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Assessment of the Climate Impact of Ireland's Emissions and Simple Future Emissions Scenarios

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Abstract

This report assesses the climate impact of Irish emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Historic emissions (1990-2015) are included, as well as different simple scenarios for the future (mostly to 2100). Alternative emission scenarios for the sectors energy, industry, and agriculture are discussed. The different greenhouse gases are compared with the emission metrics, radiative forcing and Absolute Global Temperature change Potential (AGTP). CH_4 and CO_2 emissions are the most important for short-term climate impacts, while CO_2 dominates in the long-term, such as for the middle and late part of the 21st century. As CH_4 is the greenhouse with the shortest perturbation lifetime, emission reduction of CH_4 is effective to reduce the global temperature in the first decade, while sustained CO_2 emission reductions give the largest impact in the long run. The report describes also how much negative CO_2 emissions are needed to offset emissions of CH_4 and N_2O. The amount needed varies with the method used to compare gases and perspective taken.

Introduction

Human activity causes emissions of a range of gases and constituents that impact the climate (Myhre et al., 2013) leading to potentially severe consequences (IPCC, 2014). Article 2 in the United Framework Convention on Climate Change (UNFCCC) states that the ultimate objective is “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (UNFCCC, 1992). Under the Paris Agreement, this objective is understood as “holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels” (UNFCCC, 2015). The agreement says that the aim is “to reach global peaking of greenhouse gas emissions as soon as possible” and specifies “to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century”. Thomas et al. (2016) give a general overview of what is meant by balancing anthropogenic sources and sinks. Negative emissions arise with a net CO_2 removal from the atmosphere. Possible options for negative emissions include afforestation, where carbon is captured and stored in living forest biomass, and bio-energy with carbon capture and storage (BECCS), whereby CO_2 is captured by biomass, which is harvested and used for energy generation, with the resulting CO_2 emission is captured for storage.

The EU 2050 greenhouse gas (GHG) emissions roadmap has been developed in line with pathways to keep the global temperature increase below 2°C. In Ireland, the National Transition Objective requires

- an aggregate reduction in carbon dioxide (CO_2) emissions of at least 80% (compared to 1990 levels) by 2050 across the electricity generation, built environment and transport sectors; and

- in parallel, an approach to carbon neutrality in the agriculture and land-use sector, including forestry, which does not compromise capacity for sustainable food production.

The second component of the National Transition Objective reflects Ireland’s focus on the close relationship between agriculture and land use, land-use change and forestry (LULUCF). Increasing demand for biomass and biofuel will tend to increase demand for land and even if the displaced fossil fuel emissions are counted as mitigated under the energy sector the resultant carbon dynamic within the LULUCF may be complex due to the various time-scales of sources, sinks, and the atmospheric response.

This report focuses on the Irish emissions of three important GHGs, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions of CO_2 is the most important contribution to man-made climate change. As different processes contribute to the removal of CO_2, we cannot give a single perturbation lifetime of CO_2 in the atmosphere. CO_2 is the gas with the longest impact on the climate, as 15 to 40% of the total emitted CO_2 remains in the atmosphere after 1000 years (Collins et al., 2013). CH_4 and N_2O have perturbation lifetimes of 12.4 and 121 years, respectively (Myhre et al., 2013). CH_4 is the most short-lived of these three gases, has a variety of indirect impacts on climate, and is often categorized as a short-lived climate forcer. As the climate system has long time scales, the temperature response and other impacts linger for decades or centuries after the gases are removed from the atmosphere.

Temperature responses of any emissions should ideally be calculated with sophisticated earth system models. As such modelling is extremely resource intensive (e.g., computing time) and not practical for small perturbations relative to natural variability (e.g., emissions from Ireland), simplified models or emission metrics are often used as simplified tools. The calculations in this report are therefore based on emission metrics for radiative forcing and the global temperature response.

Methodology

Emissions

The emission data are from the official emissions Ireland report to the UNFCCC. We utilize historic emissions for the 1990-2015 period, while different simple and illustrative scenarios are used for future emissions. The different scenarios are as follows:

- Pulse of reported emissions in 2015 (Case 1)
- Only historic emissions, 1990-2015 (Case 2)
- Historic emissions and assume constant emissions for 2015-2050 (Case 3)
- Historic emissions and assume constant emissions for 2015-2100 (Case 4)
- Special case for N_2O, assume constant emissions far into the future to find the stabilization level (Case 5)
- As Case 4, but including a linear reduction of 80% of emissions from energy and industry for 2016-2050 (Case 6)
- As Case 4, but including a linear reduction from agricultural emissions for 2016-2025, reduction of 5, 10, and 20% (Case 7)

Radiative Forcing

The temporal radiative forcing (RF) for species i at *H* years after a pulse emission is given by (see for instance Aamaas et al., 2013)

$$RF_i(H) = RE_i \times IRF_i(H) \qquad (1)$$

IRF stands for impulse response function, the removal from the atmosphere after an emission. *RE* is the radiative efficiency. For any emission scenario (E(t)), the total radiative forcing can be estimated by a convolution:

$$RF_i(H) = \int_0^H E_i(t) RF_i(H-t) dt \quad (2)$$

We estimate this convolution numerically by summing the contribution from each emission year

$$RF_i(H) = \sum_{t=0}^{H} E_i(t) RF_i(H-t) \quad (3)$$

Temperature calculations

The global temperature change due to emissions are calculated with the help of the emission metrics Absolute Global Temperature change Potential (AGTP). AGTP for species i is defined as at time *H* is defined as (Shine et al., 2005),

$$AGTP_i(H) = \int_0^H RF_i(t) IRF_T(H-t) dt \quad (4)$$

where RF is the radiative forcing following a pulse emission and $IRF_T(H\text{-}t)$ is the impulse response function for global temperature change at time *H* to a unit of radiative forcing at time *t*.

The AGTP value of any emissions can be normalized to the corresponding effect of CO_2, to give CO_2 equivalent emissions:

$$GTP_i(t) = \frac{AGTP_i(t)}{AGTP_{CO_2}(t)} \quad (5)$$

For any emission scenario (E(t)), the temporal temperature change (ΔT) can be estimated by a convolution

$$\Delta T_i(H) = \int_0^H E_i(t) AGTP_i(H-t) dt \quad (6)$$

In our calculations, we estimate the temperature response with summing up the contribution from each emission year

$$\Delta T_i(H) = \sum_{t=0}^{H} E_i(t) AGTP_i(H-t) \quad (7)$$

For more details on the methodology and how emission metrics can be used, see Aamaas et al. (2013); Aamaas et al. (2016). The temperature response in latitude bands, such as the temperature increase in the Arctic due to Irish emissions, could be studied (see e.g., Aamaas et al., 2017), but is more interesting for constituents that are not well-mixed in the atmosphere (e.g., black carbon) and outside the scope for this report.

