inner Mongolia grasslands. J Soils Sediments. Thomas, B.W., Gao, X., Zhao, M., Bork, E.W. & X. Hao. 2018. Grazing altered carbon exchange in a dry mixed-grass prairie as a function of soil texture. Conrad R. 2009. The global methane cycle: recent advances in understanding the microbial processes involved. Env Microbiol Rep 1:285–292.

45. (page 36, line 3–5) Whether soils are a net source or sink for methane depends on the balance between methanogenesis (methane production) and methanotrophy (methane consumption) (Conrad, 2009; Praeg et al. 2014). Grasslands are, in general, an important methane sink (Mosier et al. 1991; Saggar et al. 2007; Holst et al. 2008; Wang et al. 2014). However, the relative abundance and community composition of methanotrophs is strongly affected by different environmental factors like land use, e.g. grazing and tillage (Abell et al. 2009; Jacinthe et al. 2014; Deng et al. 2019), water availability (Gao et al. 2018), and nutrient availability (Bodelier et al. 2004). Soil moisture is the major driver of temporal dynamics of methane fluxes (Rong et al. 2015; Shrestha et al. 2012; Praeg et al. 2014; Bai et al. 2018; Thomas et al. 2018). Ma et al. (2016) found that non-grazing (enclosures) changed the methanotrophic community structure with time, resulting in less abundance and activity and less methane uptake. Methane produced by grazers is taken up by the methanotrophs in the grassland. In industrial operations, with wet/muddy conditions, methanogens dominate and in the absence of methanotrophs, methane is released. Rong, Y.P., Ma, L., Johnson, D.A., 2015. Methane uptake by four land-use types in the agro-pastoral region of northern China. Atmos. Environ. 116:12–21. Shrestha, P.M., Kammann, C., Lenhart, K., Dam, B. & W. Liesack. 2012. Linking activity, composition and seasonal dynamics of atmospheric methane oxidizers in a meadow soil. The ISME International Society for Microbial Ecology Journal 6: 1115–1126. Praeg, N., Wagner, A.O. & P. Illmer. 2014. Effects of fertilisation, temperature and water content on microbial properties and methane production and methane oxidation in subalpine soils. European Journal of Soil Biology 65: 96–106. Bai, X., Li, X., Wen, W., Mi, X., Li, R., Huang, Q. & M. Zhang. 2018. CO2, CH4 and N2O flux changes in degraded grassland soil of Inner Mongolia, China. J Arid Land, 10(3):347–361. Ma, T., Chen, H., Wang, Y., Kang, X., Tian, J., Zhou, X., Zhu, Q., Peng, C., Liu, L., Hu, J., Zhan, W. & E. Zhu. 2016. Effects of enclosure time on the community composition of methanotrophs in the soils of the Inner Mongolia grasslands. J Soils Sediments. Thomas, B.W., Gao, X., Zhao, M., Bork, E.W. & X. Hao. 2018. Grazing altered carbon exchange in a dry mixed-grass prairie as a function of soil texture. Conrad R. 2009. The global methane cycle: recent advances in understanding the microbial processes involved. Env Microbiol Rep 1:285–292.

