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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 #1 (Anonymous)

I am in favor of publishing the paper after following points have been carefully considered.

Authors' Response: We thank the Anonymous Referee for his/her constructive comments and many helpful suggestions on how to improve the manuscript. Below we provide detailed point by point replies to the questions.

1. The term "F-gas" is somehow reserved for the HFCs, PFCs, SF6 regulated for example in the F-gas directive. The definition of this term as it is done in the paper (i.e.

by including HCFCs) is therefore problematic. Authors should come up with a new term or just use this F-gases just as it is generally used and combine it with the HCFCs. E.g. "emissions of F-gases and HCFCs: : :". Anyway, HCFCs are not really at the core of this analysis. For me it was for example not clear where authors got there information about activities and emission factors for HCFCs. Is that related to UNEP reporting or just a ratio with F-gases? Maybe it would be better to not really calculate emissions for HCFCs anymore but just focus on the HFCs.

Authors' Response: Yes, we agree with the reviewer that the term "F-gases" should be reserved for HFCs, PFCs and SF6. In the revised version we make sure to use the term only for these three substance groups. Although phase-out of HCFCs is already addressed under the Montreal Protocol (MP) and therefore not a target of interest when analyzing future abatement efforts in F-gases, we still find it useful to keep track of and display baseline HCFC emissions in parallel to HFCs, since HCFCs are very close HFC substitutes with equally strong global warming potentials. We will, however, make it clearer to the reader that the HCFC reporting is only for the purpose of "keeping track" and not intended as a potential target for future abatement opportunities. We have estimated the total refrigerant (HCFC/HFC) consumption at the sectoral level. For Annex-I countries (primarily non-Article 5 parties) HFC consumption in years 2005 and 2010 are taken as reported to the UNFCCC (UNFCCC, 2012). For non-Annex-I countries (i.e., primarily Article 5 parties), information on HCFC/HFC consumption by sector in years 2005 and 2010 is taken from available literature (GEF 2009; MoEF, 2009; UNEP, 2011a; PU, 2012; UNDP, 2012; MoEF, 2013; Yong, 2013; GIZ, 2014; UNDP, 2014a-b; UNEP, 2014b), basically assuming 100 percent consumption of HCFCs in developing countries in 2005, except for mobile air conditioners and domestic refrigerators. Future fractions of HCFC in HFC/HCFC consumption have been made consistent with the phase-out schedule of HCFCs as described in the latest revision of the Montreal Protocol (UNEP, 2007) and with reported baselines of parties, including updates based on later reporting of the parties to the UNEP Ozone Secretariat and the HCFC Phase-out Management Plans (HPMPs) of parties. The latter provide information on how much

HCFC can be used by a given country in a given year – and the rest of the demand is assumed met through HFCs. We have made changes in the text of Section 2.2 of the manuscript to make it clearer for the reader how HFC/HCFC shares were constructed.

2. P. 4 L. 17: HFC-23 is not really a replacement compound. Please look for other compounds with high GWP.

Authors' Response: Although HFC-23 is primarily generated as a side-product of HCFC-22 production, it is also used directly in fire protection and integrated circuits or semiconductor industry. A small share of HFC-23 is also reported by parties to be used in commercial and industrial refrigeration sectors (UNFCCC, 2012). HFC-23 is therefore also a replacement compound to ODSs. In view of the above, we did not make any changes in the manuscript in response to this comment.

3. P. 4 L. 25: the term PFPB is not explained

Authors' Response: Following the reviewer's advice, point feed prebake (PFPB) technology is now written out in full in the text in Section 2.3 of the manuscript.

4. P. 7 L 23: full abatement is not possible. In case of shut-down processes there are always emissions. In addition figures are mentioned further back in the results part. Maybe that could be done already here.

Authors' Response: Please note that "full abatement" does not necessarily mean that all emissions are removed, but merely that abatement technology is installed to the maximum technically feasible extent. How much emissions are removed will depend on the removal efficiency of the technology. In this case, post-incineration of HFC-23 is assumed to have a removal efficiency of 99.99% and accordingly that 0.01% of emissions will remain also under full abatement. To make this distinction clearer in the text, the sentence has been rewritten as: "HFC-23 emissions from HCFC-22 production are assumed fully equipped with post-combustion technology in OECD countries" in Section 3.1 of the manuscript.

5. P. 7 L. 28 the assumption that the CDM will go on in the future is not really realistic. EU for example has stopped the CDMs with HFC-23 and for example Miller et al. have increasing emissions in the future. Again, figures are mentioned further back in the results part. Maybe that could be done already here.

Authors' Response: Due to CDM, HFC-23 emissions from HCFC-22 production is controlled in most developing countries (except China where 36% is controlled). Since China is expected to produce 85% of global HCFC-22 in 2030, the rate of abatement adoption assumed for China after removal of CDMs is critical. Two core reasons are pointed out in an Ecofys study (Sachweh and Zhu, 2015) for why the abatement might continue also in the absence of CDM incentives. First, companies do continue running the abatement equipment, and in some instances even replace it with new equipment, to act in accordance to values defined under China's corporate social responsibility (CSR) policies. Second, the project operators in China anticipate future benefits from carbon market developments. This is reflecting the activity around carbon pricing in China, where, besides the China Certified Emissions Reduction (CCER) scheme, seven pilot emissions trading systems (ETSs) are in operation and a national ETS will be launched in 2017.

