Global Commitment: Achieving the Less than 2-degree Target

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Climate Change Working Paper No. 25

November 2015

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Abstract

As countries develop and negotiate their Intended Nationally Determined Contributions to reducing greenhouse–gas emissions, total emissions continue to grow while the chances of avoiding 'dangerous climate change' and keeping global–mean surface temperature change to less than 2 °C relative to pre-industrial remain a significant challenge. Using a simple climate model we investigate some of the key over–arching issues to achieving the International Energy Agency's IEA2DS scenario, a low–emission pathway that is consistent with the 2 °C target. Testing of four idealized variations to this scenario demonstrates the need for every nation, both developed and developing, to achieve ambitious mitigation outcomes consistent with the principles of common but differentiated responsibilities and capabilities. This applies to both CO_2 and non-CO2 emissions; success is only possible if every nation, both developed and developing, plays its part across all sectors of the economy, including energy production, transport and agriculture. Continued growth in methane emissions associated with natural gas production and demand for food will reduce the probability of staying below the 2 °C target from likely (a 2 in three chance) towards a 50/50 chance.

1 Introduction

The UNFCCC has established a target for limiting the change in Earth's global–mean surface temperature to less than 2 °C relative to pre-industrial [*Randalls*, 2010; *UNEP*, 2014; *UNFCCC*, 2012; 2014]. This is a significant challenge, yet one which the international community is focused on achieving through the mechanisms of the UNFCCC. A number of scenarios have been proposed to achieve reductions in greenhouse–gas (GHG) emissions that are consistent with this target. One example is the Representative Concentration Pathway RCP2.6 [*Meinshausen et al.*, 2011b]. It is a low emission/high mitigation scenario, although many different pathways can achieve the same outcome [*Moss et al.*, 2010]. Characteristics of this scenario include negative CO_2 emissions from fossil fuels by 2080 and emissions from land use and land clearing halved by 2100. CO_2 emissions from OECD countries are approximately 18% of 2010 levels by 2050 while emissions from Asian countries are less than half of 2010 levels by 2050. Another low emission scenario is the International Energy Agency's IEA2DS [*IEA*, 2015]. Here, we focus on the latter scenario, since it is supported by the detailed analysis carried out by the IEA for energy-based CO_2 emissions, the most significant contributor to greenhouse-gas induced warming, both in terms of the amount of emissions but also the longevity and long-term effects of those emissions. Modeling of future temperature change has been carried out followed by testing the sensitivity of the results to some key challenges.

Section 2 outlines the IEA scenarios, including the extension of these CO_2 scenarios to create GHG scenarios out to 2100 and then projecting probabilistic temperature change for the IEA and RCP emission scenarios. The modeling approach behind these projections is outlined in Section 3. Four variations to the IEA2DS scenario were investigated in order to explore some key scenario sensitivities, as discussed in Section 4. These variations demonstrate the need for all nations to contribute to halting the growth in GHG emissions, with all of the OECD countries and China needing to achieve significant reductions, while other nations need to avoid following the same high carbon intensive energy pathways. China's emissions, along with those of the USA and EU, are critical to holding global–mean temperature change to less than 2 °C.

Not only do CO_2 emissions have to be reduced to around zero by 2080, but the major non-CO_2 gasses methane and nitrous oxide also have to be reduced significantly, a topic that does not receive as much attention. Similarly sulfur dioxide emissions, a major contributor to air pollution and associated aerosol direct and indirect effects [*Boucher and Pham*, 2002; *Boucher et al.*, 2013] have to be addressed. Section 5 concludes with a summary of the findings.

2 The IEA2DS scenario

The IEA2DS scenario is one of three scenarios developed by the IEA [*IEA*, 2015]. These scenarios, labeled 2DS, 4DS and 6DS, are detailed in terms of CO_2 emissions from energy, transportation, buildings and industrial sources. CO_2 emissions for the high emissions pathway, 6DS, continue to grow until 2050, the end of the IEA's projection period. Under the 4DS case the growth in CO_2 emissions slows and then stabilizes by mid-century. The 2DS scenario provides for a substantial reduction in CO_2 emissions, peaking in 2020 and then declining thereafter.

Considerable detail is provided by the IEA for the derivation of the projected CO_2 emissions out to 2050 [IEA, 2015], although details for land–use change and other greenhouse–gas emissions are not given. These details stem from in-depth analysis of CO_2 emission sources and technologies out to 2050. This scenario is arrived at from a bottom up approach that delivers CO_2 emissions very similar to RCP2.6. We draw on the RCP scenarios [*Meinshausen et al.*, 2011b] to in-fill for land-use change and non-CO2 emissions missing from the IEA scenarios.