46. (page 36, line 3–5) New references to added text same page and lines: Mosier, A., D. Schimel, D. Valentine, K. Bronson & W. Parton. 1991. Methane and nitrous oxide fluxes in native, fertilized and cultivated grasslands. Nature, 350:330-332. Saggar, S., Hedley, C.B., Giltrap, D.L. S.M. Lambie. 2007. Measured and modelled estimates of nitrous oxide emission and methane consumption from a sheep-grazed pasture. Agriculture, Ecosystems and Environment, 122:357–365. Holst, J., Liu, C., Yao, Z., Brüggemann, N., Zheng, X., Giese, M. & K. Butterbach-Bahl. 2008. Fluxes of nitrous oxide, methane and carbon dioxide during freezing–thawing cycles in an Inner Mongolian steppe. Plant Soil 308:105–117. Deng, Y., Che, R., Wang, F., Conrad, R., Dumont, M., Yun, J., Wu, J., Hu, A., Fang, Z., Cui, X. & Y. Wang. 2019. Upland Soil Cluster Gamma dominates methanotrophic communities in upland grassland soils. Science of the Total Environment 670: 826–836. Jacinthe, P-A., Dick, W. A., Lal, R., Shrestha, R.K. & S. Bilen. 2014. Effects of no-till duration on the methane oxidation capacity of Alfisols. Biol Fertil Soils 50:477–486. Abell, G.C., Stralis-Pavese, N., Sessitsch, A. L. Bodrossy. 2009. Grazing affects methanotroph activity and diversity in an alpine meadow soil. Environmental Microbiology Reports, 1(5):457–465. Gao, X., Thomas, B.W., Beck, R., Thompson, D.J., Zhao, M., Willms, W.D. & X, Hao. 2018. Long-term grazing alters soil trace gas fluxes from grasslands in the foothills of the Rocky Mountains, Canada. Land Degrad. Develop. 29: 292–302. Rong, Y.P., Ma, L., Johnson, D.A., 2015. Methane uptake by four land-use types in the agro-pastoral region of northern China. Atmos. Environ. 116:12–21. Shrestha, P.M., Kammann, C., Lenhart, K., Dam, B. & W. Liesack. 2012. Linking activity, composition and seasonal dynamics of atmospheric methane oxidizers in a meadow soil. The ISME International Society for Microbial Ecology Journal 6: 1115–1126. Praeg, N., Wagner, A.O. & P. Illmer. 2014. Effects of fertilisation, temperature and water content on microbial properties and methane production and methane oxidation in subalpine soils. European Journal of Soil Biology 65: 96-106. Bai, X., Li, X., Wen, W., Mi, X., Li, R., Huang, Q. & M. Zhang. 2018. CO2, CH4 and N2O flux changes in degraded grassland soil of Inner Mongolia, China. J Arid Land, 10(3):347–361. Ma, T., Chen, H., Wang, Y., Kang, X., Tian, J., Zhou, X., Zhu, Q., Peng, C., Liu, L., Hu, J., Zhan, W. & E. Zhu. 2016. Effects of enclosure time on the community composition of methanotrophs in the soils of the Inner Mongolia grasslands. J Soils Sediments. Bodeliere, P.L.E. & H.J. Laanbroek. 2004. Nitrogen as a regulatory factor of methane oxidation in soils and Sediments. FEMS Microbiology Ecology 47: 265–277. Thomas, B.W., Gao, X., Zhao, M., Bork, E.W. & X. Hao. 2018. Grazing altered carbon exchange in a dry mixed-grass prairie as a function of soil texture. Wang, Y.F., Chen H., Zhu Q.A., Peng, C., Wu, N., Yang, G., Zhu, D., Tian, L., Kang, X., He, Y., Gao, Y. & X. Zhao. 2014. Soil methane uptake by grasslands and forests in China. Soil Biology and Biochemistry. 74:70–81.

47. (page 37, line 13–18) Nitrogen fertiliser use should also be correlated with higher yields, higher nitrogen efficiency (+30 percent in Sweden in the period 1987–2007 and higher carbon sequestration due to higher yields.

48. (page 39, line 4) Section Innovations and governance, Table 7.3: Changes in farming systems: Important to quantify potential in innovation, eg. precision agriculture, plant breeding. New breeding technologies (such as CRISPR Cas9) not mentioned at all. Sustainable intensification is mentioned here and in other parts of the document as an important measure to secure increased food production without having to increase the area of arable land. The importance of this cannot be overestimated. Section Institutions and governance, Agreements and Finance: The potential of the financial sector as an important driver is almost neglected. The new international taxonomy on sustainable investments (under development) will with the current regulations steer investments away from agriculture and forestry since they are not regarded as sustainable.

49. (page 42, line 26) Here it is stated that there are – with high confidence – land management options that mitigate climate change as well as land degradation, food security, SDG and NCP and these are primarily agriculture and soil based land management options. The current report under review has main focus on reforestation and afforestation as an carbon mitigation potential (see Table 7.5). In this table, the emphasis is strongly on forest mitigation potential. Under "Reducing conversion of savannah and grasslands" there is no regional data provided. This is especially disturbing as The World Resource Institute estimates that grasslands cover about 40 % of the earth's ice-free surface and store about 34% of terrestrial soil carbon stocks (White et al. 2000). Grasslands store 50% more carbon than forests worldwide and represent around 20% of global soil organic carbon (Conant et al. 2017). Several recent regional studies and global reviews have shown that grassland soils may be an important carbon mitigation sink (Conant et al. 2017, McSherry and Ritchie 2013, Lal 2004, 2008, Soussana et al. 2007; Soussana and Lüschert 2007, Smith 2014, Ward et al. 2014, Teague et al. 2016, Viglizzo et al. 2019). Under "Agriculture" – "Soil carbon management in grasslands", there is only one reference given for regional mitigation potential, "Soils Revealed" – and that citation is not in the reference list. For other regional mitigation potential, only one reference is for the most given – and one "Griscom et al. 2017" dominates. To build guidance for the world's climate policy based on data given in table 7.5 to 2050 is not trustworthy. Conant, R.T., Cerri, C.E.P., Osborne, B.B., Paustian, K., 2017. Grassland management impacts on soil carbon stocks: a new synthesis. Ecological Applications, 27:662–668. White R., Murray S., Rohweder M. 2000. Pilot Analysis of Global Ecosystems (PAGE): Grassland Ecosystems World Resources Institute, Washington, DC. McSherry, M. E., and M.E. Ritchie, 2013. Effects of grazing on grassland soil carbon: a global review. Global Change Biology, 19(5):1347-57. Lal, R. 2004. Carbon sequestration in dryland ecosystems. Environ. Mgmt. 33(4):528-544. Lal, R. 2008. Sequestration of atmospheric CO2 in global carbon pools. Energy Environ. Sci., 1:86–100. Soussana, J. F.; Allard, V.; Pilegaard, K.; Ambus, P.; Amman, C.; Campbell, C.; Ceschia, E.; Clifton-Brown, J.; Czobel, S.; Domingues, R.; Flechard, C.; Fuhrer, J.; Hensen, A.; Horvath, L.; Jones, M.; Kasper, G.; Martin, C.; Nagy, Z.; Neftel, A.; Raschi, A.; Baronti, S.; Rees, R. M.; Skiba, U.; Stefani, P.; Manca, G.; Sutton, M.; Tubaf, Z.; Valentini, R. 2007. Full accounting of the greenhouse gas (CO2, N2O, CH4) budget of nine European grassland sites. Agriculture, Ecosystems and Environment, 121:121-134. Soussana, J.F. and Lüschert, A. 2007. Temperate grasslands and global atmospheric change: a review. Review Article. Grass and Forage Science, 62 :127-134. Smith, P. 2014. Do grasslands act as a perpetual sink for carbon? Global Change Biology, 20:2708–2711. Teague W.R., Apfelbaum S., Lal R., Kreuter U.P., Rowntree J., Davies C.A., Conser R., Rasmussen M., Hatfield J., Wang T., Wang F., and Byck P. 2016. The role of ruminants in reducing agriculture's carbon footprint in North America. Journal of Soil and Water Conservation 71(2): 156-164. Viglizzo, E.F., M.F. Ricard, M.A. Taboada, G. Vázquez-Amábile. 2019. Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review. Science of the Total Environment 661: 531–542. Wang, YF, Chen H, Zhu QA et al. 2014. Soil methane uptake by grasslands and forests in China. Soil Biology and Biochemistry, 74:70–81. Ward, A.; Dargusch, P.; Thomas, S.; Liu, Y.; Fulton, E.A. 2014. A global estimate of carbon stored in the world's mountain grasslands and shrublands, and the implications for climate policy. Glob. Environ. Change, 28:14–24.

