CLIMATE ANALYTICS

Supporting science-based policy to prevent dangerous climate change, enabling sustainable development

Briefing paper

Rebuttal of “Ditch the 2 °C warming goal!” by David G. Victor and Charles F. Kennel, *Nature* published 1 October 2014

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Summary

Victor and Kennel argue that the target of limiting global warming below 2°C relative to pre-industrial levels (the "2°C goal," or rather, "limit"), adopted by the international community, should be dropped. They put forward two main reasons: that it is no longer feasible to meet the 2°C limit, in large part because there has been insufficient action to date, and that the 2°C limit is not measurable and cannot be translated into emission limits for countries and regions. They go on to argue that there should be a new process started to develop a a new set of global goals starting in Paris to replace the 2°C limit.

Both major reasons put forward to drop the 2°C limit are hopelessly flawed or just plain wrong:

- Whilst no one is in doubt about the difficulty of limiting warming below 2°C, it is incorrect to claim that achieving this goal is infeasible and cannot be done. The scientific community, in the form of the IPCC AR5 Working Group III report, has assessed that limiting warming below 2°C limit is technically and economically feasible, and at low to modest cost. No one in the scientific community has any doubt about the difficulty of the political decisions that need to made to realise this. Each person is entitled to their own views of whether or not political leaders will take the steps needed, but for the authors to dress up their own judgements - that these decisions will not be made - as a scientific fact is wrong.

- The argument that the 2°C limit cannot be translated into emission goals and budgets is, to put it mildly, unconvincing, and demonstrates a deep ignorance of scientific developments over the last ten years. If this were so, then there would be no science-based policy debate about the size of the gap between where emissions are headed at present and where they need to be in 2020 and 2030 at global, regional, and national levels. In fact, there have been annual scientific assessments of this since 2010.

No global goal on an issue as complex as climate change is going to be perfect, however it turns out that a temperature limit is actually a very good composite indicator of many serious impacts and risks. And it is understandable to the public and to political leaders,

and it can be translated into quantifiable emission actions, which can be updated with new science regularly, accounting for the full range of scientific uncertainties.

There has been an enormous amount of work by the scientific community on issues related to planetary boundaries and on the implications of different indicators for emission pathways beyond global mean temperature. When put together, this research has shown the 2°C limit provides an upper bound on emissions if other key systems are to be maintained, within safe limits, a fact which, startlingly, does not come through at all in this Comment, despite the space spent discussing alternative climate indicators. On this issue, the scientific literature contradicts the authors and shows clearly that including other metrics (objectives, such as reducing sea level rise, reducing ocean acidification) will increase the level of mitigation (emission reductions) needed.

And last but not least, the 2°C limit has triggered considerable political action at national, regional and global level – indeed the present process to negotiate a new global agreement with legal force and applicable to all stems very much from the scientific "pressure" generated by the existence of this limit. If action has not been sufficient it's certainly not because of the limit.

Many countries have indeed taken action – or are now planning more ambitious measures; however, in overall terms, the collective effort has been fully inadequate. The world is confronted with rapidly rising emissions - fastest from one of the most intensive source of CO_2 emissions, coal – exactly at a time when CO_2 emissions should be decreasing. It is wrong, however, to conclude that this means the issue is lost, when the main battle lies ahead and just when the process of developing a new agreement is building momentum.

It would be an act of grave irresponsibility for the 2°C limit to be dropped. This would signal a clear deflation of pressure to reach an ambitious agreement, delegitimise the international negotiations, weaken efforts at a national level to build ambitious policies, and send a highly adverse signal to the private sector.

Without the emission pressures of the 2°C limit there would effectively be a green light for continued massive expansion of coal and other fossil fuel intensive infrastructure in the next decade. As the International Energy Agency has warned, this infrastructure could lock-in warming levels of 4^{o}C this century.