IEA2DS relies on significant improvements in energy efficiency and fuel switching in the power sector, with less reliance on fossil fuels and switching to low-carbon renewable energy sources and nuclear power complemented by carbon capture and storage. Significant improvements in energy efficiency for transport, industrial processes and buildings are also called for, together with a range of other measures. Following *Schaeffer and Vuuren* [2012], we extend the IEA scenarios out to 2100. IEA6DS CO_2 emissions continue to increase, peaking in 2070 before starting to drop, while a small amount of growth is provided in IEA4DS, and the strong decline continues in IEA2DS, going negative in 2080. These paths are illustrated in Figure 1(a). The other greenhouse gases and scenario components are included, drawing on the RCPs [*Meinshausen et al.*, 2011b] as a guide, with some interpolation and scaling to harmonize the component emissions. This enables modeling of the projected surface temperature changes to the end of this century.

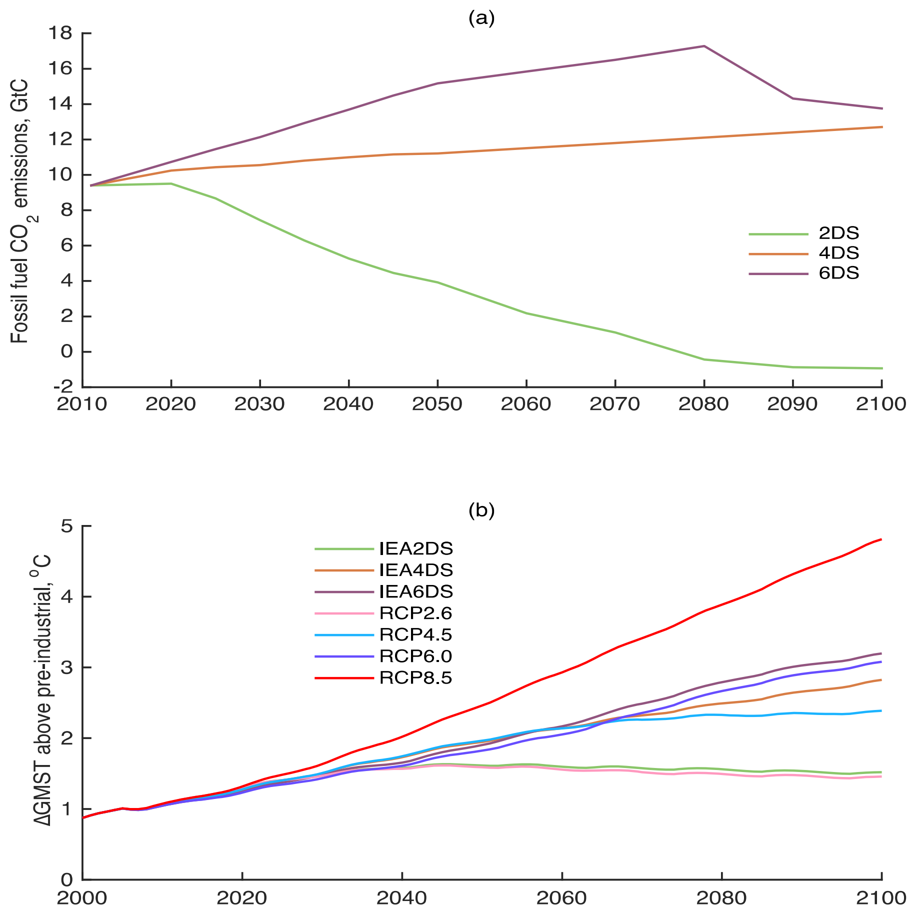
Global–mean surface temperature change (ΔGMST) projections for the three IEA scenarios are plotted together with those for the four emissions–driven RCPs in Figure 1(b); temperature change at 2100 is given in Table 1. The modeling methodology is explained in the next section (Section 3). Temperature change for IEA2DS and RCP2.6 were found to be very similar. Allowing some continued growth in GHG emissions after 2050 for IEA4DS results in a somewhat higher temperature outcome as compared to RCP4.5, while IEA6DS and RCP6.0 have similar projected ΔGMST.