Results

Since Irish emissions are small relative to the global total, the radiative forcing (RF) and temperature response (ΔT) are measured in units of 10^{-3} (milli).

Pulse emissions

As pulse emission is the building block for any scenario, radiative forcing and temperature response are first presented for a pulse emission of historic 2015 emissions (see Figure 1 for Case 1). The temporal response decays first for radiative forcing, as the climate system is slow and the temperature response linger for some period. This difference is most clearly seen for CH_4, the constituent that is the most short-lived of the three GHGs.

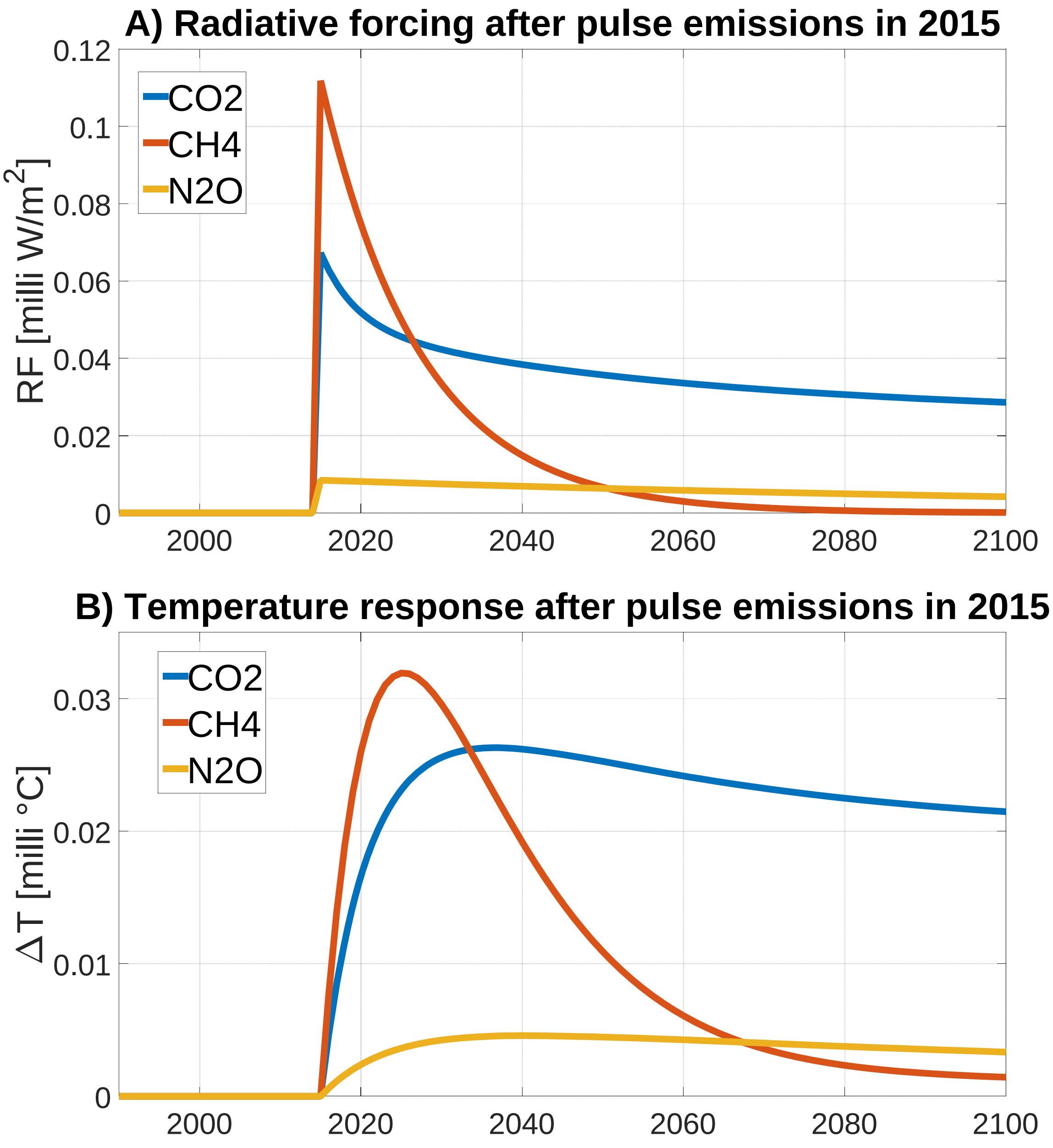


Figure 1: Case 1, the global radiative forcing (A) and temperature response (B) of pulse emissions in 2015.

Historic emissions

The historic emissions of CO_2, CH_4, and N_2O in the period 1990-2015 (see Figure 2) lead to a global warming of 1.4 m°C in 2015 and 0.70 m°C in 2100 (see Figure 3B). The halving is mainly due the decay of the CH_4 perturbation. The reduction is even larger for radiative forcing, which goes from 2.8 mW/m^2 in 2015 to 0.87 mW/m^2 in 2100 (see Figure 3A).