Dropping the 2^{o}C limit , and with it pressure for the needed level of emission reductions, while starting a debate about a multitude of other goals is akin to doctors dithering over a critically ill patient. As in medicine, there are several indicators addressing different aspects of the vitality of the planet, but each of them would call for action if it reached a critical state. The planet's rising temperature is a vital sign and the prognosis is clear for future warming without urgent action. What doctor would refuse to provide treatment to a patient with a body temperature exceeding 40°C because their blood pressure cannot be measured?

Paragraph by paragraph rebuttal

Original text from Comment is in italics:

For nearly a decade, international diplomacy has focused on stopping global warming at 2 °C above preindustrial levels.

The goal adopted at Copenhagen in 2009 by global leaders, and confirmed in Cancun in 2010, is to hold warming below a 2°C increase above preindustrial levels.[1] Prior to 2009, the 2°C limit, which had been promoted by the European Union since 1996,[2] had not been supported by other major emitters. In 2005, the European Council (heads of government) adopted the goal that "the global annual mean surface temperature increase should not exceed 2°C above pre- industrial levels". The Council's reasoning was based on the likelihood of "major negative global environmental, economic and social implications."[3]

This goal — bold and easy to grasp — has been accepted uncritically and has proved influential.

The goal was contested diplomatically for over 13 years and was subject to different levels of scientific and political criticism prior to its adoption at Copenhagen in 2009. The steady accumulation of evidence, however, in particular from successive IPCC reports, and perhaps most notably from the Nobel prize-winning Fourth Assessment Report (AR4) in 2007, led to the emergence of a political consensus on the 2°C limit.

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[1] UNFCCC Decision 1/CP.16 Para I(4) :Further recognizes that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above preindustrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity; also recognizes the need to consider, in the context of the first review, as referred to in paragraph 138 below, strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5 °C;

[2] EU Environment Council 1996: "[...] the Council believes that global average temperatures should not exceed 2 degrees above preindustrial level and that therefore concentration levels lower than 550 ppm CO2 should guide global limitation and reduction efforts. [...]" (1939th Council meeting, Luxembourg, 25 June 1996)

[3] Presidency Conclusions – Brussels, 22 and 23 March 2005 Para. 43. The European Council acknowledges that climate change is likely to have major negative global environmental, economic and social implications. It confirms that, with a view to achieving the ultimate objective of the UN Framework Convention on Climate Change, the global annual mean surface temperature increase should not exceed 2ºC above preindustrial levels.

By the time that this was adopted in 2009, based on the emerging scientific evidence from the IPCC assessment processes, the most vulnerable countries – the Least Developed Countries (LDCs) and Small Island Developing States (SIDS) - had begun to express serious reservations about the level of damage and risk that they faced at 2°C warming above preindustrial. As a consequence, the Copenhagen meeting also agreed at head of government level to review the 2°C limit, with a view to strengthening it, and referenced the 1.5°C called for by SIDS and LDCs. This review is now underway at the UNFCCC and will conclude during 2015.

The emissions-mitigation report of the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) is framed to address this aim, as is nearly every policy plan to reduce carbon emissions — from California's to that of the European Union (EU).

The IPCC emissions-mitigation report (WG3)[4] is not framed to address the 2°C limit. The report analyses the scientific literature, and is capable of, and designed to be used to, assess the emission/mitigation consequences and requirements for very different levels of warming and/or CO_2 concentrations. The IPCC is not policy-prescriptive and hence does not "support" the 2°C limit, but it is required to be policy-relevant and, as the 2°C limit is supported by nearly all governments, it is only natural that a substantive and prominent strand of its assessment includes specific conclusions on this issue. To do otherwise would not reflect the mandate and responsibility of this entity.

It is indeed correct that an increasing number of national and regional plans to limit and reduce greenhouse gas emissions are framed, if not driven, by the globally agreed limit of holding warming below 2°C. For most governments, the 2°C limit is not the only issue in designing their national energy and climate plans. It is, however, a defining element as this goal places fundamental constraints on choices, which could be quite different in

[4] IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

the absence of a need to limit greenhouse gas emissions to pathways consistent with the global goal.

