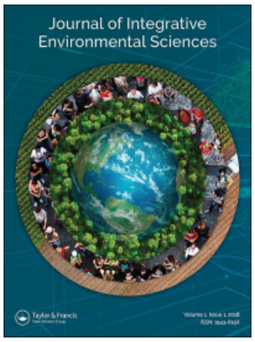

Journal of Integrative Environmental Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/nens20

Non-CO_2 greenhouse gases: the underrepresented, complex side of the climate challenge

Mathijs Harmsen, Jillian Student & Carolien Kroeze

To cite this article: Mathijs Harmsen, Jillian Student & Carolien Kroeze (2020) Non-CO_2 greenhouse gases: the underrepresented, complex side of the climate challenge, Journal of Integrative Environmental Sciences, 17:3, i-viii, DOI: 10.1080/1943815X.2020.1907106

To link to this article: https://doi.org/10.1080/1943815X.2020.1907106

Published online: 13 Jun 2021.

JOURNAL OF INTEGRATIVE ENVIRONMENTAL SCIENCES
2020, VOL. 17, NO. 3, i–viii
https://doi.org/10.1080/1943815X.2020.1907106

Taylor & Francis
Taylor & Francis Group

EDITORIAL

OPEN ACCESS Check for updates

Non-CO_2 greenhouse gases: the underrepresented, complex side of the climate challenge

When it comes to mitigating climate change, the focus tends towards carbon dioxide (CO_2) emissions. However, human-induced emissions of non-CO_2 greenhouse gases (GHGs) are important contributors to global warming. These include methane (CH_4), nitrous oxide (N_2O), fluorinated greenhouse gases (HFCs, PFCs and SF_6) and ozone depleting substances. Other non-CO_2 emissions, such as aerosols (e.g. black carbon (BC)) and pollutants that function as aerosol or GHG precursors, contribute to changes in the atmosphere's energy balance.

This editorial overview introduces a Special Issue (SI) of Journal of Integrative Environmental Sciences that includes contributions from the 8th Non-CO_2 Greenhouse Gas Symposium (NCGG8), which took place in Amsterdam, June 10–15th, 2019. NCGG8 covered recent scientific advancements in understanding non-CO_2 sources, climate implications and mitigation challenges. The articles in this special issue highlight some of outcomes of these discussions.

Niche topic, despite massive implications

Since the early 1990s, eight NCGG symposium editions have been organized in The Netherlands. The NCGG symposia bring together scientists and engineers on the one hand, and decision makers in the public and private sectors on the other hand. As such, these actively support the implementation of promising policies and technologies to reduce non-CO_2 GHG-emissions. Special attention is paid to environmental targets such as the United Framework Convention on Climate Change (UNFCC), and to the UN Sustainable Development Goals (SDGs). Based on preceding editions and particularly NCGG7 (Kroeze et al. 2014; Kroeze and Pulles 2015), it was concluded that there is a widely recognized essential role of non-CO_2 mitigation in reaching deep mitigation targets (limiting global warming to 2 degrees Celsius or lower), in line with recent literature (Frank et al. 2018; Rogelj et al. 2019; Harmsen 2019). However, it was found that this is not reflected in the attention for non-CO_2 related research and policy, compared to that of CO_2. Moreover, the presented research has shown that a large share of non-CO_2 mitigation can be realized at relatively low costs. Interest in the topic has been increasing over the past decades, but it can still relatively be considered a niche. About 300 people attended NCGG8, comprising a large share of the leading non-CO_2 specialists. This is a small group compared to other research fields (e.g. picture approximately 10,000+ attendee medical symposia), considering the large implications, complexities and uncertainties that could be reduced by upscaling research.

Diversity and complexity

The overarching theme of NCGG8 was *Global Challenges and Local Solutions* (illustrated in Figure 1). Attention was paid to (1) sources, sinks, and atmospheric processes of non-CO_2 greenhouse gases, (2) mitigation options and emission reduction technologies and practices, (3) policies and measures, both in the public and private sectors; and (4) the science-policy-industry interface. These themes build on previous discussions on non-CO_2 GHGs. The aim was to seek integrative and innovative studies of sources of non-CO_2 GHGs, their effects and strategies to reduce these effects. These aims matches this journal's ambition to integrate different scales of societal and environmental challenges and bring together science and policy (Kroeze et al. 2019).