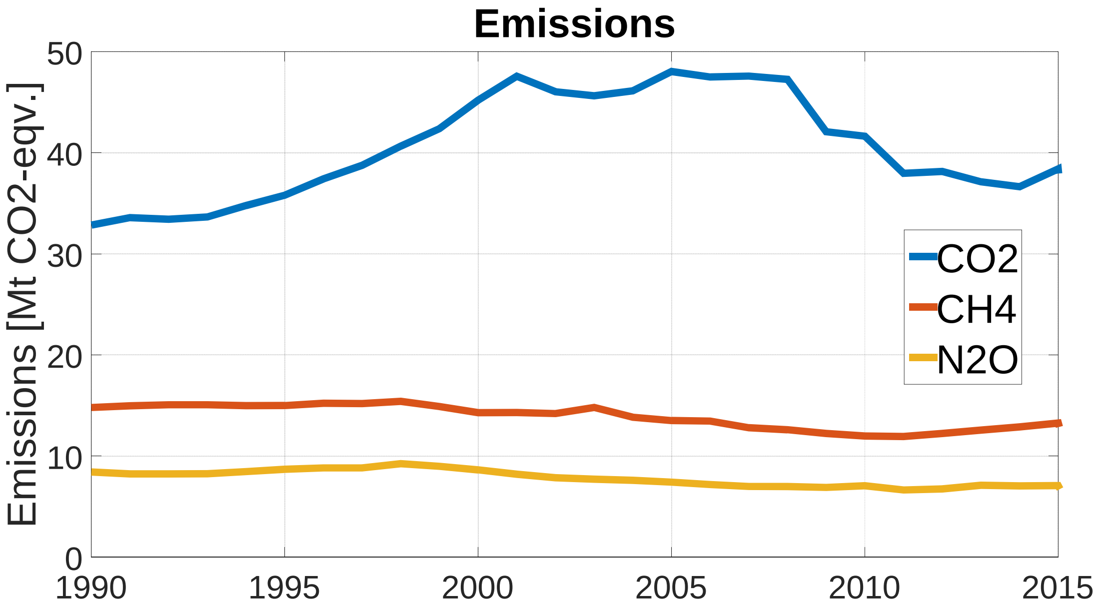
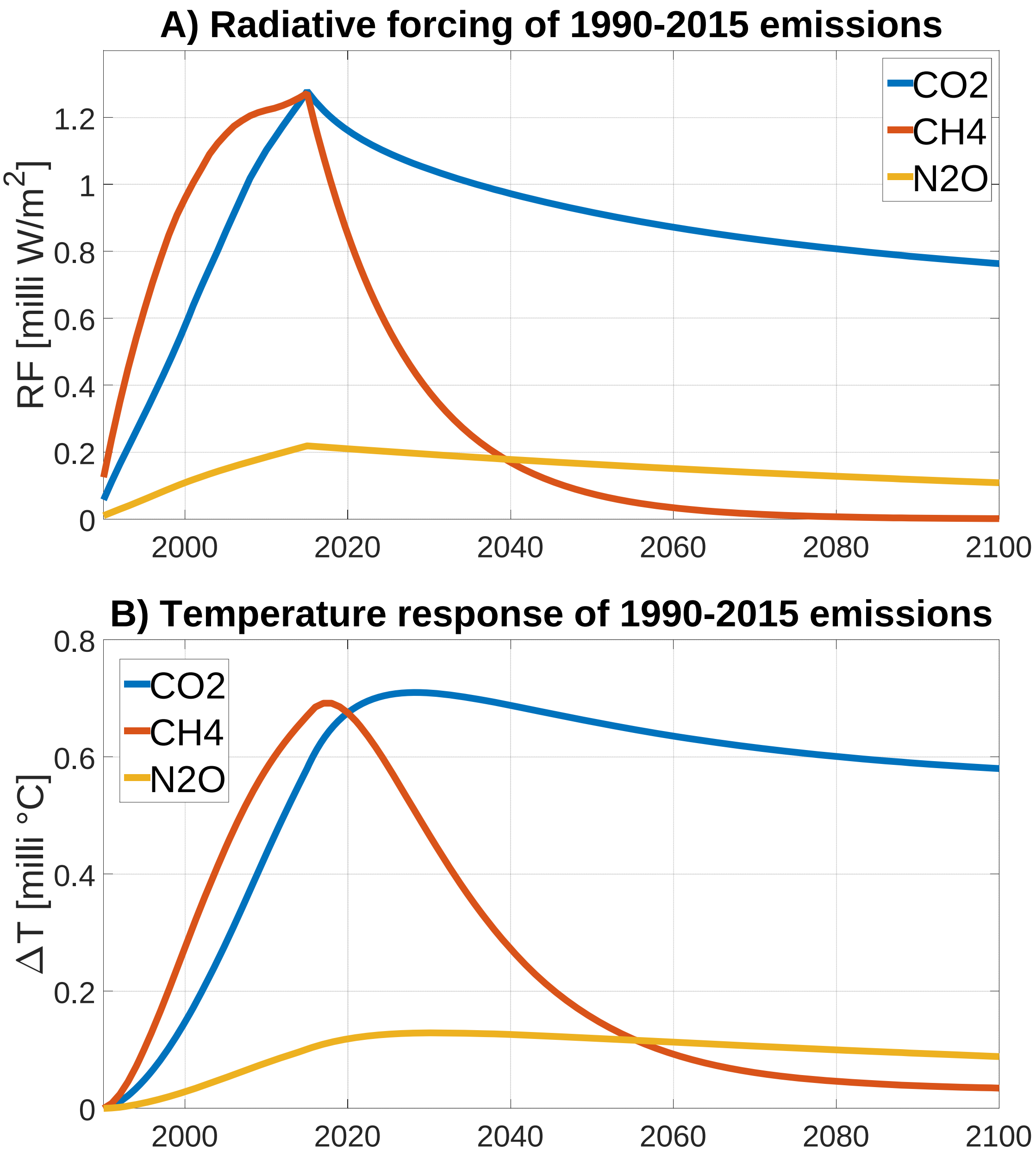


Figure 2: The historic Irish emissions of CO_2, CH_4, and N_2O for the period 1990-2015. Emissions of CH_4 and N_2O are given in CO2 eqvivalents based on AR4 GWP(100).



A) Radiative forcing of 1990-2015 emissions

B) Temperature response of 1990-2015 emissions

Figure 3: Case 2, the global radiative forcing (A) and temperature response (B) from historic emissions for 1990-2015. No emissions are included after 2015.

Constant future emissions

Here we apply 1990-2015 emissions, and then keep emissions constant at 2015 levels to 2050 (and 2100), Figure 4 (Figure 5). These two emission scenarios represent Case 3 and 4. This leads to three different phases in the response. First, from 1990-2015 the response grows as in Figure 3. Second, while emissions are constant (2015-2050/2100) the radiative forcing and temperature response increases almost linearly for CO_2 emissions (and N_2O at much lower levels), while approaching an asymptotic level for CH_4. The differences are due to the different perturbation lifetimes. CH_4 has the largest impact in the first years, while CO_2 is the dominant GHG by the middle and end of this century with sustained emissions. N_2O emission has the smallest share, until towards the end of the century. The third phase is the decay after emissions stop, with the temperature response of CH_4 decaying within decades, while the temperature impacts of CO_2 and N_2O last for centuries. If emissions are kept constant at today's level (2015), the total temperature response 2.6 m°C in 2050 is and 3.9 m°C in 2100.