This month, diplomatic talks will resume to prepare an agreement ahead of a major climate summit in Paris in 2015; again, a 2 °C warming limit is the focus.

Heads of government at the Climate Summit in New York in September 2014 reiterated strongly the need to limit warming below 2°C.[5]

Bold simplicity must now face reality. Politically and scientifically, the 2 °C goal is wrong-headed.

Politically, the 2°C limit has formed a very important point of focus for policy in terms of judging the level of effort and ambition, which has become sharper as a consequence of insufficient action. The fact that the level of effort required to meet the 2°C limit is increasing due to lack of action does not provide an argument to drop the limit in favour of something easier or fuzzier. Instead it is an invitation to increase the level of effort nationally and globally. As is outlined elsewhere in this rebuttal, the scientific basis for the 2°C limit in term of impacts, risks and vulnerabilities is stronger and clearer now than it ever was. Consequently dropping the 2°C limit would likely lead to major loss of confidence and legitimacy in the UNFCCC, and at the national level be seen by the public concerned about the lack of sufficient action as abrogation of responsibility by governments and political leaders.

Politically, it has allowed some governments to pretend that they are taking serious action to mitigate global warming, when in reality they have achieved almost nothing.

There is little or no evidence to support the contention that the 2°C limit has been used as a means to avoid action. Governments who are taking little or no action

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[5] Executive Office of the Secretary General, 2014 Climate Change Summary - Chair's Summary. *UN Climate Summit 2014*. Available at: http://www.un.org/climatechange/summit/2014/09/2014-climate-change-summary-chairs-summary/

generally fail to link this to the 2°C limit, or mount arguments that it is another country's - or group of countries' - responsibility to act either because the country concerned is a very small emitter globally, or that other countries have a greater historical and ethical responsibility to act. Such arguments would apply to virtually any situation, irrespective of the existence of a global limit or not.

On the contrary, the existence of the 2°C limit, combined with the scientific capacity to evaluate national and regional emission pathways consistent with its achievement, has provided sustained pressure on national climate plans. The fact that governments have been slow to introduce required policies cannot be seen as a criticism of 2°C limit itself, but a reflection of the operation of larger political forces and economic interests.

Politically, 2°C limit has contributed to substantive discussions within fora such as the major economies Forum (MEF) on the levels of action required by different parties, that otherwise would be unlikely to have occurred.

Scientifically, there are better ways to measure the stress that humans are placing on the climate system than the growth of average global surface temperature — which has stalled since 1998 and is poorly coupled to entities that governments and companies can control directly.

This demonstrates a serious misunderstanding about the nature of the 2°C limit as a long-term climate target and an ignorance of the scientifically robust connection between cumulative greenhouse gas emissions and global mean warming. The fact that the rate of global mean *surface-air* temperature (GMT) warming over the last 15 years is smaller than the long-term trend since the 1950s due to natural variability of the climate system and recent changes in forcing[6] has no relevance to the 2°C limit itself (equally warming could

[6] As shown in e.g.: England, M., et al., Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus. *Nat. Clim. Ch.* **4,** 222–227 (2014) and also assessed by IPCC's Working Group I in their AR5 contribution: "The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the

occur faster due to natural variability superimposed on the effects of human induced warming). Year-to-year changes in GMT that are strongly influenced by natural variability of the global climate system are not seen generally by the scientific community as a robust indicator of stress on the individual elements of the climate system. Over periods longer than a decade, however, the average increase in GMT has been strongly associated with a variety of impacts on natural and human systems, and thereby provides a very good compound indicator of the level of stress and damage, much as a person's elevated body temperature over a sustained period of time is not the key problem itself, but is a good indicator, or symptom, of an underlying problem, or disease.

At the same time, the already observed warming trend has been shown to be very robustly and quantitatively linked to cumulative carbon dioxide and other greenhouse gas emissions.[7] As the authors acknowledge, these emissions are coupled strongly to "entities that governments and companies can control directly".

Failure to set scientifically meaningful goals makes it hard for scientists and politicians to explain how big investments in climate protection will deliver tangible results.