50. (page 47, line 3) Table 7.5. Include a section on damage to forests (other than fire). For example, insect damage, fungal damage, etc. cause significant emissions of carbon and should therefore be included. These damages are also possible to reduce through forest management.

51. (page 49, line 1–45) Table 7.5. The loss of substitution effect arising from the production of biochar, as well as when biochar is buried in the soil, should be included more clearly.

52. (page 50, line 1–45) Table 7.5 It is likely that the climate benefit from the use of wood products is underestimated. New technologies and applications can quickly increase the substitution effect. The opportunities for innovation are considered to be great. See, for example: Gustavsson, L., Truong, N.L., Sathre, R., Tettey, U.Y.A. (2021). Climate effects of forestry and substitution of concrete buildings and fossil energy. Renewable & sustainable energy reviews. 136. 1-15. Truong, N.L., Gustavsson, L. (2020). Production of district heat, electricity and/or biomotor fuels in renewable-based energy systems.Energy. 202. 1-12. Piccardo, C., Dodoo, A., Gustavsson, L. (2020). Retrofitting a building to passive house level: A life cycle carbon balance. Energy and Buildings. 223. 1-13.

53. (page 52, line 1–45) In Table 7.6, the "categories" for mitigations measures is questioned. Under "Forest and other ecosystems" – "Afforestation and Reforestation" is grouped together. Afforestation – defined in Box 7.2 – is "The conversion to forest of land that historically has not contained forests" and Reforestation is "Reforestation Conversion to forest of land that has previously contained forests but that has been converted to some other use." There is a fundamental ecological difference between these. Afforestation can often be highly questioned as natural or semi-natural occurring ecosystems are converted to forest. More often these are "plantations" with very low biodiversity, often labeled "green deserts". In many countries in N-Europe, afforestation campaigns for climate mitigation is threatening natural, biodiverse ecosystems and causing SOC losses and ecosystem function from soil disturbance during ecosystem conversion. Further, often introduced/foreign and highly invasive tree species are used (i.e. Pinus contorta, Sitka spruce Picea sitchensis, Cottonwood, Populus trichocarpa), threatening native ecosystems (i.e. Iceland, Ireland, Norway, New Zealand, Chile and Argentina). It is very important that guidelines from IPCC make a clear division between Afforestation and Reforestation and raise warnings against tree plantations with invasive species that threaten biodiversity (see https://www.cabi.org/isc/). The note in "Best practices" on avoiding conversion of grasslands, planting monocultures and albedo is very important but should also be highlighted specially in the report (see also 7.4.2.2) as these are practiced today in many countries and needs to be specially warned in the Critical assessment and conclusion (page 63). The note on Risk in "Reduce grasslands and savannas conversion" limits land use for farming and food production is a highly questionable statement as most pastoral food production is based on grazing grasslands.

54. (page 52, line 1–45) Table 7.6. Forest tree breeding should be included in the sections afforestation/reforestation or sustainable forest management since there is such great potential in traditional breeding methods, but also through new technology, see e.g.: Rosvall O, Bradshaw RHW, Egertsdotter U, Ingvarsson PK, Mullin TJ, Wu H. 2019. Using Norway spruce clones in Swedish forestry: implications of clones for management Scand. J. For Res. 34(5):390-404.