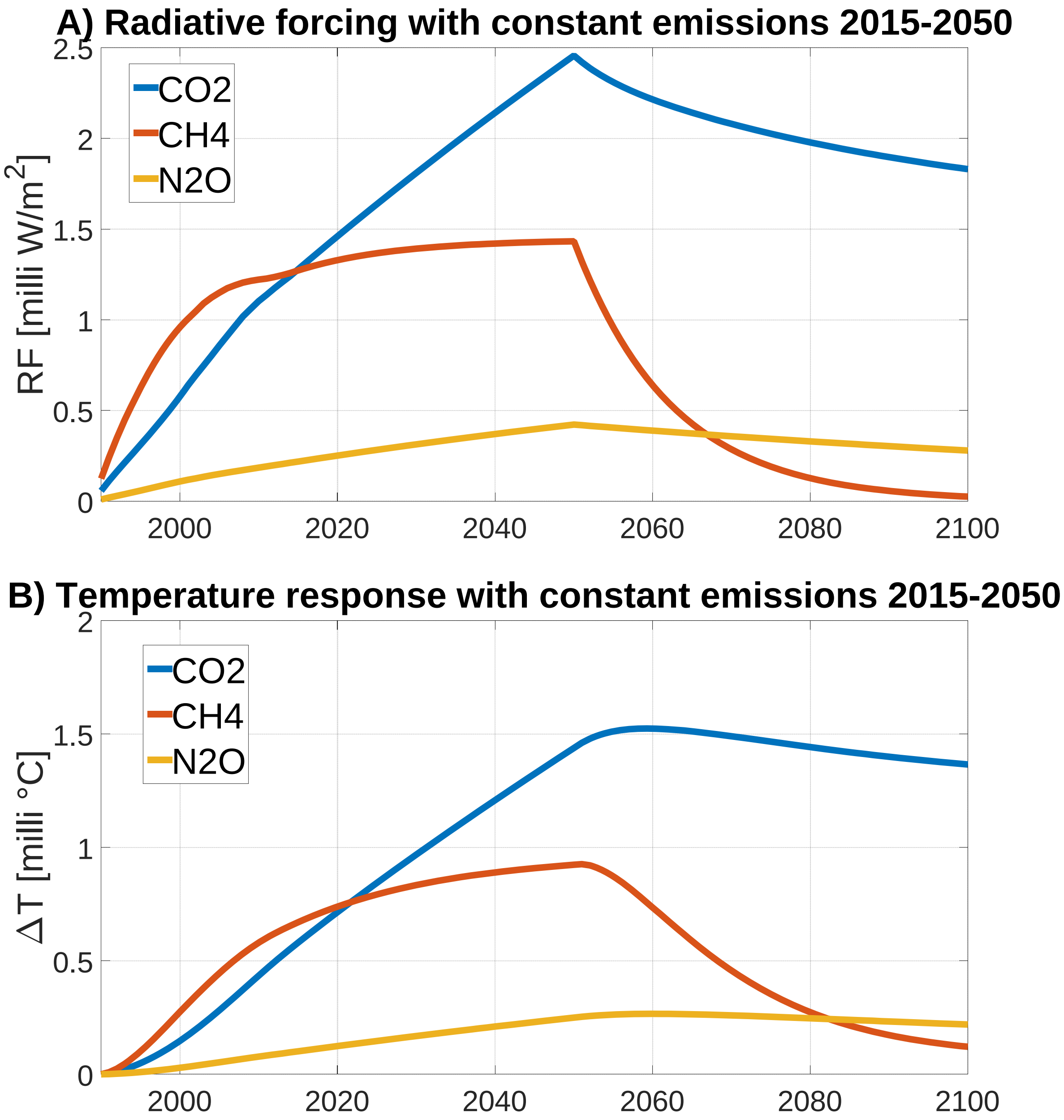


Figure 4: Case 3. The same as Figure 3, but assuming that the level of emissions in 2015 is kept until 2050.

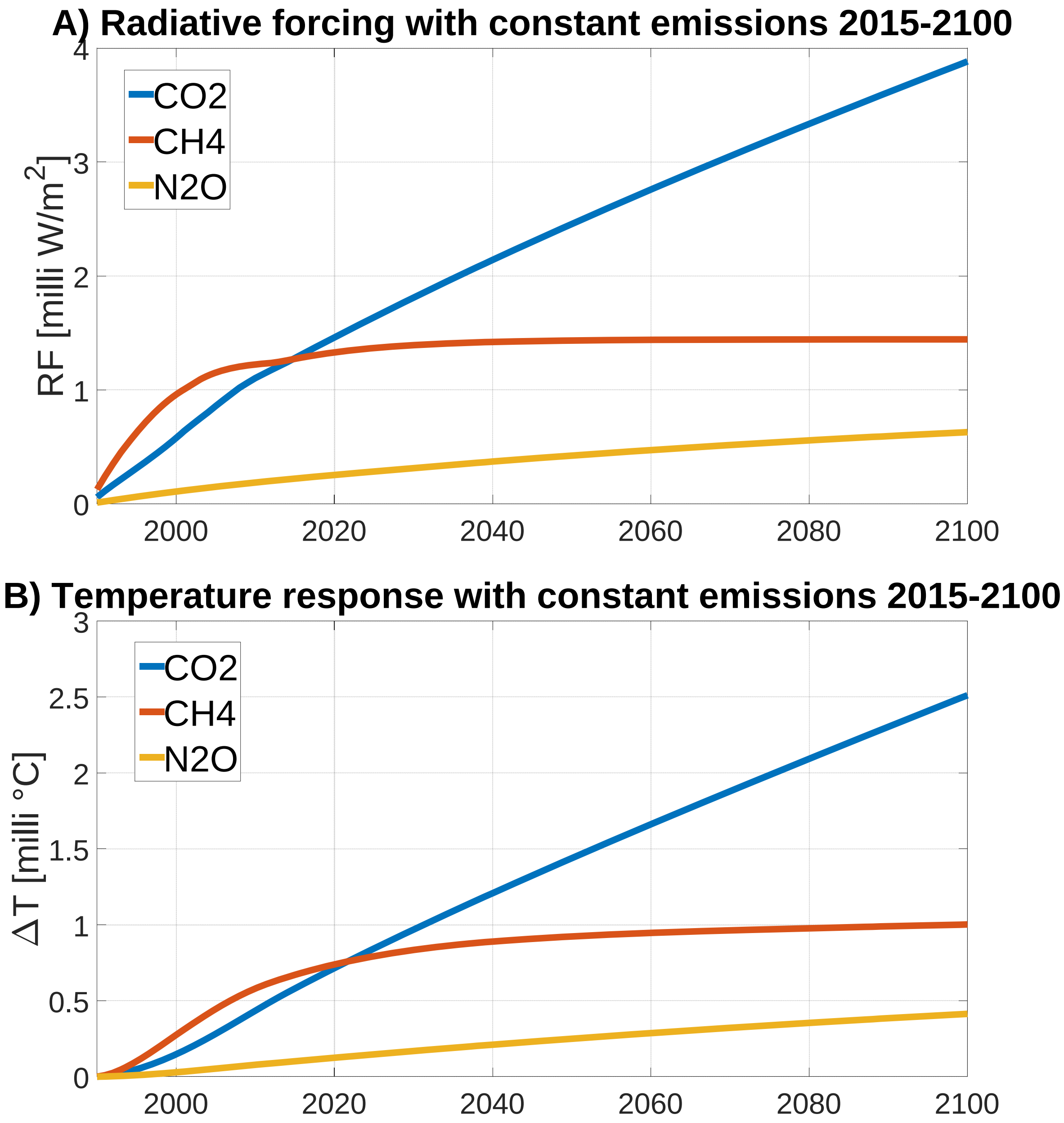
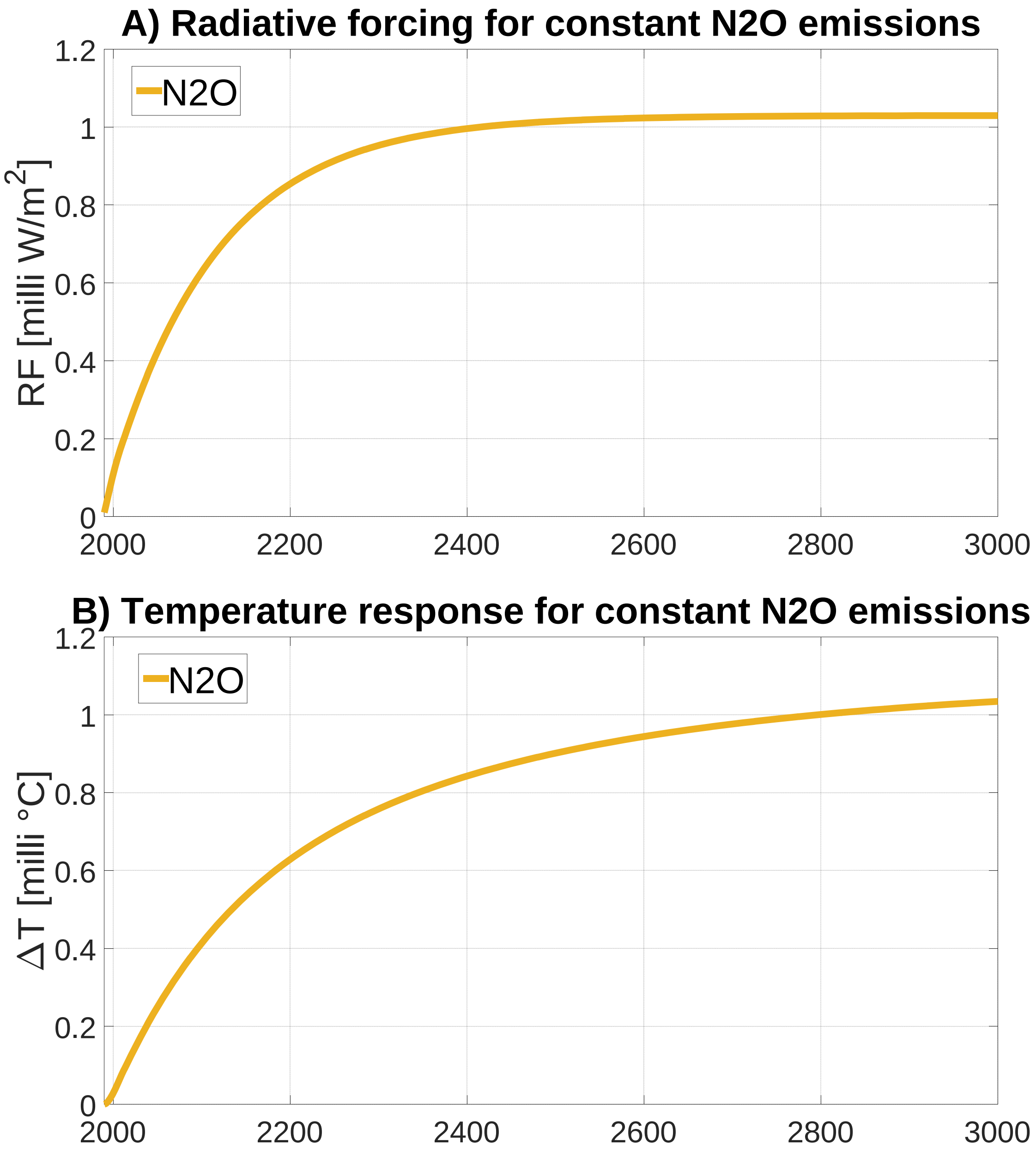