Table 1: Key indicators for the IEA and RCP and emission scenarios at 2100 according to MAGICC

Scenario	CO_2 concentration by 2100 (ppmv)	CO_2-equivalent concentration by 2100 (ppmv)	Median temperature change by 2100 relative to pre-industrial, °C	Probability of staying below 2 °C at 2100
IEA2DS	433 (378–585)	480 (427–656)	1.6 (0.8–3.3)	69%
IED4DS	632 (510–926)	720 (596–1073)	3.2 (1.8–5.5)	10%
IEA6DS	703 (553–1035	820 (660–1224)	3.6 (2.1–6.0)	5%
RCP2.6	424 (372–571)	470 (421–641)	1.6 (0.7–3.2)	72%
RCP4.5	545 (445–813)	630 (521–943)	2.8 (1.5–5.0)	19%
RCP6.0	679 (540–994)	790 (644–1174)	3.5 (2.0–5.9)	6%
RCP8.5	938 (704–1457)	1280 (986–2005)	5.0 (2.9–8.0)	1%

Notes: Median values with 90% confidence intervals in parentheses.
Source: [*Bodman et al.*, 2013, updated to most recent program versions].

Figure 1: (a) Energy and industrial CO_2 emissions for the three IEA scenarios, 2DS, 4DS and 6DS extended to 2100 [*IEA*, 2015], (b) Median global–mean surface temperature change (ΔGMST) projections for three IEA extended emission scenarios and four RCP standard emission scenarios (relative to pre-industrial).



3 Projecting temperature change for the IEA and RCP scenarios

3.1 Modeling the emission scenarios

The temperature change associated with each scenario was modeled using MAGICC version 6, a simple energy–balance upwelling–diffusion climate model [*Meinshausen et al.*, 2011a; *Wigley and Raper*, 2001]. Values for the model's key parameters were based on an updated posterior parameter set of 24,000 determined using a Bayesian calibration process [*Bodman et al.*, 2013]. This method compares model results against a set of historical observations to assess the likelihood of the fit between them, accepting and rejecting accordingly. Features of this approach include the use of observed time series for the land minus ocean temperature difference, northern hemisphere minus southern hemisphere temperature difference, multi-layer ocean heat content (100m, 300m and 700m) and an ocean vertical temperature change profile in addition to global–mean surface temperature anomalies. The key climate parameters are equilibrium climate sensitivity, ocean diffusivity and aerosol radiative forcing (direct and indirect). The key carbon cycle parameters are the CO_2 fertilisation factor, temperature feedback effect on plant respiration and an oceanic impulse response scale factor [refer *Bodman et al.*, 2013 and *Meinshausen et al.*, 2011a for model details].

The time series of surface temperature differences and ocean temperature change contribute by providing additional information since these have weaker correlations to the global–mean surface temperature change than the temperature and ocean heat content time series by themselves. Observed CO_2 concentrations were used to calibrate the carbon cycle rather than being calibrated against other models.

The resulting posterior parameter distribution was used for the forward projections. Probability distributions for projected GHG concentrations, forcing and global–mean temperature change were produced for the various emission scenarios. Median ΔGMST results for the three extended IEA and four standard RCP scenarios are illustrated in Figure 1(b) and values for CO_2 concentration, CO_2 equivalent concentration, median ΔGMST and the probability of remaining below 2 °C at 2100 presented in Table 1. Note that utilizing emissions means that the carbon cycle is active in the model, with a CO_2 fertilization effect and temperature feedbacks affecting atmospheric CO_2 concentrations.

The temperature increase for IEA2DS at 2100 is very similar to that for RCP2.6, with median values of 1.6 °C at 2100 (relative to pre-industrial), 90% confidence intervals of respectively 0.8–3.3 °C and 0.7–3.2 °C. Note that our results produce different temperature results and probabilities to other studies [for example, *Rogelj et al.*, 2012] stemming from a different treatment of carbon cycle uncertainties as well as being emission–driven scenarios, rather than concentrations–driven. Close similarities between these RCP results and the IPCC [*IPCC*, 2013] builds confidence in the model and calibration method employed here.

Based on these model results, staying below 2 °C is most unlikely for all of the IEA and RCP emissions scenarios except for the very high mitigation scenarios IEA2DS and RCP2.6. Even then, there remains an approximately one in three chance of failing to meet this target.

4 Scenario variations

Four variations to our version of the extended IEA2DS scenario were investigated to address major feasibility challenges for successfully keeping global warming to under 2 degrees.

Variation 1 considers a case where emissions from the 'rest-of–the-world' (defined here as countries other than the OECD and China) follow an emissions pathway consistent with IEA4DS rather than the 2DS case.

As an alternative perspective, in Variation 2 China's emissions were tested. China's emissions contribute significantly to total anthropogenic CO_2 emissions, exceeding that of any other single nation (refer Figure 3). To illustrate the impact of these emissions in the context of the IEA2DS scenario, we model two variations in which CO_2 intensity is: a) significantly reduced or, b) remains static.

