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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Global emissions of fluorinated greenhouse gases 2005–2050 with abatement potentials and costs" *by* Pallav Purohit and Lena Höglund-Isaksson

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Referee #3 (A. McCulloch)

The paper is a result of very comprehensive modelling of the projected deployment of HFCs, PFCs and SF6 in each of their current end uses and each region of the world. This has involved the assembly of a large quantity of data and many assumptions. The end result is only as good as the quality of the data and assumptions and both of these need to be revisited if the work is to be of any value. I have not attempted a comprehensive review of the changes required and, while the following are intended as examples of shortcomings, they are not the only ones that need to be addressed.

Authors' Response: We thank Dr. McCulloch for his comments and helpful suggestions on how to improve the manuscript. Below we provide detailed point by point replies to the questions.

We would have highly appreciated if the reviewer had explained the exact nature of the many shortcomings he is referring to. We can of course only respond to short-comings that the reviewer actually lists and not address sweeping comments that are not made more explicit by the reviewer.

1. The values of the GWPs, quoted as being from AR5, in Table S2 are incorrect, particularly those for HFC-134a, the most widely used HFC, but also HFC-23, PFC 14 and SF6. This affects the numerical values of all of the results.

Authors' Response: No, the GWPs taken from IPCC AR5 and used in the report in Figure 12 as comparison to AR4 results (which were used for all estimations) are not incorrect, but correspond to GWPs over 100 years with climate–carbon feedback effects (IPCC AR5 Section 8.SM.15, Table 8.SM.16 on p.8SM-24: Metric Values for Halocarbons Including Climate–Carbon Feedback for Carbon Dioxide to Support Section 8.7.2, http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf). Hence, the reviewer is correct in so far that for HFC-134a the GWP-100 without climate-carbon feedback effects is 1300, but it is 1550 with climate-carbon feedback effects. The difference between these two values is due to indirect effects on warming when the substance is released to the atmosphere and exposed to other substances and variable conditions. Albeit not available with climate-carbon feedback effects in AR4, we consider it more appropriate to compare to the AR5 GWPs with feedback effects as these are available. After all, we are interested in the effect on global warming when these substances are released to the atmosphere. To make this distinction clearer to the reader, a note has been added in Table S2 that the GWPs taken from AR5 refer to values with climate-carbon feedback effects.

2. There seems to be an assumption in the models (or their inputs) that the industries using these materials are isolated regionally whereas in fact they are globalized. One result of this is that the prohibition of use of HFC-134a in mobile air conditioning (MAC) in Europe is considered not to affect its use in this application in the rest of the world. The reality is that manufacturers of original equipment are supra-regional and MAC systems that use HFC-134a have now, or shortly will be, superseded world-wide. The modelling needs to reflect the realities of the markets.

Authors' Response: We agree with the reviewer that the modelling should reflect the realities of the markets, but disagree on the conclusion he draws about how new technologies marketed worldwide can be expected to be taken up in the absence of further directed regulations (which is how we define our baseline). In the case of HFC-134a use in Mobile Air-Conditioners (MACs), the existing alternatives HFO-1234yf and CO2-based systems are still relatively expensive compared with HFC-134a. Therefore, adoption of these technologies in new cars requires regulations that ban/tax/restrict the use of HFC-134a in MACs. To the extent that such regulations are currently in place (e.g., in the US, Canada, EU and Japan), the GAINS model assumes a phase-in of new alternatives in these markets, i.e., HFOs or CO2-based technology (whichever has the lowest marginal cost -which happens to be HFO-1234yf in most markets). Does a phase-out of HFC-134a in MACs in these markets automatically lead to uptake also in other markets that do not have similar regulations in place as suggested by the reviewer? We do not think so and for the following reasons:

a. HFC-134a is currently considerably cheaper than HFO-1234yf. We therefore see no reason to believe that new cars sold to unregulated markets will use HFO-1234yf although it is readily available in the world market. A parallel can be made to the spread of catalytic converters, which is a technology that has been around for decades and used as standard in developed countries. Still, cars manufactured in industrialized countries but for export to African countries without legislation on catalytic converters, are frequently manufactured and delivered without catalytic converters (UNEP, 2012).

Similarly, HFO technology availability on the world market will not be enough to spur uptake. Global uptake requires either that the price of the new technology is lower than the conventional technology or that regulations are put in place that force uptake of the more expensive technology.

b. Many countries have import bans on used cars (e.g., Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Venezuela, Uruguay) or restrictions that imported cars may not be more than 3 years old (e.g., Bolivia, India) or high import duties for used cars which severely hampers imports (e.g., Russia, China) (UNEP, 2011; Macias et al., 2013). New MAC technology can therefore not be expected to rapidly spread world-wide with export of used cars from regions with regulations in place. Exceptions may be Mexico and African countries. Mexico imports used cars from the US that may in the future be equipped with HFO-1234yf. Used cars exported from regulated regions to African countries may in the future be equipped with more expensive AC technology, however, it is questionable if these will be refilled with the relatively expensive HFO-1234yf if this is not required by regulations. The African market is however a very small fraction of the global car market.