The 2°C limit is indeed scientifically meaningful in the most profound sense for policy: achievement of this goal can be robustly shown to limit and/or avoid damages and risks from higher levels of warming. Avoidance of these impacts and risks has been, and is, used as reasoning by political leaders, some in the private sector and industry, and stakeholders to explain how, why and when investments in climate protection are needed.

It is a mistake, as implied here, to assume that climate protection measures will deliver tangible results within just a few years. It has been known for many decades that the climate system has a

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ocean (medium confidence). The reduced trend in radiative forcing is primarily due to volcanic eruptions and the timing of the downward phase of the 11-year solar cycle." (IPCC WGI AR5 SPM D.1).

[7] Bindoff, N.L., P.A. Stott, K.M. AchutaRao, M.R. Allen, N. Gillett, D. Gutzler, K. Hansingo, G. Hegerl, Y. Hu, S. Jain, I.I. Mokhov, J. Overland, J. Perlwitz, R. Sebbari and X. Zhang, 2013: Detection and Attribution of Climate Change: from Global to Regional. In: Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

variety of inertia, and is slow to respond to changes in greenhouse gas concentrations (in fact, large-scale ocean and cryosphere systems respond on multi-centennial to millennial time scales). Climate change impacts already observed today emerge from past emissions, and avoidance of future impacts indicates the necessity to take early action in cutting emissions. This is one of the most fundamental features of the scientific basis for climate policy, and one that all analysts have a responsibility to fully account for.

Some of the backlash from 'denialists' is partly rooted in policymakers' obsession with global temperatures that do not actually move in lock-step with the real dangers of climate change.

The so-called "backlash" from climate denialists pre-dates what the authors refer to as policymakers' "obsession" with global mean temperatures. This sentence also contains a profound misunderstanding, repeated, about the linkage between a long-term global temperature limit and year-to-year temperature variability. The scientific community has never argued, nor demonstrated, that there is a "lock-step" between annual temperature changes and what the authors term the "real dangers of climate change."

Scientific concerns are based in large parts on projections about the future consequences of emissions, supported by observed impacts and changes in human and natural systems attributed to past emissions effect on climate. Indeed, ongoing changes of climate system are observed in all parts of the climate system including dramatic changes in the cryosphere (loss of Arctic sea ice, rapid decay of mountain glaciers, accelerating loss of ice from Greenland and Antarctica), increasing climate related extremes, ocean acidification and rising sea-levels,[8] as well as in human systems and agricultural yields.[9]

[8] Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[9] W. Cramer, G. Yohe, M. Auffhammer, C. Huggel, U. Molau, M. Assuncao Faus da Silva Dias, A. Solow, D. Stone, L. Tibig, 2014: Detection and Attribution of Observed Impacts In: Climate Change 2014 Impacts, Adaptation, and Vulnerability

. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field CB, Barros VR, Dokken DJ, Mach KJMastrea, MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, others (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

New goals are needed.

What is urgently needed, as has been demonstrated thoroughly by the scientific community, is increased action to reduce CO2 and other greenhouse emissions to meet the present 2°C limit. Other goals consistent with protecting planetary boundaries are likely to need greater and faster emission reductions than the 2°C limit in future decades.

Recent science shows that if multiple climate targets such as transient sea level rise, ocean acidification and net primary production on land, as well as global mean surface-air temperature are assessed, required emission reduction targets would be deeper and faster than by temperature alone, as any individual, alternative climate target could at any point become the limiting factor resulting in a lower permissible combination of CO_2 and non-CO_2 emissions .[10] Indeed, concern about the level of such individual climate targets is driving the large group of countries that consider 2°C too high a limit. This would seem to contradict directly the Authors' concern that the 2°C limit should be dropped because of infeasibility, i.e. being too low and therefore requiring emission reductions not deemed feasible by the authors.

It is time to track an array of planetary vital signs — such as changes in the ocean heat content — that are better rooted in the scientific understanding of climate drivers and risks.