In Variation 3, methane (CH_4) and nitrous oxide (N_2O) emissions increase slightly rather than being substantially reduced on the basis that new oil and natural gas extraction along with the need to feed a growing world population could have this outcome.

The fourth variation tests the effect of a slower decline or small growth in sulfur emissions associated with burning fossils fuels, the main contributor to aerosol radiative forcing.

4.1 Variation 1 – the Rest of the World catches up

In this variation, emissions for the OECD and China are kept the same as in the IEA2DS extended scenario while emissions for the rest-of-the-world (RoW) continue to grow, following the IEA4DS extended pathway. The RoW countries have generally low per capita emissions and are relatively poor. As their circumstances improve there is likely to be some rise in GHG emissions unless considerable effort is made to achieve this economic growth without corresponding GHG emission increases. This scenario variation results in a noticeable difference to temperature change results, with the median temperature change at 2100 being 2.5 °C rather than 1.6 °C, while the probability of staying below the 2.0 °C target reduces considerably, from 69% to 30% (refer Figure 2(a) and results Table 2).

While much of the focus on CO_2 reductions rests with China, the USA and other major economies, this demonstrates the important role and contribution that every nation makes towards limiting emissions growth.

Figure 2: (a) Median global–mean surface temperature change (ΔGMST) with respect to (wrt) pre-industrial for IEA2DS (green line), IEA4DS (brown line) and Variation 1 (V1, magenta line). (b) Median temperature change projections (relative to pre-industrial) for IEA2DS and IEA4DS scenarios with variations V2a and V2b.

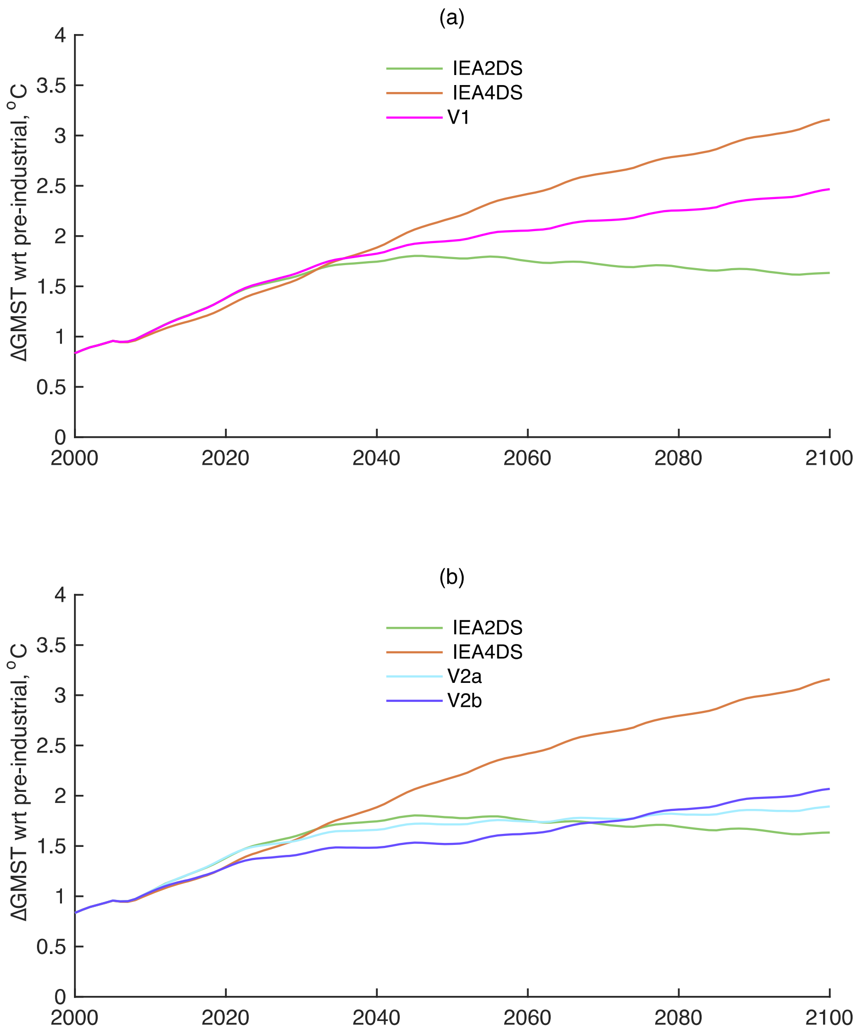


Table 2: Temperature change at 2100 results (relative to pre-industrial) for IEA2DS, IEA4DS and variation 1 (V1) plus variation 2a and 2b (V2a and V2b) (top section) along with variation V3 and variations V4a and V4b (bottom section). Results tabled as median ΔGMST relative to pre-industrial with 67% confidence interval (CI) and estimated probability of staying below 2 °C target.