Climate change has often been referred to as the textbook example of a wicked problem (Levin et al. 2012). Several characteristics of wicked problems clearly apply to the non-CO_2 part of climate policy: incomplete or contradictory knowledge, i.e. uncertainty; the number of people and opinions involved; the interconnected nature of these problems with other problems (air quality, land-use), a solution possibly means new problems; and uncertainty of what defines a resolved problem. Non-CO_2 greenhouse

Figure 1. The scope of NCGG8 (conference image).

gases, in general, have a large diversity in sources and consequently in solutions. Clearly, there are countless possible solutions, but it is unclear what (combination) is most effective. The diversity in the Special Issue studies illustrates the complexity.

Many contributions during NCGG8 addressed long-term aim to limit global warming to 1.5 degrees Celsius. To meet this aim, net global GHG emissions need to be reduced to zero or lower within a generation. One of the observations during NCGG8 was that for several non-CO_2 greenhouse gases, it is technically possible to reduce emissions to very low levels. This holds in particular for emissions from energy and industry. However, it was also observed that it will be difficult to reduce total non-CO_2 GHG emissions to zero. The two sources that are most difficult to reduce are N_2O emissions associated with food production, and CH_4 emissions from ruminants. This implies that in a 1.5 degree world, food production needs to be much more fertilizer efficient than today, but also that diets need to shift away from animal products, including both meat and milk. As earlier editions, NCGG8 focused on emission measurements (e.g. inverse modelling of emissions), as well as on understanding what drives these emissions locally (as reflected in this Special Issues' topical papers) and how these can be mitigated. We observe an increasing understanding of emission sources (although there are still mismatches between bottom-up and top-down data) and a trend towards a more solution-driven policy approach in recent years. However, based on the large range of projected emission reduction potentials in the presented work, it can be concluded that large uncertainties remain, and case-study-based assessments of promising mitigation measures are often lacking.

This Special Issue contains a selection of contributions to the symposium. It consists of this overview and seven topical papers as illustrative examples of the scientific results presented at the symposium (Wilson and Scholes 2020; O'neill et al. 2020; Godwin and Ferenchiak 2020; Howarth 2020; Laban et al. 2020; Verchot et al. 2020; Zou and Osborne 2020). In the following section, we give an impression of the seven contributions.

Topical papers in the special issue

The Special Issue papers described below are structured as follows. The first five mainly cover analyses of emission sources and determinants that influence emission fluxes (i.e., related to the 1st and 2nd theme of NCGG8). Combined, these papers cover a range of geographical settings and topics of land-use change (LUC). The last two papers are focused on policy, mitigation measures and emission accounting (i.e. more related to the 3rd and 4th theme of NCGG8)

Laban et al. (2020) Statistical analysis of factors driving surface ozone variability over continental South Africa

Laban et al. (2020) determined statistical relationships between surface ozone (O_3), its precursor species and meteorological conditions in South Africa. Multiple linear regression analysis revealed that atmospheric carbon monoxide (CO), temperature and relative humidity were the strongest factors affecting daily O_3 variability. Based on partial residual plots, it was found that temperature, radiation and nitrogen oxides most likely have a non-linear relationship with O_3, while the relationship with relative humidity and CO is probably linear. In the winter, O_3 variability was more strongly associated with temperature and CO while in the summer variability relative humidity was the strongest factor. The findings emphasize how both regional-scale O_3 precursors and meteorological conditions impact daily variances of regional O_3 levels.

Zou and Osborne (2020) No effect of warming and watering on soil nitrous oxide fluxes in a temperate sitka spruce forest ecosystem

N_2O soil fluxes influences the global greenhouse gas budget, but are less studied than CO_2 soil fluxes. Quantifying and understanding N_2O soil fluxes are critical for anticipating potential nitrogen sinks and emissions. Zou and Osborne (2020) studied the Sitka spruce, an important tree type in Ireland's reforestation efforts, to understand nitrogen fluxes in relation to different levels of water stress and atmospheric warming. However, their findings suggest that not all forests beds are affected the same by climate change. In contrast with Griffis et al. (2017)'s study that proposed that drier and/or warmer soil compositions influences emissions, Zou and Osborne (2020) results from Dooaray Forest, central Ireland, indicate that soil N_2O emissions in temperate forest ecosystems are not significantly affected. They conclude that more extreme temperature changes may be necessary in order to significantly influence increases to nitrogen emissions.