In Section 3.1 of the manuscript we have explicitly mentioned that: "Due to the relatively high cost of HFO-1234yf compared to HFC-134a (Schwartz et al., 2011; Carvalho et al., 2014; USEPA, 2013; Purohit et al., 2016) and extensive import bans and restrictions on international trade with used cars (UNEP, 2011b; Macias et al., 2013), we consider it unlikely that new MAC technology will be taken up in the absence of directed regulations or spread globally through export of used cars from regions with regulations in place."

3. On a similar note, there is little or no justification for assumptions such as that in lines 21 to 24 of page 11 that abatement of HFC-23 emissions from Chinese production of HCFC-22 will remain constant. While it might happen that no new HCFC-22 production will have HFC-23 treatment and disposal, this is by no means certain. This is such an important assumption that, if Feng et al. (2012) give reasons, they should be repeated

in this paper.

Authors' Response: HFC-23 emissions from HCFC-22 production is assumed controlled in most developing countries due to CDM (except China where 36% is controlled). Since China is expected to produce 85% of global HCFC22 in 2030, the rate of abatement adoption assumed for China in the baseline is critical. In China, the State Council announced in May 2014 that it would strengthen domestic management of HFC emissions and accelerate the destruction and replacement of HFCs, focusing first on subsidizing the destruction of HFC-23 from manufacture of HCFC-22 (Finamore, 2015). According to the investment plan to support destruction of HFC-23 issued by the National Development and Reform Commission (NDRC) 2015 (NDRC, 2015; Schneider et al., 2015; Munnings et al., 2016), the Chinese government plans to introduce subsidies per tonne CO2eq for implementation of new HFC-23 destruction devices for HCFC-22 production plants that are already in operation without support from CDM. According to personal information from Zhai (2016), a current subsidy per tonne CO2eq emissions removed is Âĕ4, Âĕ3.5, Âĕ3, Âĕ2.5, Âĕ2, Âĕ1 in respective year 2014 to 2019. The subsidy will end in 2020. Enterprises are already encouraged to report data about the production amount, destruction amount and new facility plans. We consider the existence of the policy efforts listed above together with the implemented incentive scheme, an indication of an interest from the Chinese government to continue to control emissions from this source also after 2020 when the subsidy is phased-out (it is after all a very cost-effective way to reduce greenhouse gases). We do not find it realistic to expect that plants currently equipped with control technology will actively remove it as the support from CDM ceases. The current level of control implementation at 36% is therefore assumed sustained into the future. We have added a description of new policies/regulation to control HFC-23 emissions from HCFC-22 production in China and India in Section 3.1 of the revised manuscript.

4. The paper contains a section on comparison with other studies but fails to mention the Representative Concentration Pathways used by IPCC to describe the future con-

centrations of all greenhouse gases. The baseline scenario given in this paper results in emissions between two and three times higher than the largest of the RCP scenarios (RCP8.5). At the very least this discrepancy needs to be addressed and sufficient reasons given to enable the scenario derived for this paper to be used in the broader context of future greenhouse gas emissions. Admittedly, the impact of the compounds covered by this paper amounts to less than 2% of the total impact of all greenhouse gases in the future, but although their effect is small, it is essential that it is placed accurately in the context of total greenhouse gas impacts.

Authors' Response: Yes, thank you this is a very good suggestion. We have now included the RCP scenarios in our comparison in Figure 10 of the revised manuscript using data from IIASA's RCP database. In addition, in the Introduction (Section 1) we also relate the importance of F-gases to total anthropogenic greenhouse gas emissions as suggested.

5. Finally, the authors should avoid using percentages where absolute values would be more instructive. For example, the abstract states "Estimates show that it would be technically feasible to reduce F-gas emissions by 86 percent between 2018 and 2050". This percentage is influenced by both the baseline values and the projection. It would be far more instructive to quote the absolute values that is "from X Pg CO2eq/yr to Z PgCO2 eq/yr". Furthermore, the value quoted does not agree with the value scaled from Figure 3 (92%).

Authors' Response: As suggested, the percentage reduction in cumulative emissions between 2018 and 2050 mentioned in the abstract has now been replaced with absolute emission levels in the Abstract and Section 4. Please note that the statement of 86% refers to technically feasible cumulative removal of emissions compared to baseline emissions over the entire time period 2018 to 2050. Due to limitations in the short-run to immediately implement full technology adoption, the maximum cumulative reduction considered possible below baseline emissions is somewhat smaller than the relative reduction of 94% that we measure between the annual emission level in 2018 and the lowest annual (not cumulative!) emission level considered technically possible to achieve in 2050.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/acp-2016-727/acp-2016-727-AC3-supplement.pdf

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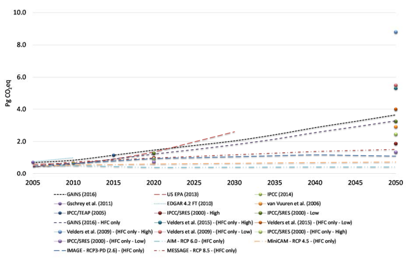

Figure 10: Comparison of GAINS baseline scenario with other F-gas business-as-usual scenarios

Fig. 1.