	2DS	4DS	V1	V2a	V2b
Median	1.6	3.2	2.5	1.9	2.1
67% CI	1.1 – 2.4	2.3 – 4.3	1.7 – 3.5	1.3 – 2.7	1.5 – 2.9
Probability <2 °C	69%	10%	30%	56%	48%
			V3	V4a	V4b
Median			2.0	2.1	1.7
67% CI			1.3 – 2.9	1.5 – 2.8	1.1 – 2.5
Probability <2 °C			52%	46%	69%

Source: Author’s estimates.

4.2 Variation 2 – changes to China's emissions

China's emissions contribute significantly to total anthropogenic CO_2 emissions, exceeding that of any other single nation (refer Figure 3). To illustrate the impact of these emissions in the context of the IEA2DS scenario, we model two variations in which:

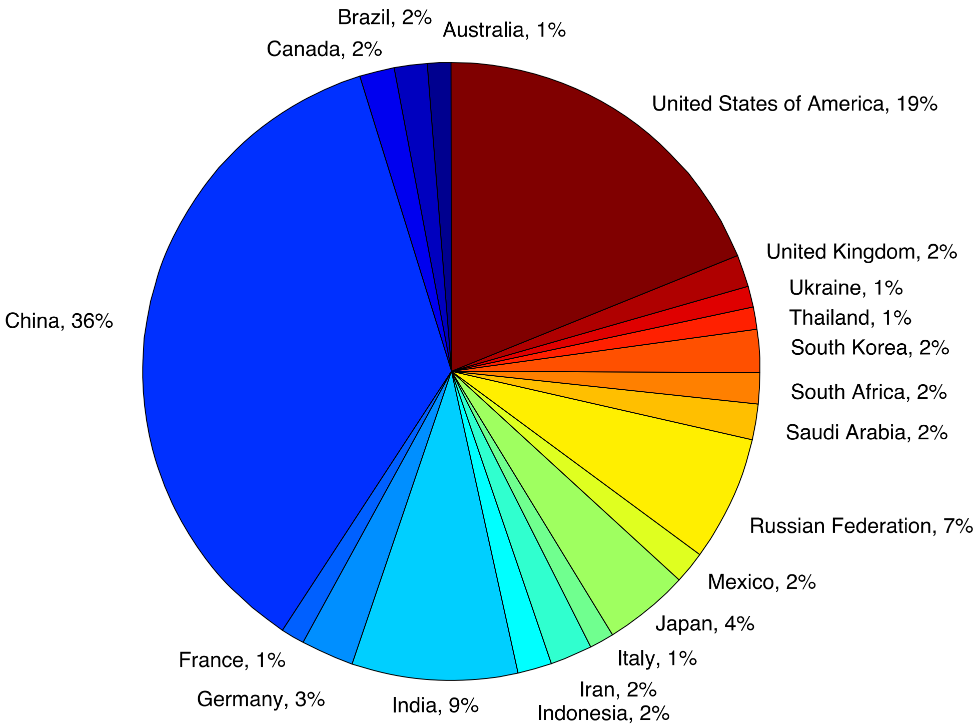
> V2a – CO_2 emissions align with China's offer for a 40–45% reduction in carbon intensity from 2005 to 2020. On the assumption that China's GDP grows at an average rate of 8% p.a., then China's emissions will increase by 90% from 2005 to 2020 (according to China's carbon trade website www.tanpaifang.com, accessed June 2014, personal communication from Enjiang Cheng).
>
> V2b – If there is no reduction in carbon intensity, China's carbon emissions will increase by more than 200% from 2005 to 2020.

These two variations were extended out to 2050: for V2a, a slower rate of decline than for the original IEA2DS case was applied after 2020, while for V2b a slower rate of growth was applied after 2020. After 2050, total global CO_2 emissions were assumed to reduce at 15% per decade, declining to 2.4 GtC at 2100 for V2a and 4.4 GtC for V2b (excluding land use change). All of the other scenario components were left unchanged, with the assumption that sulfur emissions continue to decline as a result of process improvements even if CO_2 emissions are higher.

Containing China's emissions growth plays an important part in avoiding warming above 2 °C. Massive reductions in carbon intensity will be needed to align China's emissions to the IEA2DS scenario while future GDP growth and GHG emissions will be significant factors.

The resulting temperature change projections (Figure 2(b) and Table 2) indicate how the median temperature increase is higher for the V2a and V2b variations as compared to the IEA2DS extended case. There is a corresponding decline in the probability of staying below 2 °C, from 69% for IEA2DS dropping to 56% and 48% for the V2a and V2b variations respectively.