In addition, the Chinese 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, a powerful greenhouse gas that is the by-product of the 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 Âě4, Âě3.5, Âě3, Âě2.5, Âě2, Âě1 in respective

year 2014 to 2019. The subsidy will end in 2020. So the enterprises are already encouraged to report data about the production amount, destruction amount and new facility plans. We consider the existence of this 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!). Given the subsidy scheme, we do not find it realistic to expect that plants currently equipped with control technology will actively remove it as support from CDM ceases. The current level of control implementation at 36% is therefore assumed sustained into the future. Finally, the Intended Nationally Determined Contributions (INDCs) submitted by China to the UNFCCC (UNFCCC, 2015 a-b) also aims to phase down emissive use of HCFC-22, a potent greenhouse gas, and to "achieve effective control" of HFC-23.

In addition to China, India announced during the 38th Meeting of the Open-Ended Working Group (OEWG 38) of the Parties to the Montreal Protocol in Kigali that its chemical industry must with immediate effect collect and destroy emissions of its most potent greenhouse gas, HFC-23 (Mahapatra, 2016). In view of the mentioned policy incentives, it appears most reasonable to assume that also without CDM developing countries will voluntarily continue destruction of HFC-23 emissions from HCFC-22 production as assumed in the GAINS baseline. To strengthen our argument here, we have added a brief description of the new policies/regulations to control HFC-23 emissions from HCFC-22 production in China and India in Section 3.1 of the revised manuscript.

6. P. 8 L. 9 the term (HSS/VSS is not explained

Authors' Response: Following the reviewer's advice, Horizontal Stud Söderberg (HSS) and Vertical Stud Söderberg (VSS) are explained in Section 3.1 of the manuscript.

7. P. 13 L 18ff. In the discussion, the following paper is missing. This contains additional information. Velders, G.J.M., S. Solomon, and J.S. Daniel, Growth in climate change commitments from HFC banks and emissions, Atmos. Chem. Phys., 14 (9),

4563- 4572, doi: 10.5194/acp-14-4563-2014, 2014. Furthermore, the Chapter 5 of the most recent Ozone Assessment (Harris and Wuebbles, 2014) (e.g. Figure 5-9) should also be part of the discussion.

Authors' Response: As far as we understand the work by Velders et al., it is more appropriate to refer to Velders et al. (2009) and Velders et al. (2015) as they are two fully different versions, whereas Velders et al. (2014), which is also referenced in Harris and Wuebbles (2014; p. 5.40), used an intermediate version that was a partial update of Velders et al. (2009).

8. P. 15 L. 20 Authors do not mention that the F-gases will possibly be part of the Montreal Protocol. This should at least be mentioned in then conclusions. This will possibly change the whole cost model dramatically.

Authors' Response: According to the Kigali Amendment (KA) of the Montreal Protocol (MP) from October this year (i.e., well after the submission date of this paper), HFC consumption will be phased-down almost completely by 2050, with binding phase-down pathways specified for four different party groups. To facilitate the phase-down a Multilateral Fund (MLF) is to be set up and decided upon in the next meeting of the parties in October 2017. The fact that an agreement has now been met about the HFC phase-down paths does of course not change the cost model that we have used here. The cost analysis and its conclusions remain the same. However, depending on how the funds from the MLF will be distributed to different parties (which we will only know next year), the net cost burden will look different for different parties. In a separate forthcoming paper, we use the cost model described in this work to analyze the cost burden of different parties of the KA. Hopefully, it can bring insights that are useful for the meeting next year when the distribution of the MLF to different parties is to be decided upon.

In Section 3.1 of the manuscript, we have added the following text: "Note that the agreement to phase-down global use of HFCs outlined in the Kigali Amendment to

the Montreal Protocol during the 28th Meeting of the Parties in October 2016 (UNEP, 2016), was made after the submission date of this paper and has therefore not been considered in the baseline presented here. Its implications for emissions and costs will be the focus of a separate analysis."

9. P. 30 Figure 9 is misleading. A lot of information is contained in other publications, if only the end point in 2050 is shown no real discussion is possible and the reader cannot really follow the discussion between the different scenarios.

Authors' Response: In the revised manuscript, we have included the RCP scenarios in our comparison in Figure 10 of the revised manuscript using data from the IIASA-RCP database. Apart for the RCP scenarios (IIASA, 2009; Moss et al., 2010) and USEPA (2013) that provide data in five-year intervals until 2050 and 2030, respectively, the other referenced studies provide only one point in 2020 and one in 2050 without describing the pathway between these two points. We can therefore not display the paths between these points as they are not provided by the original source. We make a short clarifying note about this in the manuscript text of Section 4.5.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/acp-2016-727/acp-2016-727-AC1-supplement.pdf

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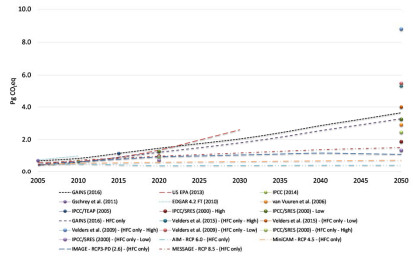

Figure 10: Comparison of GAINS baseline scenario with other F-gas business-as-usual scenarios

Fig. 1.