O'neill et al. (2020) Assessment of nitrous oxide emission factors for arable and grassland ecosystems

Many GHG emission estimates use default values to derive N_2O emissions from fertilizer application in agriculture. However, O'neill et al. (2020) argue that these emission factor estimates need to be disaggregated and they challenge the use of emission calculations based on assumption that N_2O emissions are linearly related to the nitrogen fertilizer rate. To this end, O'neill et al. (2020) studied to what extent N_2O fluxes were affected by different fertilizing practices and land types (arable lands and grasslands) in south-east Ireland. For arable lands, they studied different tillage practices combined with varying fertilizer rates. For grasslands, they looked at mineral nitrogen, different rates of livestock slurry, and no fertilizer application. The general trend was that increased nitrogen fertilizer applications resulted in higher N_2O fluxes. However, higher temperatures and higher soil moisture levels were linked to higher N_2O production. Moreover, fertilizer practices in grasslands are related to higher variability in emissions than in arable lands. This indicates that measurements to understand fertilizer's contribution to N_2O emissions, more cite-specific is required.

Verchot et al. (2020) Land-use change and biogeochemical controls of soil CO2, N2O and CH4 fluxes in Cameroonian forest landscapes

LUC, and deforestation in particular, alters N_2Osoil emissions. Tropical forests are also an important sink of atmospheric CH_4. At the same time, most conversion of forests to agriculture occurs in the tropics and this affects both CH_4 and N_2O contributions to total GHGs. However, uncertainty about how CH_4 and N_2O fluxes are affected by LUC in tropical forests is high. Verchot et al.'s (2020) study looks at the data-limited region of Central Africa and zooms into how LUC and deforestation in the Congo affect soil-atmosphere exchange. In addition to quantifying CO_2, the study focuses on the influences of CH_4 and N_2O. Soil gas fluxes were quantified for three LUCs: secondary forest, cocoa agroforest, and unfertilized cropland. They also studied biogeochemical mechanisms that explain temporal and spatial variation of these fluxes. Two key findings suggest that in LUC in tropical regions decreases soil respiration and the strength of CH_4 soil storage. Verchot et al. (2020) observed that in the absence of fertilizer use, N_2O emissions decreased with LUC. They also found that soil water content, instead of temperature, was the dominant driver of variability; average fluxes in the wet season were more pronounced than in the dry season. Land-use type also affected the range of variability. Namely, unfertilized cropland's wet season had a 17% higher flux than its dry season whereas the seasonal fluxes for the other two land-use types were more pronounced, approximately 50% more variability. Thus, land type and soil content are important drivers of these fluxes in this region.

Wilson and Scholes (2020) The climate impact of land use change in the miombo region of south central Africa

Sustainable trajectories for land-use change (LUC) is critical for us to meet the 1.5 C target. However, incorporating non-CO_2 GHGs in LUC climate studies can lead to paradoxical results and different policy recommendations. Wilson and Scholes (2020) study contributes to the debate on LUC directions in Africa. They explore the implications of LUC on GHG emissions in the *miombo* region, which are woodlands located in south central Africa. These woodlands are vast and relatively unexploited, but have potential as agricultural lands. Wilson and Scholes (2020) analyse three patterns of LUC: low-input, low-yield smallholder subsistence farming; large-scale, high-input (pesticides, fertilization, and mechanization), high-yield commercial farming of commodity crops for export; and an improved high-yield, high-input smallholder farming. The last option attempts to minimize the negative implications of the first two methods by balancing the local needs of the community with goals of increased production and the environment by limiting deforestation. Surprisingly, they find that intensive commercial agriculture is the better than low-input (other than labour) traditional low-yield smallholder agriculture for climate goals based on surface reflexivity and net emission changes over 33 years of simulated time. Their model suggests that net brightening of the land surface going from dark forests to brighter/more radiant crop coverage has a net larger cooling effect than the loss of forested areas. They conclude that leaning too much on carbon dioxide emissions to assess LUC can result in misguided recommendations and advise integrating all of the major greenhouse gases in these assessments.