Figure 5: Case 4. The same as Figure 3, but assuming that the level of emissions in 2015 is kept until 2100.

Stabilization level for N_2O

As the perturbation lifetime of N_2O is 121 years (Myhre et al., 2013), a stabilization of the atmospheric concentration takes centuries following sustained emissions. Different formal definitions of “stabilization” (for an e-folding function) will lead to different time periods, but visually, stabilization is reached after roughly 500 years for radiative forcing, while the temperature response is still slowly increasing after 1000 years (see Figure 6 for Case 5). Emission metrics are not meant to be used for scenarios over several centuries; hence, the results in Figure 6 should be used with care. The stabilization level for radiative forcing is roughly 1 mW/m^2 and for temperature response roughly 1 m°C. This is of a similar magnitude as the temperature response of all three GHGs in 2015 due to historic emissions in 1990-2015.


A) Radiative forcing for constant N2O emissions

B) Temperature response for constant N2O emissions

Figure 6: Case 5. The same as Figure 3, but assuming that the level of N_2O emissions in 2015 is kept for illustration purposes until

the year 3000. Emission metrics were not developed to estimate temperature responses so far into the future; hence, the results should be used with care.

Reducing energy and industry emissions

Most of the Irish CO_2 emissions comes from the energy and industry sector, while these sectors have very small shares of total CH_4 and N_2O emissions. A 80% emission reduction for these sectors by 2050 will reduce the temperature response for CO_2 with 49% by 2100 and for all GHGs with 32% by 2100 (see Figure 7 for Case 6).