55. (page 53, line 1–45) Table 7.6. Evidence is not presented in the text on the value of "ProSilva type of management or continuous cover forest management" as climate mitigation measures to justify inclusion of in the table listing "best practices to maximise benefits and reduce risks" even though there are other features of these practices (e.g. biodiversity) that are documented in the text. On land where forest production is allowed, a central feature of forest management for climate mitigation is the rate of forest growth. The evidence we are aware of indicates that the growth rates achieved by continuous cover forestry in relation to other management alternatives are dependent on site conditions and management history (Lundmark et al., 2016; Lundqvist et al., 2017). This makes it difficult to see a general endorsement of continuous cover forestry as a best management practice for

climate mitigation, which inclusion in Table 7.6 implies. A comparison of carbon balances between conventional even-aged management with clear-cutting and continuity forestry is published in: Lundmark, T., Bergh, J., Nordin, A. et al. (2016). Comparison of carbon balances between continuous-cover and clear-cut forestry in Sweden. Ambio 45, 203-213. A summary of growth differences between conventional stand management with clear-cutting and continuous cover forestry is published in: Lundqvist. 2017. Tamm Review: Selection system reduces long-term volume growth in Fennoscandic uneven-aged Norway spruce forests For Ecol. Manage. 391, 262-375.

56. (page 55, line 1–45) Table 7.6. Peatland restoration. Include ”avoid ditch-cleaning (where the production effect is weak)”, as ditches will fill in again. Afforested peatlands can often be climate neutral, or have a positive effect on the greenhouse gas balance as long as good forest growth continues.

57. (page 55, line 1–45) Table 7.6. For temperate and boreal conditions, we question the recommendation to remove planted trees from peatlands since afforested peatlands can often be climate neutral or have a positive effect on the greenhouse gas balance as long as good forest growth continues.

58. (page 56, line 1–45) In Table 7.7, the “categories” for mitigations measures is questioned and were Soil organic carbon in croplands and grasslands is grouped together. Grasslands and croplands are very different ecosystems, especially in terms of SOC were grasslands (especially permanent grasslands) can mitigate carbon while croplands usually emit carbon caused by plowing and tilling of soil for seeding (see also 7.4.2.5). Most global croplands are on previous permanent grasslands as natural grasslands have deep, SOC rich soils good for cultivation. It is important to distinguish between grasslands and croplands for mitigation measures. Why it is difficult to monitor and verify Resources and Technology under risk needs explanation.

59. (page 57, line 1–45) Bottom of Table 7.7. Enteric fermentation. What is the link between enteric fermentation and animal welfare? No reference provided and not intuitive? Rumination has a positive effect on well-being.

60. (page 68, line 42–44) Is that still so today after the forest fires in Australia and USA etc. in the last three years? New data available?

61. (page 70, line 1–3) Is that so with climate change? The statements in “Critical assessment and conclusion”, are questioned. As most of carbon storage in savannas are belowground while aboveground in forests, fires must affect carbon stores in these systems very differently (see also Dass 2018). Seems that this critical assessment and conclusion needs to be updated. Dass, P., Houlton, B.Z. Wang, Y. & Warlind, D. 2018. Grasslands may be more reliable carbon sinks than forests in California. Environ.Res.Lett. 13 (7): 074027.

62. (page 70, line 17–48) Stated here is that grasslands hold more carbon than forests. This fact is not taken to any critical analysis in the report and the extensive literature and research publications on grasslands that have been published in the last decade is not finding its way to this report. Why do grasslands store more carbon than forests? Why do grassland soils hold more carbon than forest soils? Why has the main effort for carbon mitigation with focus on forests – not grasslands were, naturally, the main storage is? In the section, the key barrier is identified as cost. Is the cost higher for implementing grasslands than afforestation? Grasslands provide many additional benefits than forests – food to be the main - along with longer lasting carbon storage in soil formation and increased soil

thickness. Carbon in wood needs to be preserved for long term storage. A life cycle analysis is needed here. In line 45 it is stated “Unlike most of the measures covered in Section 7.4, there are currently no global, spatially explicit mitigation potential estimates for reduced grassland conversion to generate technical and economic potentials by region”. Currently there is much evidence for the important potential of grasslands for carbon mitigation and therefore it must be a priority for IPCC to gather estimates on this potential. Some data seems though to be available as the first sentence in Critical assessment and conclusion (line 12 p.71) states that “Reduce conversion of grasslands and savannas showed considerable mitigation potential with most of the carbon sequestration in belowground biomass and soil organic matter. “There is however no reference for this statement. The last sentence in the section: “Conversion grasslands and savannas has received less national and international attention, despite growing evidence of concentrated cropland expansion into these areas” – and …despite growing evidence of the importance of grasslands in the global carbon cycle. IPCC needs to put more focus on grasslands on the agenda.

63. (page 73, line 48–page 74, line 1) “fertile” should be added in front of the words “drained temperate and boreal peatlands….”