Figure 3: Top 20 CO_2 emitters by country in 2013



Source: Global Carbon Atlas, http://www.globalcarbonatlas.org, accessed 21 July 2015.

4.3 IEA2DS Variation 3

In Variation 3, methane (CH_4) and nitrous oxide (N_2O) emissions were modified from those allowed for in the IEA2DS extended scenario, Figure 4(a). Here they grow slightly on the basis that, with new oil and natural gas production alongside the need to feed a growing world population, this will prevent reductions below current emission levels. Agriculture accounts for around 15% of overall anthropogenic emissions, largely from CH_4 and N_2O [*Popp et al.*, 2010]. An increasing demand for a better quality diet along with technical and practical challenges in limiting these emissions suggest that scenarios such as RCP2.6 may be difficult to achieve. Stabilizing CH_4 and N_2O emissions may also be difficult in a warming world with positive ecosystem feedbacks [*Randerson et al.*, 2015]. Scenarios with higher emissions, such as RCP6.0 and RCP8.5 have growth rates up to 2050 of around 0.2% to 1.1% for CH_4 and 0.2 to 0.3% for N_2O. To illustrate the challenge posed by these non-CO2 gases we test a fairly conservative scenario that has a 0.5% growth rate for CH_4 and zero growth for N_2O.

Variation 3 is the same as the IEA2DS extended scenario except:

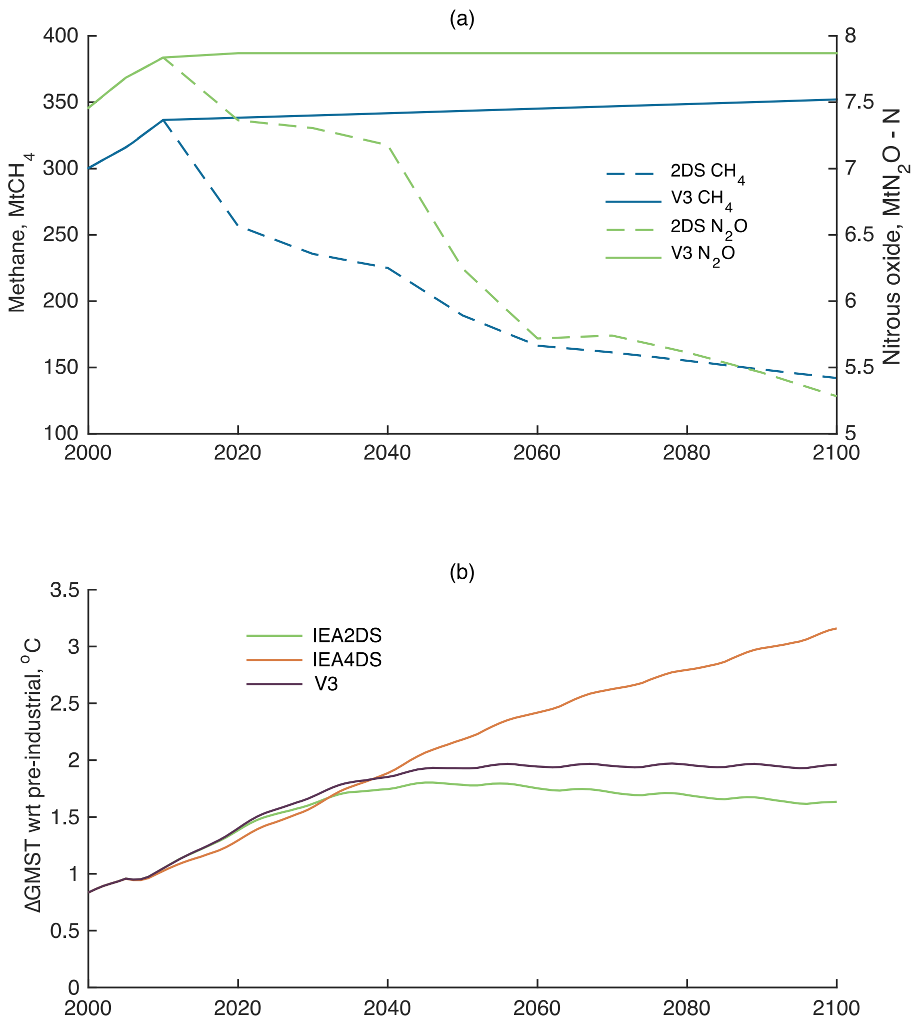
> CH_4: instead of significant reductions, CH_4 emissions are held at a small growth rate of 0.5% per decade, since, even despite reductions associated with fossil fuel production

and with significant improvements to agricultural practices, population growth and increased per capita food consumption could result in a small increase rather than a rapid decline in CH_4 emissions;

N_2O: instead of reducing, N_2O emissions remain constant from 2020, with reasoning on a similar basis to CH_4.