The scientific community has indeed been tracking a wide range of "planetary vital signs," including ocean heat content, sea level rise, ocean acidification, changes in glaciers, ice sheets, ecosystems, agricultural systems and so on. Indeed, what we have learnt from these observations, and assimilated into our complex models, which are the basis of many climate impact projections, is exactly what gives us confidence that many of these changes and risks increase dramatically as emission levels, and thus global temperatures, rise. In fact, the IPCC Working Group II contribution to the Fifth Assessment Report (AR5)[11] assessment adopted a framework assessing five different reasons for concern and the scaling of the associated risks with

[10] Steinacher, M., Joos, F. & Stocker, T. F. Allowable carbon emissions lowered by multiple climate targets. *Nature* **499,** 197–201 (2013).

[11] Climate Change 2014: Impacts, Adaptation, and Vulnerability. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field CB, Barros VR, Dokken DJ, Mach KJMastrea, MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, others (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

global mean temperature rise. With all risks being at least moderate and three already being high around 2°C, this multi-metric assessment illustrates the actual capability of comprising a variety of risk indicators into a global temperature limit.

In the scientific community we focus on understanding the Earth as a system, and consequently the integration of understanding of climate drivers and risks is an essential task of science in this area. It is one that has led directly to, in many senses, the idea of a global goal being scientifically defensible, and at the same time accessible to understanding by policymakers who are not trained in Earth system science. The author do not seem to know, or understand, the array of work underway in this area and how it integrates into our system-wide understanding of the response of the Earth to greenhouse gas forcing.

Targets must also be set in terms of the many individual gases emitted by human activities and policies to mitigate those emissions.

The basic issue of climate policy is at what level to set reductions of emissions of greenhouse gases? This cannot be done in any reasonable sense without some concept of a global goal, be it temperature, CO_2 concentrations, radiative forcing or some other metric. The question of how to achieve climate policy objectives, given the existence of many individual sources and gases is non-trivial and does not necessarily lead to the conclusion that all individual gases be individually controlled or regulated. Based on economic efficiency grounds, the policy consensus has tended to favour a "basket of gases" approach where individual gases are weighted according to an agreed metric so that the aggregate outcome is consistent with the "global" goal set for greenhouse gas reductions.

Actionable goals have proved difficult to articulate from the beginning of climate- policy efforts.

Indeed, this is correct at the international level. However, since 2009, the establishment of the 2°C limit has motivated several important developments. The present effort underway to negotiate a comprehensive agreement with legal force applicable to all is an example of the consequence of the 2°C limit at the international level, as is the current process on increasing the level of domestic action and ambition prior to 2020 to close the emissions gap between where emissions are headed, and where they need to be for 2°C consistency.

The 1992 United Nations Framework Convention on Climate Change (UNFCCC) expressed the aim as preventing "dangerous anthropogenic interference in the climate system". Efforts to clarify the meaning of 'dangerous' here have proved fruitless because science offers many different answers depending on which part of the climate system is under scrutiny, and each country has a different perspective.

Clearly, efforts to define the meaning of "dangerous" in terms of the ultimate objective of the Climate Change Convention, have not proved "fruitless", as the 2°C limit was indeed adopted, and support recently restated at the 2014 UN Climate Summit in New York. More importantly, perhaps, is the fact that science cannot give an answer to this question: science can inform policy and political debates about what is "dangerous." Political leaders have clearly made a judgment based on scientific developments and IPCC assessment report, that the 2°C global warming limit is appropriate, but have also agreed to review this limit amidst concerns that it may not be strong enough.

The 2009 and 2010 UNFCCC Conference of the Parties meetings, in Copenhagen and Cancun respectively, reframed the policy goal in more concrete terms: average global temperature. There was little scientific basis for the 2 °C figure that was adopted, but it offered a simple focal point and was familiar from earlier discussions, including those by the IPCC, EU and Group of 8 (G8) industrial countries. At the time, the 2 °C goal sounded bold and perhaps feasible.