64. (page 78, line 20–40) In this important section there are a very few references – and all to Smith et. al. – that is Smith et al. 2014: 2019 and 2020. Looking up these references, there are several 2019 and 2020 references and not to be seen in the section what is being referred to (a, b, c, etc. is missing). Further, non of these Smith references (2014 and all the ones 2019 and 2020) seem to be on grasslands specifically – they are all general references mostly on GHG removal – not on grasslands. This section must be rewritten with appropriate references.

65. (page 79, line 17–20) The statement “For soil carbon management in grasslands, the feasibility is greatest in areas where grasslands have been degraded (e.g. by overgrazing) and soil organic carbon is depleted. For well managed grasslands, soil carbon stocks are already high and the potential for additional carbon storage is low” has no references. This statement is highly questionable and accumulating evidence is for the contrary. The same is repeated in concluding remarks in the section were grasslands and croplands are put under one hat – and concerns over saturation and permanence is put forward – stated without any references. What is the difference in regional capacity for monitoring and verifying carbon mitigation in grasslands vs. forests?

66. (page 80, line 13–page 81, line 44) The effect of biochar application on yield increase variates depending on soil type and region from high increases on tropical soils, but no effect in temperate climate regions (Jeffery et al., 2017). There are also indication that biochar can reduce yields by adsorption of nutrients, the same mechanism that, correctly, can adsorb organic pollutants, heavy metals and ions in soil of which the biochar can’t tell the good ones from the bad Laxmar (2017). References: Laxmar E., 2017. The effect of biochar addition and fertilization on yield levels in two field experiments. Master thesis Report 2017:03, Department of soil and environment, SLU. Jeffery, S., Abalos, D., Prodana, M., Bastos, A.C., van Groenigen, J.W., Bruce, A., Hungate, B.A., Verheijen, F., 2017. Biochar boosts tropical but not temperate crop yields. Environ. Res. Lett. 12: 053001.

67. (page 88, line 24–28) The management practices mentioned are of incremental art and of no real significance if not combined with improved with the implementation of decision support systems and cropping system strategies through farm management information systems.

68. (page 91, line 32–page 93, line 38) Göte Bertilsson Agr.Dr has made the following calculations based on the Swedish agriculture which show a great potential in a changed cultivation concept such as Conservation Agriculture. (Under publication) Soil C build-up, 0 in the reporting. Should actually have been 1.8 as a carbon sink according to SLU. Improved cultivation systems with catch / intermediate crops can provide an additional 300 kg C per year and hectares. A decent but realistic development according to the table below would result in the binding of 0.4 million tonnes of carbon dioxide. If this comes up to today's trend, the sum would be 2.2 million tonnes of carbon dioxide. Bioenergy. If agriculture's main crops go to bioenergy, agriculture should not be credited. Then the more arable land may be needed in, for example, the Amazon. But it should be different if agriculture, in addition to the main crop, produces biomass or by-products. One such by-product is straw. Agriculture has the alternative of using it down for soil management or arranging the soil management with an improved cultivation system. The straw can be said to be a side production that should be able to be credited to agriculture in this context, because without agriculture there will be nothing. Denmark has a current production of 4 TwH from straw. There is an opportunity to strongly propagate this with partly manure and partly biomass production as a second crop in the autumn. A table that summarizes different possibilities. Starting points: grain cultivation of about 1 million hectares. Number of cows 500,000, fattening pigs 800,000. 3 tonnes of straw per hectare can be stored for direct energy production. One, medium crop can give 3 tons of dry matter per hectare, and can be harvested for biogas. For greenhouse gases, oil replacement has been calculated, a rough estimate. What is hereinafter referred to as the “Total resource” for intermediate crops is an assessed practical adjustment. This possibility that Bertilsson describes is missing in the report. It is mentioned that bioenergy effects from agricultural production benefits other sectors in the report. To give agriculture realistic goals for mitigation some kind cross-reference should be introduced. A rough estimate for Swedish conditions is that agriculture can give for about 5 TWH of bioenergy from side products and replacing fossil emissions of about 2 million tons GHG. (30% farm adoption). This is not very substantial on the total land budge, but quite substantial for the sector Agriculture. And a very important factor: this would strengthen the soils, sustainability and diversity. The discussion here is supported by the following references: Bolinder M.A., Crotty F., Elsen A., Frac M., Kismanyoky T., Lipiec J., Tits M., Toth Z., Kätterer T. 2020. The effect of crop residues, cover crops, manure and nitrogen fertilization on soil organic carbon changes in agroecosystems: A synthesis of reviews. Mitigation and Adaptation Strategies for Global Change 25: 929–952; Kätterer T., Bolinder M.A., Berglund K., Kirchmann H. 2012. Strategies for carbon sequestration in agricultural soils in northern Europe. Acta Agr. Scand. Section A. 62: 181-198.

69. (page 92, line 3) Box 7.7. Sustainable intensification mentioned as part of IPS, see above. The reduced emissions and carbon sequestration advantages listed for organic farming are on reasonable grounds questioned on page 7-93 rows 11-23, why it is difficult to understand why the management system is mentioned at all.