The impact of these modifications as compared to the IEA2DS ΔGMST reference scenario is shown in Table 2 and illustrated in Figure 4(b). The median temperature increases slightly, from 1.6 to 2.0°C, reducing the probability of staying below the target of 2.0 °C down to 52% (roughly a two in three chance down to a 50/50 chance).

Figure 4: (a) Methane (blue) and nitrous oxide (light green) emissions for IEA2DS reference scenario (dashed lines) and Variation 3 (V3, solid lines). (b) Median ΔGMST projections (relative to pre-industrial) for IEA2DS and IEA4DS scenarios with Variation 3.



4.4 IEA2DS variation 4 – sulfate emissions

Variation 4 has the same emissions as the IEA2DS extended scenario but with changes to sulfur dioxide emissions, which are assumed to:

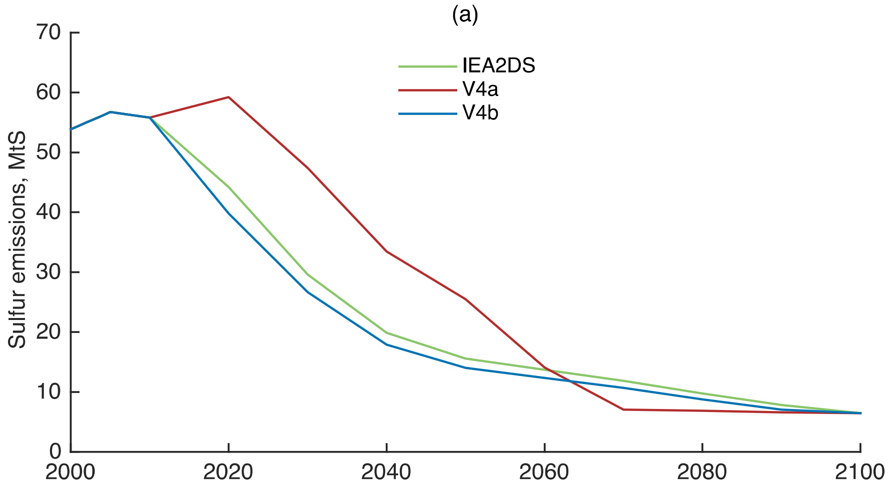
> V4a – increase until 2020 and then decline in proportion to reductions in fossil fuel CO_2 emissions to 2070 and then remain constant out to 2100, Figure 5(a).
>
> V4b – instead of increasing, sulfur emissions actually decrease an additional 10% below the IEA2DS extended case, Figure 5(a). This could occur as concerns over air pollution, such as in China [*Sheehan et al.*, 2014], drive even more rapid reductions (sulfur dioxide being a significant contributor to air pollution among a number of other components that include nitrogen oxides, black carbon and organic carbon).

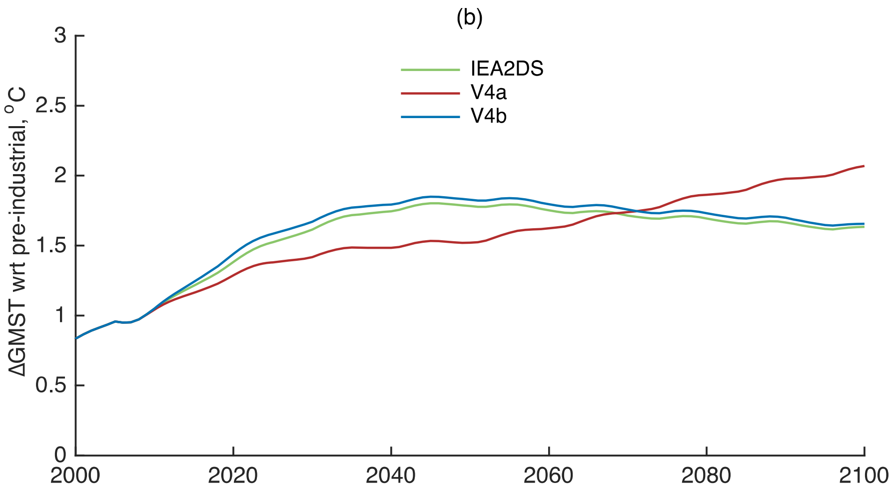
The outcome at 2100 is very similar in terms of sulfur emissions, but variation V4a has less warming through mid-century as a consequence of delayed reductions in sulfur emissions (increased aerosols reduce net radiative forcing and hence are associated with less temperature change). However, by 2070 this 'cooling bonus' is lost and temperature change continues to increase. The corresponding projected temperature change is illustrated in Figure 5(b). The probability of staying under the 2 °C target is also reduced to less than 50%.