It is conceptually wrong, and a misconception, to argue that there was "little scientific basis" for the adoption of the global goal. The scientific basis for 2°C, available to leaders and policymakers, was the IPCC Fourth Assessment report, as well as national assessments and other scientific works that governments wished to take into account. The IPCC's AR4 assessment showed a wide range of impacts, risks and vulnerabilities at

2°C warming, and higher. The richness and diversity of this assessment clearly provided governments with a basis for serious concern about the consequences of warming exceeding something approaching 2°C. Consequently, adopting the 2°C limit was far from simple, as governments worried about the longer term emission consequences. Nevertheless, ultimately leaders accepted that the goal was an essential step in the global policy discussion about how far and how fast emission reductions needed to be made.

Since then, two nasty political problems have emerged. First, the goal is effectively unachievable. Owing to continued failures to mitigate emissions globally, rising emissions are on track to blow through this limit eventually. To be sure, models show that it is just possible to make deep planet-wide cuts in emissions to meet the goal. But those simulations make heroic assumptions — such as almost immediate global cooperation and widespread availability of technologies such as bioenergy carbon capture and storage methods that do not exist even in scale demonstration.

In claiming that the 2°C global warming call is effectively unachievable, the authors are making a political judgement claim. No one contests that present policies put in the world on a pathway towards a global mean warming of 3.7°C or higher,[12] nor that it will be difficult, politically, to reverse this trend. However, the IPCC Working Group III reported just recently in its AR5 that it is technically feasible to keep warming below 2°C, with a likely probability, while the average global macro-economic costs of this century are modest compared to expected economic growth.[13]

In particular, to achieve this, the IPCC found that large-scale global changes in the energy supply sector are possible and needed, reducing CO_2 emissions by 90% or more

[12] See e.g. http://climateactiontracker.org/publications/briefing/152/Warsaw-unpacked-A-race-to-the-bottom.html, while IPCC Working Group III in its contribution to AR5 estimated that "Baseline scenarios, those without additional mitigation, result in global mean surface temperature increases in 2100 from 3.7 °C to 4.8 °C compared to pre-industrial levels" (IPCC AR5 WGIII SPM).

[13] Working Group III notes that a broad class of energy-economic scenarios in the literature keeps warming below 2°C with a likely (>66%) chance. The technical aspects of those were carefully identified and include e.g. "more rapid improvements of energy efficiency, a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050". Economic feasibility has been assessed as e.g. "annualized [global] reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the [21st] century relative to annualized consumption growth in the baseline that is between 1.6 % and 3 % per year" (IPCC AR5 WGIII SPM).

below 2010 levels between 2014 and 2070. Such changes are indeed feasible, and will ultimately involve deployment of technologies not at all common today.

Perhaps a better approach by the authors here would have been to rely upon the IPCC assessment itself and call for a ramping up of political ambition and action, as the IPCC also notes that "delaying mitigation efforts beyond those in place today through 2030 is estimated to substantially increase the difficulty of the transition to low longer-term emissions levels and narrow the range of options consistent with maintaining temperature change below 2 °C relative to pre-industrial levels."[14]

Because it sounds firm and concerns future warming, the 2 °C target has allowed politicians to pretend that they are organizing for action when, in fact, most have done little.

There is little evidence to support this contention, and much to indicate the contrary. The 2°C limit has indeed provided to be a strong motivation for governments, and has provided a metric to judge whether or not their proposed actions are consistent with climate policy goals. The fact that many have done little, or even gone backwards, does in no way undermine the efficacy of the 2°C limit but points to larger problems of the influence of the fossil-fuel industry and incumbents in sectors affected by greenhouse gas policy. The latter problems have been well studied in the scientific literature.

Pretending that they are chasing this unattainable goal has also allowed governments to ignore the need for massive adaptation to climate change.