Howarth (2020) Methane emissions from fossil fuels: exploring recent changes in greenhouse-gas reporting requirements for the State of New York

Howarth (2020) provides an assessment of newly implemented greenhouse gas reporting rules in New York state. Two key additions in this calculation are the inclusion of out-of-state emissions associated with in-state energy use and the shortening of the time frame from 100 years to 20. The inclusion of out-of-state emission helps reflect the emissions burden of transitioning from fuels such as coal to natural gas. The shorter time frame emphasizes the role of methane on short-term climate change effects. This new calculation paints a different picture of the current trajectory of New York State's GHG emissions. Traditional calculations of New York State's emissions indicated a 15% decrease in carbon emissions and thus, lower total GHG emissions, while the newer calculation suggest that total emissions have remained relatively unchanged with increased methane emissions replacing decreased carbon emissions.

Godwin and Ferenchiak (2020) The implications of residential air conditioning refrigerant choice on future hydrofluorocarbon consumption in the United States

Another paper that reflects the challenges of transitioning one material source to another is the paper by Godwin and Ferenchiak (2020). Hydrofluorocarbons (HFCs) have been used in air conditioning to replace ozone-depleting substances such as chlorodifluoromethane, which were phased out under the Montreal Protocol. However, HFCs also contribute to GHGs, and the World Meteorological Organization (WMO 2018) estimates limiting their use globally can mitigate 0.2–0.4 degrees Celsius temperature rise by 2100. Godwin and Ferenchiak (2020) explore the GHG implications of increased use of residential air conditioning (RAC) in the United States, which is expected to increase globally (UNEP 2019). Godwin and Ferenchiak (2020) model's findings suggest that improving the efficiency and use of virgin HFCs is insufficient to meet many possible emission targets alone. The long lifetime of RACs (5–40 years) coupled with the long time for manufacturing to convert to efficient RACs, limits emission reduction potential. They suggest that industry support is needed to limit leaks, recover and re-use the HFCs. RACs are an example of needing to integrate the supply chain to reduce the need for virgin HFC refrigerants and reduce inefficient HFC consumption.

Conclusions and discussion

The papers in this Special Issue help to address the gap of non-CO_2 GHG research identified in Kroeze et al. (2014) and Kroeze and Pulles (2015). Based on the outcome of NCGG8 conference, it can be concluded that non-CO_2 GHG related research remains an important, yet relatively small field, given the fact that 1) stringent climate targets require non-CO_2 mitigation to become a key part of global climate policy (Frank et al. 2018; Rogelj et al. 2019) and 2) non-CO_2 related policy will need to consist of a combination of many independent solutions, even more than in the case of CO_2 emissions.

The topics addressed at NCGG8 and in this Special Issue seem to indicate a trend towards aiming to understand what drives (local) emissions and what implications this could have for mitigation options. Unsurprisingly, recent studies also show a stronger focus on assessing the role of non-CO_2 GHGs limiting global temperature increase by 1.5 degree Celsius, i.e. achieving the Paris Agreement's goals.

The Special Issue's topical papers do not fully cover all non-CO_2 GHG emission and mitigation-related topics (e.g. topics addressed at the symposium, but not or partly covered in the Special Issue are measurement techniques, mitigation measure assessments, policy assessment and global emission projections). However, the studies in the Special Issue address several key topics, such as emission sources and their determinants, atmospheric chemistry, climate impacts, mitigation options, scenario analysis and emission accounting and reporting. The Special Issue papers demonstrate some of the debates in emission studies and their diversity illustrates the complexity of the topic.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Frank S, Havlík P, Stehfest E, Van Meijl H, Witzke P, Pérez-domínguez I, Van Dijk M, Doelman JC, Fellmann T, Koopman JFL, et al. 2018. Agricultural non-CO2 emission reduction potential in the context of the 1.5 °C target. Nat Clim Change. 9(1):66–72. doi:10.1038/s41558-018-0358-8.

Godwin DS, Ferenchiak R. 2020. The implications of residential air conditioning refrigerant choice on future hydrofluorocarbon consumption in the United States. J Integr Environ Sci. 17(3):29–44. doi:10.1080/1943815X.2020.1768551.