Achieving a 10% greater reduction in sulfur emissions over the IEA2DS reference scenario, that is variation V4b, has little impact on the temperature change trajectory and ΔGMST at 2100 (Figure 5(b) and Table 2).

These results exhibit a degree of path dependency associated with sulfur emissions that could upset the ability of a low GHG emission scenario to achieve a less than 2 °C ΔGMST outcome.

Figure 5: (a) Sulfate aerosol precursor emissions, MtS, for IEA2DS reference scenario and variations V4a and V4b. (b) Median ΔGMST projections relative to pre-industrial for IEA2DS and variations V4a and V4b.





5 Summary and conclusions

Using our IEA2DS extended scenario, four variations were investigated to test some key sensitivities for keeping global warming under 2 °C during this century. Variation 1 tested the focus on the OECD and China's CO_2 emissions. While it is critical that the major emitters achieve very significant reductions, the rest of the world cannot be neglected. Economic growth for the latter is important but needs to be achieved with little growth in GHG emissions. It is in the developed nation's interest to encourage and support this growth with renewable energy technologies rather than outmoded fossil fuel based energy production.

The so-called developed nations have to achieve CO_2 emission reductions of more than 80% by 2050 and zero or negative by 2080. There is very little flexibility in this, yet very few nations have made commitments of this magnitude leading in to the Conference of the Parties (COP21) this year. Although an agreement on mitigation targets for 2020 emissions is extremely important [*Kriegler et al.*, 2013], these commitments will need to be intensified over time. Variation 2 also illustrates the significant role that China has to play. While not officially classed as a developed nation, as the world's largest emitter reductions in both carbon intensity and absolute emissions, its GHG emissions are critical to achieving the 2-degree target.

CO_2 emissions and the carbon budget receive a lot of attention but the other non-CO_2 emissions are also important. Variation 3 tests this concern by examining methane and nitrous oxide reductions. The significant reductions for these two that are included in RCP2.6, and hence our IEA2DS extended scenario, are needed to maintain the probability of staying below 2 °C of global warming to a two in three chance rather than 50/50. As countries formulate their INDCs (Intended Nationally Determined Contributions) and settle on their future mitigation targets, non-CO2 emissions will need to be specifically addressed. Very large reductions in CH_4 and N_2O will not be achieved without considerable research efforts, technological change and effective implementation. Although they can be included as part of a CO_2-equivalent emissions budget [see for example, *UNEP*, 2014], there is a vast gap between such aspirations and detailed implementation across all the emission sources that need attention.

Variation 4 examines the role of another non-CO_2 emission, sulfur dioxide (SO_2), one of the primary precursors to aerosols. Anthropogenic emissions of SO_2 are primarily associated with fossil fuel burning. Forming sulfate aerosols, these emissions have a negative radiative forcing stemming from both direct and indirect effects. The significant reductions of SO_2 in RCP2.6 stem from both reductions in fossil–fuel emissions but also assume both technological improvements and their widespread adoption to reduce environmental impacts. This study suggests that delays in reducing SO_2 could impact adversely on the 2 °C target outcome, although the results from the simplified modeling approach employed here may need verifying against more complex Earth system models.

While highly aggregated and stylized, the four variations to the IEA2DS extended scenario indicate the fragile nature of this emission pathway. For success, every element of the scenario has to be achieved, with every nation contributing according to its circumstances, capabilities and capacities. There is very little room for tradeoffs between different components, particularly later this century. Negative CO_2 emissions could, for example, be avoided by earlier and faster reductions and large–

scale reforestation and afforestation so that land use and land use change becomes a sink rather than a source of CO_2 emissions.

This analysis is based on one simple climate model, MAGICC with its limitations. It is a simplified earth system model that lacks certain processes that could increase uncertainty (such as water and nutrient cycles, changes in ocean ventilation, stratification and biological carbon cycle, and the release of carbon from permafrost and albedo changes due to ice cover and vegetation). The results and uncertainty ranges given here depend on this particular model and the associated approach to calibrating the model's key parameters Nevertheless, it is a widely used and well–established tool for evaluating and comparing emission scenarios.

Acknowledgements

The author would like to thank M. Meinshausen and J. Kattge for the MAGICC and MCMH code respectively. Supporting data can be made available on request from the author. This work was supported by Victoria University under the Research Development Grant Scheme number RDGS 46/13.

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