70. (page 92, line 15–19) Add following clarification after the sentence: ”However, the risk of leakage of GHGs from different sources on biogas plants could in some cases outnumber the positive climate effects for the biogas systems (Daniel-Gromke et al., 2015), especially on small scale plants (Scheutz & Fredenslund, 2019). Storage of digestate has been identified as the main source of GHGs on digestion plants (Liebetrau et al., 2013), as well as the combined heat and power (CHP) unit (Fredenslund et al., 2018). This means that measures like collecting biogas from storages, CPU leakage control of reactors must be mandory when introducing such technique.” Daniel-Gromke J., Liebetrau J., Denysenko V. and Krebs C., 2015. Digestion of bio-waste – GHG

emissions and mitigation potential. Energy, Sustainability and Society 5:3, DOI 10.11186/s13705-014-0032-6. Fredenslund A. M, Hinge J., Holmgren M. A., Rasmussen S. G., Scheutz C.,2018. On-site and ground-based remote sensing measurements of methane emissions from four biogas plants: A comparison study. Bioresource Technology 270, 88-95. Liebetrau J., Reinelt T., Clemens J., Hafermann C., Friehe J., Weiland P., 2013. Analysis of greenhouse gas emissions from 10 biogas plants within the agricultural sector. Water Science Technology 67(6), 1370-9. doi: 10.2166/wst.2013.005… Scheutz C., Fredenslund A. M., 2019. Total methane emission rates and losses from 23 biogas plants. Waste Management 97, 38-46.

71. (page 100, line 13–17) The future use of BECCS and BECCU are also important components when considering the European policy concerning LULUCF. If the LULUCF regulation reduces forest and agricultural production this will reduce possibilities for BECCS and BECCU.

72. (page 101, line 24–30) Springmann et al (2018) don't include CO2 emissions in their calculations which means that the statement is not correct. Further, its projections are totally dependent on some assumptions, which should be declared if the article is cited. They assume that population will grow with 50 % and global income grow three times. They also assume that the demand for crop land will increase by 67 percent. Looking back, that assumption seems unsubstantiated. The gross output of global agriculture grew from 3,760 calories per capita to 5,740 calories per capita between 1960 and 2012 while the population more than doubled and consumption of animal products increased a lot. But during the same period global crop land just increased by around 15 percent.

73. (page 101, line 30–35) It should be noted that the scenario by Poore and Nemecek (editorial: the year is 2018 and not 2019) includes the abandonment of all pastureland as well as the prohibition of pastoralism as a livelihood. Pastoralism constitute the livelihood of hundreds of million people and the land has almost no alternative food producing use. Further, if livestock I culled those pasturelands will most likely be populated by wild herbivores, which may be a nice thing, but they are likely to emit more or less the same methane and nitrous oxide as the sheep, camels, cattle and goats they replace. If the reference to the article is kept those issues should be clarified.

74. (page 109, line 18–19) Reference is needed to which models are used. It is unclear if several models are used and results are presented as mean and variances from different models, or if one model is constructed with sensitivity analysis. It is also unclear if computable general or partial equilibrium models are used.

75. (page 116, line 1) The chapter would benefit from an introduction of the specific policy design problem associated with AFOLU compared with other mitigation measures, which mainly includes uncertainty in effect, and assurance of additionality and permanence.

76. (page 149, line 1–20) Other barriers could be ”low farmers income” to mentioned under social-economical questions.

77. (page 149, line 20–27) The need for more knowledge on the mitigation potential of sustainable intensification is lifted. This is strongly supported.

78. (page 150, line 20) The effect of biochar application on yield increase variates depending on soil type and region from high increases on tropical soils, but no effect in temperate climate regions (Jeffery et al., 2017). There is also indication that biochar can reduce yields by adsorption of

nutrients, the same mechanism that, correctly, can adsorb organic pollutants, heavy metals and ions in soil of which the biochar can't tell the good ones from the bad Laxmar (2017). References: Laxmar E., 2017. The effect of biochar addition and fertilization on yield levels in two field experiments. Master thesis Report 2017:03, Department of soil and environment, SLU. Jeffery, S., Abalos, D., Prodana, M., Bastos, A.C., van Groenigen, J.W., Bruce, A., Hungate, B.A., Verheijen, F., 2017. Biochar boosts tropical but not temperate crop yields. Environ. Res. Lett. 12: 053001.

79. (page 59, line 1–10) Table 7.8: Here and in other places the expression a ”healthy sustainable diet” is used and then it is written that it means reduced consumption of animal products in some countries. However, there is little evidence that reduced consumption of animal products is the most important factor for a healthy food. The Lancet Volume 393, ISSUE 10184, P1958-1972, May 11, 2019 demonstrates clearly that most other diet related issues are much more important (more vegs, more whole grain, less sugar etc.). It also shows that too low consumption of milk is a bigger health problem than high red meat consumption. Therefore it is misleading to qualify a healthy diet with a reduction in animal sourced foods. It is recommended, that the whole food system and different consumption patterns and diets are improved in future reports.