Griffis TJ, Chen Z, Baker JM, Wood JD, Millet DB, Lee X, Venterea RT, Turner PA. 2017. Nitrous oxide emissions are enhanced in a warmer and wetter world. Proc Natl Acad Sci U S A. 114 (45):12081–12085. doi:10.1073/pnas.1704552114.

Harmsen JHM. 2019. Non-CO2 greenhouse gas mitigation in the 21st century. Utrecht University, Utrecht, The Netherlands.

Howarth RW. 2020. Methane emissions from fossil fuels: exploring recent changes in greenhouse-gas reporting requirements for the State of New York. J Integr Environ Sci. 17 (3):69–81. doi:10.1080/1943815X.2020.1789666.

Kroeze C, De Vries W, Seitzinger SP. 2014. Editorial overview: n-related greenhouse gases: innovations for a sustainable future. Current Opin Environ Sustainability. 9-10:105–107. doi:10.1016/j.cosust.2014.09.009.

Kroeze C, Moll HC, Student J. 2019. Editorial. J Integr Environ Sci. 16(1):i–iii. doi:10.1080/1943815X.2019.1571780.

Kroeze C, Pulles T. 2015. The importance of non-CO 2 greenhouse gases. J Integr Environ Sci. 12 (sup1):1–4. doi:10.1080/1943815X.2015.1118131.

Laban TL, Van Zyl PG, Beukes JP, Mikkonen S, Santana L, Josipovic M, Vakkari V, Thompson AM, Kulmala M, Laakso L. 2020. Statistical analysis of factors driving surface ozone variability over continental South Africa. J Integr Environ Sci. 17(3):1–28. doi:10.1080/1943815X.2020.1768550.

Levin K, Cashore B, Bernstein S, Auld G. 2012. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. Policy Sci. 45(2):123–152. doi:10.1007/s11077-012-9151-0.

O'neill M, Gallego-lorenzo L, Lanigan GJ, Forristal PD, Osborne BA. 2020. Assessment of nitrous oxide emission factors for arable and grassland ecosystems. J Integr Environ Sci. 1–21. doi:10.1080/1943815X.2020.1825227.

Rogelj J, Shindell D, Jiang K, Fifita S, Forster P, Ginzburg V, Handa C, Kheshgi H, Kobayashi S, Kriegler E, et al. 2019. Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, et al., editors. Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, Geneva: Intergovernmental Panel on Climate Change; p. 93-174.

UNEP. 2019. Refrigeration, air conditioning and heat pumps technical options committee 2018 assessment report. United Nations Environment Programme (UNEP). [accessed 2019 Feb].

Verchot LV, Dannenmann M, Kengdo SK, Njine-bememba CB, Rufino MC, Sonwa DJ, Tejedor J. 2020. Land-use change and Biogeochemical controls of soil CO_2, N_2O and CH_4 fluxes in Cameroonian forest landscapes. J Integr Environ Sci. 17(3):45–67. doi:10.1080/1943815X.2020.1779092.
Wilson SA, Scholes RJ. 2020. The climate impact of land use change in the miombo region of south central Africa. J Integr Environ Sci. 1–17. doi:10.1080/1943815X.2020.1825228.
WMO. 2018. Scientific assessment of ozone depletion: 2018. Geneva (Switzerland). Global Ozone Research and Monitoring Project–Report No. 58, p. 588
Zou J, Osborne B. 2020. No effect of warming and watering on soil nitrous oxide fluxes in a temperate sitka spruce forest ecosystem. J Integr Environ Sci. 17(3):83–96. doi:10.1080/1943815X.2020.1823421.

Mathijs Harmsen
PBL Netherlands Environmental Assessment Agency, The Hague, The Netherlands
Copernicus Institute for Sustainable Development, Utrecht University, The Netherlands,
PBL Netherlands Environmental Assessment Agency, Bezuidenhoutseweg 30, 2594 AV, The Hague, The Netherlands
mathijs.harmsen@pbl.nl

Jillian Student and Carolien Kroeze
Water Systems and Global Change Group, Wageningen University & Research, Wageningen, The Netherlands
Wageningen Institute for Environment and Climate Research, Wageningen University & Research, Wageningen, The Netherlands
http://orcid.org/0000-0002-2859-3691