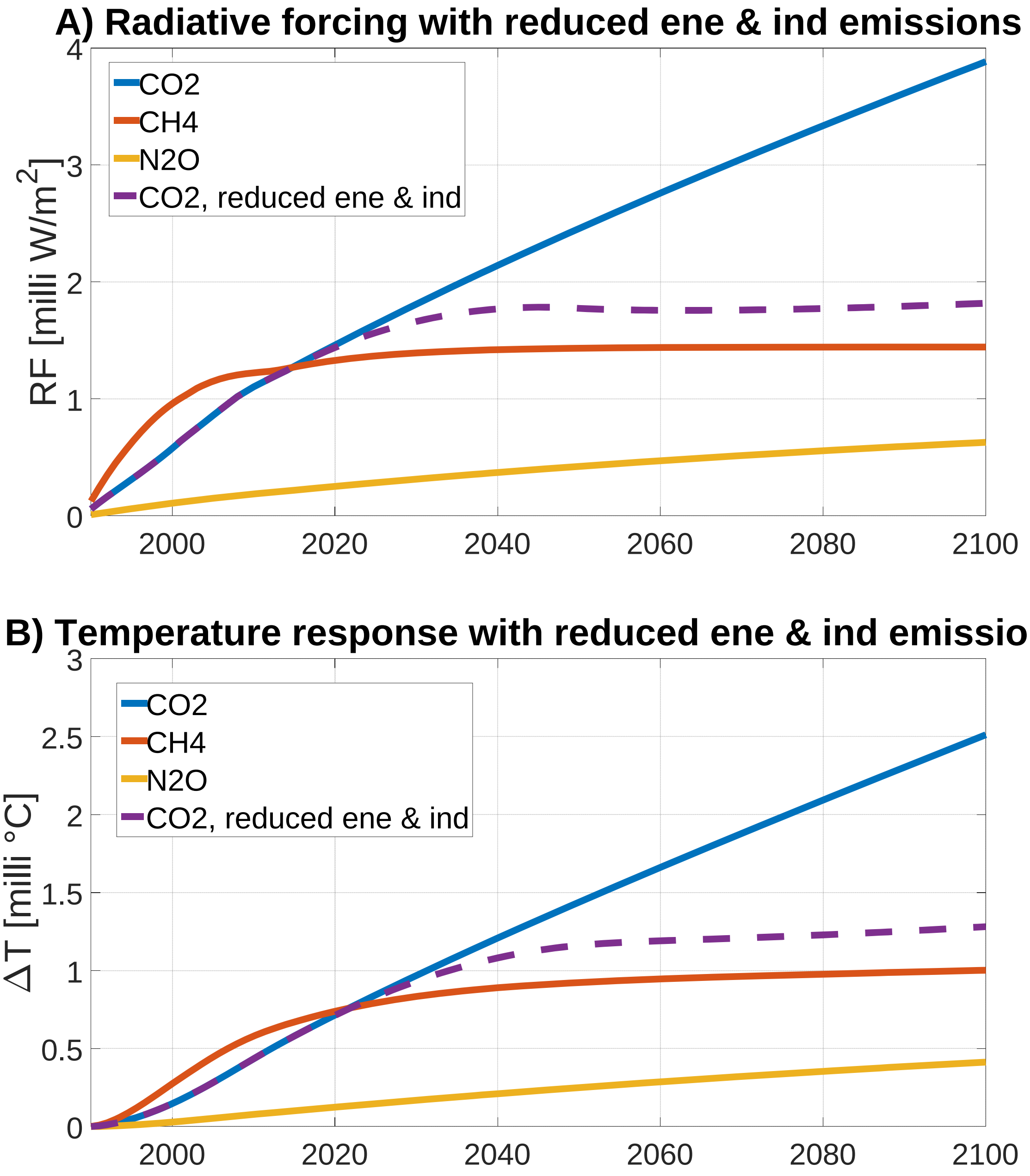


Figure 7: Case 6. This is similar to Figure 5, but assuming that emissions from energy and industry can be reduced 80% linearly in the period 2016-2050. A 80% reduction of CH_4 and N_2O emissions in the energy and industry sectors has a very small impact and is therefore left out. Emissions are kept sustained at the 2050 level for the second part of the century.

Changing emissions from agriculture

Agriculture is responsible for most of the emissions of CH_4 and N_2O in Ireland. The sector is also emitting CO_2, but only marginally comparing to the energy and industry sectors. A change in emissions will first be seen for the temperature response of CH_4 emissions due to the shorter atmospheric perturbation lifetime than for N_2O. See Figure 8 for Case 7. A 20% reduction of agricultural emissions will reduce the temperature response in 2050 (2100) by 0.24 m°C (0.27 m°C) for CH_4 and by 0.04 m°C (0.09 m°C) for N_2O.

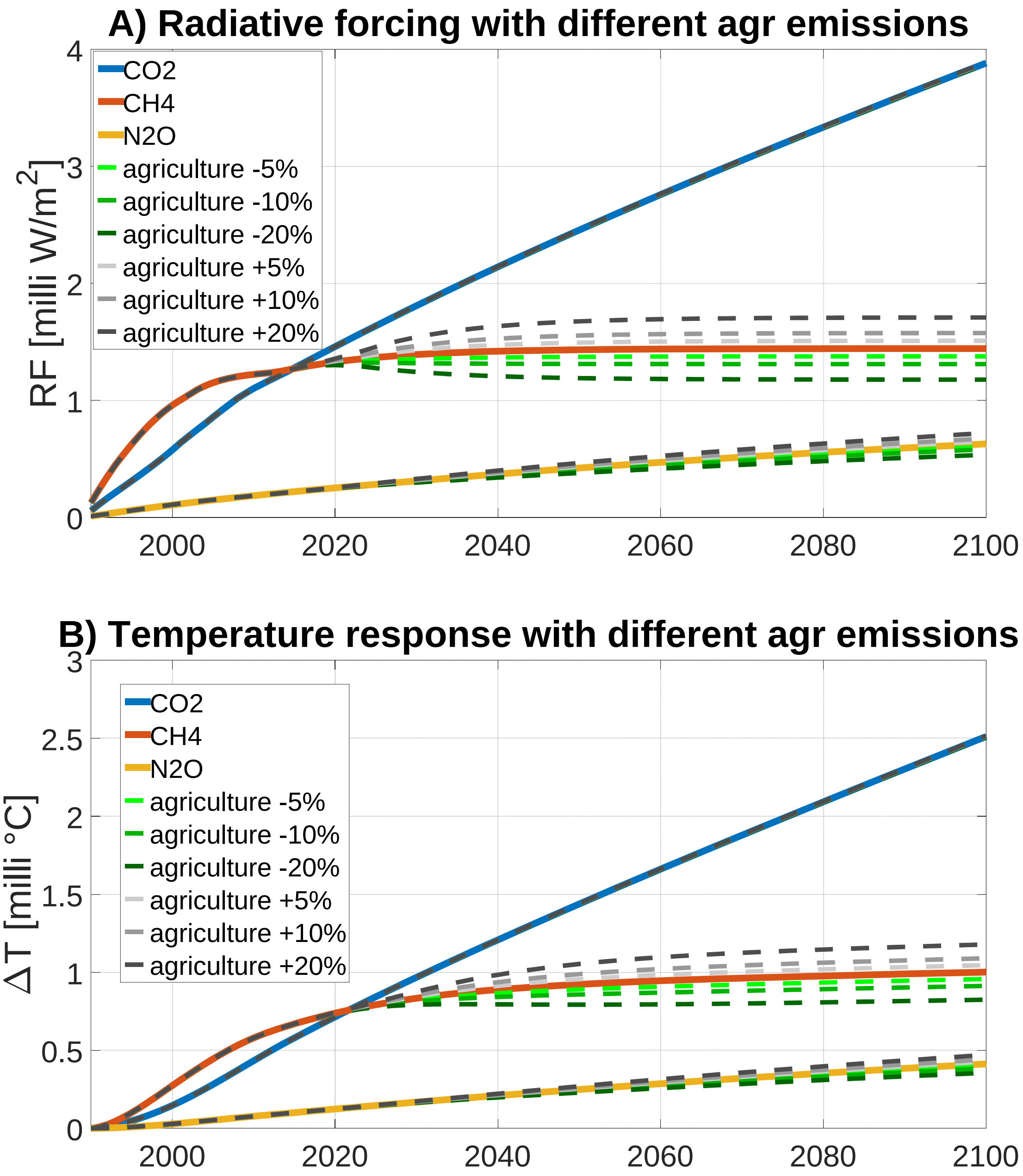


Figure 8: Case 7. This is similar to Figure 5, but the emissions from agriculture are changed, either increasing or decreasing. The emissions are assumed to change linearly in the period 2016-2025, followed by sustained emissions. The emission changes for this ten-year period is ±5, ±10, and ±20%.