80. (page 147, line 1–45) Table 7.10. The effect of dietary shift vary tremendously across the planet. Semba, R.D., de Pee, S., Kim, B. et al. Adoption of the ‘planetary health diet’ has different impacts on countries’ greenhouse gas emissions. Nat Food 1, 481–484 (2020) show that emissions will increase in countries with a total of 2 billion people with the adoption of the diet proposed by Willet et al (2019).

On Chapter 12 Cross sectoral perspectives:

81. (page 1, line 36–45) No link to the effect on Carbon sink potential with grassland crops in Land use can make this information biased on terms of potential.

82. (page 29, line 20–33) Compare to fertilization and productivity effect in arable soils. Fertilization in agriculture with precision is easier than this example and should be more emphasized as a CDS in agriculture.

83. (page 75, line 19–27) The definition of what perennial crops means, is it 2,3, or more years in order not to lose productivity. What is gain under the growing period can be lost in the breaking process to a new culture by higher GHG emissions. The same goes for perennial grain crops were the yielding and productivity must be evaluated better before this solution gives a lower carbon footprint versus intensive controlled cropping with annual varieties.

84. (page 39, line 1–page 67, line 3) Miss the social and socio-economic aspects of malnutrition. Tends to exaggerate possibility to reduce GHG emissions and malnutrition due to farm practices.

85. (page 42, line 21–30) ”Transport” as a whole has a large contribution to GHG emissions if one consider all steps in the food system from transport of inputs (seeds, fertilizers etc) to the farm to the transport of food from shops by consumers. When lifecycle analyses show limited emissions from transport in the food system it is often because they report only one or two stages of transport, often only the stage to the retailer. Even for a bulk product like soy beans, transport and processing can cause much more emissions than the agriculture part, even more than land-use change (Escobar et al., 2020, Spatially-explicit footprints of agricultural commodities: Mapping carbon emissions embodied

in Brazil' soy exports, Global Environmental Change Volume 62, May 2020, 102067). For vegetables transport and refrigeration is often a major source of emissions (A. Frankowska, H. K. Jeswani, and A. Azapagic "Environmental impacts of vegetables consumption in the UK" Science of the Total Environment 682 (2019) p. 80-105).

86. (page 42, line 31–32) The figure for emissions caused by production of fertilizers could be discussed. According to FAO 115 million tons N fertilizer is used and emissions from average N-fertilizer is in the range of 4-5 kg CO2e. The figure quoted is equal to emissions only in China (Chai, R., Ye, X., Ma, C. et al. Greenhouse gas emissions from synthetic nitrogen manufacture and fertilization for main upland crops in China. Carbon Balance Manage 14, 20 (2019). https://doi.org/10.1186/s13021-019-0133-9). In addition there is considerable methane leakage from the natural gas and fertilizer industries.

87. (page 43, line 9–page 46, line 20) The prominence given to results of lifecycle analysis when comparing emissions from various foods and diets is problematic on many counts. 1. Basically all lifecycle analyses are using the emission metric GWP-100 for methane. But as the report shows in Annex B, Appendix AB10 this metric has major limitations and works best in describing marginal changes and not ongoing emissions, which is largely the case in the food system (For further elaboration see John Lynch et al 2020 Environ. Res. Lett. 15 044023.). It basically constitutes a major bias against ruminants in general and against extensive pastoralism in particular. 2. The food and agriculture systems are dynamic and one can't extrapolate the value for individual products into full diets as allocation of emissions change when the system change. I.e. The calculation of emissions of vegetable oil is based on that oil cakes can be used as animal feed and therefore substantial emission is allocated to oils cakes. If consumption of vegetable oil would increase dramatically as proposed e.g. by Willet et al (2019) and consumption of animal products are dramatically reduced the emissions per kg of vegetable oil would approximately double. This is not captured by any of the studies referenced. 3. In a circular food system, animals play a very important role for using leftovers, natural grasslands etc. This is not captured by lifecycle analyses but is demonstrated e.g. by van Hal, O., de Boer, I. J. M., Muller, A., de Vries, S., Erb, K. H., Schader, C., Gerrits, W. J. J. & van Zanten, H. H. E., 10 May 2019, In: Journal of Cleaner Production. 219, p. 485-496 12 p. and Röös, Elin & Patel, Mikaela & Spångberg, Johanna & Carlsson, Georg & Rydhmer, Lotta, 2016. "Limiting livestock production to pasture and by-products in a search for sustainable diets, Food Policy, Elsevier, vol. 58(C), pages 1-13. 4. The diet scenarios are not tested against the realities of agriculture, soils and climate. What crops farmers can successfully depend on a multitude of factors and the proportion of different crops and animals in the production system is essential.