Negative CO_2 emissions

Anthropogenic emission sources can be balanced by anthropogenic sinks. Such sinks are often labelled negative CO_2 emissions. CO_2 can be removed by the atmosphere by afforestation or utilizing BECCS. Negative CO_2 emissions can also be used to counteract the warming from CH_4 and N_2O emissions. The required level of negative CO_2 emissions will depend heavily on the scenario and method of comparison, such the treatment of time. In Table 1 and Figure 9, we consider the required constant CO_2 emissions from 2016 to 2050/2100 to offset constant emissions of CH_4 and N_2O. The needed offset is slightly larger when looking at temperature change than radiative forcing due to inertia in the climate system, with some exceptions for N_2O in 2050. As the general trends are the same for temperature change and radiative forcing, the following discussion based on temperature is also applicable for radiative forcing. Emissions of CH_4 have the largest weight, especially in the short-term. The calculations show that a higher level of negative CO_2 emissions are needed to offset warming by CH_4 and N_2O in 2050 than in 2100. This is because cumulative CO_2 emission is nearly proportional to temperature perturbation. Since the temperature response of CH_4 and N_2O in 2100 (Figure 5) is not proportionally larger compared to 2050 (Figure 4), lower CO_2 emissions can be used to 2100 because of the additional 50 years to accumulate CO_2 emissions. If emissions from agriculture grow, even larger negative CO_2 emissions are needed to balance emissions. More negative CO_2 emissions are needed if historic emissions of CH_4 and N_2O are included, but the importance of these historic emissions diminishes towards the end of the 21st century. The cumulative emissions of CO_2 to offset temperature increase in 2050 and 2100 from CH_4 and N_2O emissions are given in Table 2. The longer the emission period, the more cumulative negative CO_2 emissions will be needed, especially to counteract the warming of N_2O emissions.

Table 1: The needed yearly reductions of CO_2 emissions in million tons to offset the temperature response and radiative forcing in 2050 and 2100 due to emissions of CH_4 and N_2O.

Emission scenario for CH_4 and N_2O	Parameter	2050		2100	
Emissions in Mt CO_2/yr		CH_4 (Mt CO_2/yr)	N_2O (Mt CO_2/yr)	CH_4 (Mt CO_2/yr)	N_2O (Mt CO_2/yr)
Constant CH_4 and N_2O emissions (2016-2100)	ΔT	-38	-6	-19	-6
As above, but added 5% from agriculture (Case 7)	ΔT	-40	-7	-20	-7
As above, but added 10% from agriculture (Case 7)	ΔT	-41	-7	-21	-7
As above, but added 20% from agriculture (Case 7)	ΔT	-44	-7	-23	-8
Historic (1990-2015) + constant CH_4 and N_2O emissions (2016-2100)	ΔT	-46	-12	-20	-8
Constant CH_4 and N_2O emissions (2016-2100)	RF	-34	-6	-18	-6
As above, but added 5% from agriculture (Case 7)	RF	-35	-7	-19	-7
As above, but added 10% from agriculture (Case 7)	RF	-37	-7	-19	-7
As above, but added 20% from agriculture (Case 7)	RF	-40	-8	-21	-8
Historic (1990-2015) + constant CH_4 and N_2O emissions (2016-2100)	RF	-36	-11	-18	-8

Table 2: The needed cumulative emissions of CO_2 in million tons in the periods 2016-2050 and 2016-2100 to offset the temperature response and radiative forcing in 2050 and 2100 due to emissions of CH_4 and N_2O.

Emission scenario for CH_4 and N_2O	Parameter	2050		2100	
Cumulative emissions in Mt CO_2		CH_4 (Mt CO_2)	N_2O (Mt CO_2)	CH_4 (Mt CO_2)	N_2O (Mt CO_2)
Constant CH_4 and N_2O emissions (2016-2100)	ΔT	-1300	-220	-1600	-550
As above, but added 5% from agriculture (Case 7)	ΔT	-1400	-230	-1700	-570
As above, but added 10% from agriculture (Case 7)	ΔT	-1400	-240	-1800	-600
As above, but added 20% from agriculture (Case 7)	ΔT	-1600	-260	-1900	-650
Historic (1990-2015) + constant CH_4 and N_2O emissions (2016-2100)	ΔT	-1600	-430	-1700	-700
Constant CH_4 and N_2O emissions (2016-2100)	RF	-1200	-230	-1500	-540
As above, but added 5% from agriculture (Case 7)	RF	-1200	-240	-1600	-570
As above, but added 10% from agriculture (Case 7)	RF	-1300	-240	-1600	-590
As above, but added 20% from agriculture (Case 7)	RF	-1400	-260	-1800	-640
Historic (1990-2015) + constant CH_4 and N_2O emissions (2016-2100)	RF	-1300	-370	-1500	-660