88. (page 47, line 1–page 51, line 45) Table 12.9 The usage of D+ and D– seems to be the opposite of the explanation below the table? Controlled environment agriculture, especially indoor farming with LED lights, has very high emissions per kcal produced. (Graamans et al. 2018, Plant factories versus greenhouses: Comparison of resource use efficiency, Agricultural Systems 160 (2018) 31-43.) It is only used for luxury greens with no relevance for nutrition or food supply. The claims of land and water saving are not including land and water use for energy production. In addition the water used for hydroponics or aquaponics is mostly of municipal drinking water quality and can't be compared with rain water or even agriculture irrigation water. It can hardly be called "transformative" and the technology is known since 100 years (although considerably improved).

89. (page 48, line 1–page 52, line 4) Interesting Food system mitigation opportunities.

90. (page 53, line 17–page 54, line 12) Controlled environment agriculture, especially indoor farming with LED lights, has very high emissions per kcal produced. (Graamans et al. 2018, Plant factories versus greenhouses: Comparison of resource use efficiency, Agricultural Systems 160 (2018) 31-43.) It is only used for luxury greens with no relevance for nutrition or food supply. The claims of land and water saving are not including land and water use for energy production. In addition the water used for hydroponics or aquaponics is mostly of municipal drinking water quality and can't be compared with rain water or even agriculture irrigation water. It can hardly be called ”transformative” and the technology is known since 100 years (although considerably improved).

On Chapter 13 National and Sub-national Policies and Institutions:

91. (page 17, line 18–page 24, line 9) Chapter 13.3 describes a lot of different types of formal institutions involved in climate policy. It is difficult to read, and an introduction is needed to classify the different types of institutions and some note on how they are important for achievement of GHG reductions in practice.

92. (page 29, line 43–page 35, line 41) The content of Chapter 13.5 seems to be very similar to that of Chapter 13.3. The text would benefit from merging these chapters. I miss a discussion of governance design for crisis management.

93. (page 36, line 15–16) In Table 13.1, the classification into three types of instruments is acceptable, but the examples provided are not clear. Voluntary agreements can be economic instruments such as the voluntary markets for carbon sequestration offsets. Public procurement is often incentive based where a winning bid is offered a profitable project. I miss a clear definition of the different categories, which would be helpful for readers without sufficient backgrounds in economics.

94. (page 37, line 21–30) Box 13.7. Usually, policy instruments are compared with respect to several criteria (e.g. cost effectiveness, fairness, etc.) but I have never seen ‘stringency’ as a criterion. Instead, ‘stringency’ is often referred to environmental targets, such as % reductions in GHG emissions.

95. (page 39, line 18–page 40, line 1) The table 13.2 lists some criteria for comparing and evaluating different policy instruments. I miss one of the most discussed criterion, incentives for innovation and technological development, which is essential for rapid transition. There is no consideration of performance under uncertainty in the environmental effects, which differ between the policy instruments. This criterion is important when society is concerned about reaching emission reductions with some safety margin.

96. (page 56, line 36–page 73, line 5) The entire Chapter 13.8 is very difficult to follow. It is well known that mitigation measures differ with respect to their multifunctional impact (e.g. reductions in fuel use, land use changes) and that different policies (economics, regulatory and others) have different dispersal effects in the economy and on the environment. The chapter mixes mitigation measures and policy instruments. It is also difficult to see the distinction between policy goals and means.

97. (page 58, line 1–3) There is a need for explaining Figure 13.6. For example, a carbon tax impacts not only emissions but several other pollutants, and it affects several objectives (e.g. employment, equity etc.) of concern for society. Why is this not listed as ‘multi-objectives’?

On Chapter 16 Innovation, technology development and transfer:

98. The potential role of biotechnology in agriculture and forestry seems entirely ignored. Emerging technologies like gene editing should be mentioned.

99. (page 9, line 15–21) It is interesting that concrete innovations are mentioned like this: "Novel irrigation technologies are helping food producers augment and improve water supplies, raise water productivity, and improve effectiveness of water demand management and irrigation system maintenance (Reinders 2020); new technologies such as nanoparticles that can significantly enhance the efficiency of agricultural inputs (Singh et al. 2020); agrivoltaics that co-develop land for agriculture and solar with water conservation benefits (Barron-Gafford et al. 2019; Schindele et al. 2020; Lytle et al. 2020)". It is missing one important kind of innovation area in relation to agriculture, namely soil compaction prevention. Instead, this sentence is suggested: "New technologies such as tire construction, automatic tire inflation systems, lightweight material, and small robot vehicles can decrease soil compaction. Easy-drawn implements like inter-row-hoeing machines with self-seeking coulters can also reduce soil compaction because they do not need heavy tractors. Lower compaction, in turn, increases yield and can reduce anaerobic reactions in the soil and therefore also reduce emissions of both CH_4 and N_2O (Frankelius, 2020). "Reference: Frankelius, P. (2020). A proposal to rethink agriculture in the climate calculations, Agronomy Journal, 112, (4), July/August, pp. 3216-3221 DOI:10.1002/agj2.20286 https://acsess.onlinelibrary.wiley.com/doi/abs/10.1002/agj2.20286I may also miss biogas capturing (like covered lagoons) from manure as an important innovation that can stop a lot of GHG emissions. In California they have brought down emissions by 20 % in just a few years.