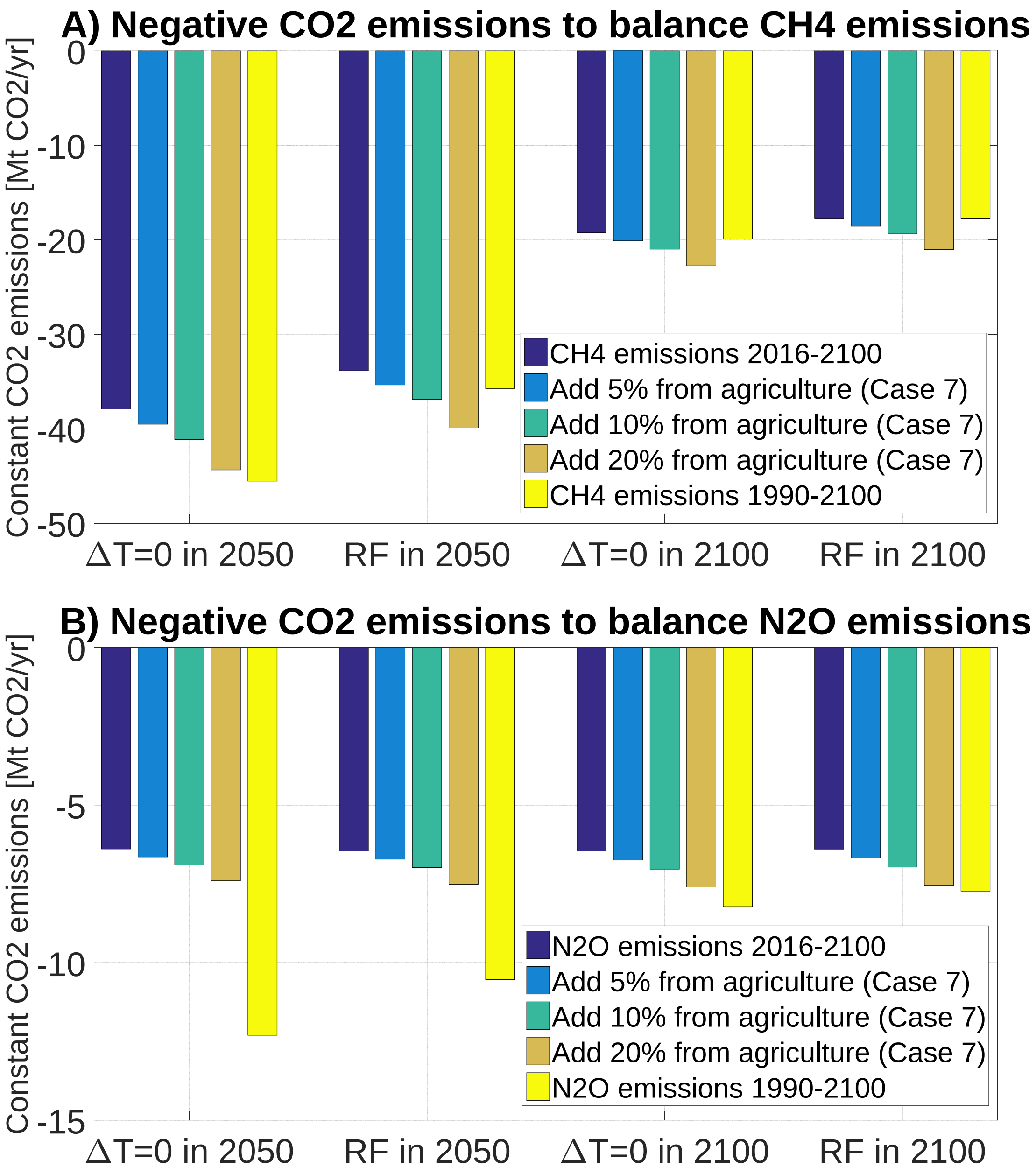


Figure 9: The needed yearly reductions of CO_2 emissions to offset the temperature response and radiative forcing in 2050 and 2100 from CH_4 (A) and N_2O (B) emissions. The negative emissions of CO_2 start in 2016.

CO_2 equivalent emissions

The emissions in 2015 can be converted to CO_2 equivalent emissions with emission metrics including a time horizon. The two most common emission metrics are the Global Warming Potential (GWP) and Global Temperature change Potential (GTP). GWP and GTP are normalized to CO_2, and GTP is linked to the very simple climate model (AGTP) used in previous sections. GWP and GTP values for a time horizon of 100 years are used, from either the Fourth (AR4) or Fifth (AR5) Assessment Report of the IPCC (Forster et al., 2007; Myhre et al., 2013). Current emissions of CH_4 and N_2O and be neutralized with 21.2 Mt CO_2 of negative CO_2 emissions by applying GWP(100) from AR5 (see Table 3). The needed negative

CO_2 emissions is highly dependent on the emission metric and time horizon, such as a much smaller quantity for GTP(100). The numbers in Table 1 and 3 are not directly comparable, as Table 1 is based on a constant level of negative CO_2 emissions for 2016-2100, while Table 3 considers emissions in 2015.

Table 3: Emission metric values from the Fourth (AR4) and Fifth (AR5) Assessment Report of the IPCC (Forster et al., 2007; Myhre et al., 2013).

Emission metric value	CO_2	CH_4	N_2O
AR4 GWP(100)	1	25	298
AR5 GWP(100)	1	28	265
AR5 GTP(100)	1	4	234

Table 4: Negative CO_2 equivalent emissions needed to neutralize CH_4 and N_2O emissions in 2015.

AR4 GWP(100)	AR5 GWP(100)	AR5 GTP(100)
20.3 Mt CO_2	-21.2 Mt CO_2	-7.7 Mt CO_2

Conclusions

Different emission metrics have been applied to assess the climate impact of Irish emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The emission metric Absolute Global Temperature change Potential (AGTP) is a useful and very quick tool to produce different temperature scenarios. The report finds that CO_2 and CH_4 emissions are the most important for short-term climate impacts, while CO_2 dominates in the long-term, such as for the middle and late part of the 21st century (50 to 100 years ahead). Due to the short atmospheric lifetime of CH_4, emission reduction of CH_4 is more effective to reduce the global temperature quickly in the short-term. However, sustained CO_2 emission reductions have the largest impact in the long run. The climate impact of CH_4 and N_2O can be offset in theory by negative CO_2 emissions. The amount of these negative emissions depends on the method of comparing climate impacts, as well as the perspective taken. For instance, roughly a doubling of negative CO2 emissions is needed to offset the temperature impact of CH_4 emissions if we move the time perspective from 2100 to 2050.

Avenues for future work could be broadly defined in two core areas: Irish impacts and implications, and global policy dimensions.

The climate impact of Irish emissions could be studied more specifically by including a wider range of emissions, such as including a number of short-lived climate forcers (e.g., black carbon), and by using more refined modelling methods. For this, estimates of the impact of regional emissions would be more relevant, not just applying a global average for Irish emissions. The regional temperature impacts could also be studied; with either more detailed models or specific regional emission metrics (or both). For example, the emission metric the Absolute Regional Temperature change Potential (ARTP) divides the temperature responses in four latitude bands. Such studies can assess emissions from sectors in greater detail than in this report, including analysis of different mitigation measures.

Future work can also focus on how to interpret the specific text in the Paris Agreement: achieving “a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases”. Several terms in this expression are open for interpretation. In this report, we have specifically focused on aspects related to the “balance” and how this is changed by time and emission metric. There are multiple ways to interpret “anthropogenic”, particularly in relation to “removals by sinks”, with the scientific community (e.g., IPCC) and emission inventory community (UNFCCC) using different definitions (Grassi et al., 2017). And, there could be different choices on what constitutes the “greenhouse gases”, such as only those specific in the UNFCCC process (e.g. the “Kyoto gases”) or all species effecting climate (e.g. IPCC). Finally, Article 4 of the Paris Agreement can also be seen in the context of more concretely defining “well below 2°C” and pursue effects to limit the temperature increase to 1.5°C as mentioned in Article 2 (Peters, 2017).

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