This is a spurious argument and without any serious evidential basis. Many governments are addressing adaptation needs and evaluating future options, but, mainly in the period

[14] IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

before the 2050s -in other words essentially below 2°C anyway. There are relatively few cases where governments are looking beyond this timeframe at higher levels of warming. Very few in the expert community believe that sufficient resources are available for adaptation, however this has little, if anything, to do with the 2°C limit. What is more interesting is that more and more governments are becoming aware of the very high adaptation burden that will exist even if warming is limited below 2°C.

Second, the 2 °C goal is impractical. It is related only probabilistically to emissions and policies, so it does not tell particular governments and people what to do.

There is a serious logical mistake in this statement, mixing probabilities with uncertainties. It is clear that the laws of physics relate emission levels to global mean temperature change. Uncertainties in this context arise from complex feedbacks in the earth system and to account for such uncertainties, probabilistic statements are made. However, uncertainty is an inherent feature of the climate system and will thus also affect all other indices suggested by the author. All consequences of rising emission levels are subject to uncertainty until they materialize.

There is no way to go from a global goal of any kind to policies that in a deterministic sense "tell particular governments and people what to do." There will always be a significant level of uncertainty in this, quite apart from the policy judgements needed to determine does what and when. Policy judgements relating to relative levels of action and responsibility will need to be made, whatever global call is or is not applied.

The authors appear to have overlooked the well-developed quantitative scientific literature, and available methodologies, to take account of scientific uncertainties and produce rigorous and bounded estimates of emission pathways corresponding to global goals. These methodologies have been deployed now over several years to evaluate present greenhouse gas emission trends and policies against emissions pathways, at different time periods, consistent with global warming goals. Apart from the primary literature, these methodologies and the results were also reviewed in the recent IPCC AR5 Working Group 3 report.

In other areas of international politics, goals have had a big effect when they have been translated into concrete, achievable actions. For example, the eight Millennium Development Goals (MDGs) adopted by the United Nations in 2000 were effective when turned into 21 targets and 60 detailed indicators — measurable, practical and connected to what governments, non-governmental and aid organizations and others could do.

It is indeed that the adoption of the eight Millennium Development Goals has been to a large extent a success story (with the notable exception of fighting world hunger and poverty, as well as goals related to environmental sustainability). However, there is no substantial difference between the MDGs and a global temperature limit like 2°C and if political action is insufficient to meet this limit, this is certainly not due to a lack of indicators, but due to a lack of political ambition.

The scientific basis for the 2 °C goal is tenuous. The planet's average temperature has barely risen in the past 16 years (see 'Heat exchange').

Linking the scientific basis for the 2°C limit to observations of the Earth's average temperature reflects some serious misunderstandings about the nature of this long-term temperature limit, as well as impacts of natural variability and observed climate variables as discussed above.

It is also important to realise, in the context of the criticisms raised by the authors of the scientific basis for the 2°C limit, that the scientific antecedents for these limits extend back to the very beginning of organised global scientific assessments of this problem - and have remained remarkably stable over quarter of a century. In 1989, the United Nations Environment Programme Advisory Group on Greenhouse Gases (AGGG) reported that a 2ºC increase was determined to be "an upper limit beyond which the risks of grave damage to ecosystems, and of non-linear responses, are expected to increase rapidly."

But other measures show that radiative forcing — the amount by which accumulating greenhouse gases in the atmosphere are perturbing the planet's energy balance — is accelerating. The Arctic, for example, has been warming rapidly. High-latitude climates are more sensitive than the planet as a whole. Amplifications in the Arctic might be causing extreme weather in middle latitudes. How could human stresses on the climate be rising faster even as global surface temperatures stay flat? The answer almost certainly lies in the oceans. The oceans are taking up 93% of the extra energy being added to the climate system, which is stoking sea-level rise and other climate impacts.

Much of this is correct, however it has little or no relevance or linkage to the 2°C limit. It is clear that the slowdown in the rate of surface temperature global warming is largely the effect of natural variability in the climate system. As is (at least in parts) the increased Arctic warming trend over the last decade. While Arctic amplification is a robust phenomenon in observations as well as projections, it is also subject to natural variability that has to do with the complex interplay of ocean and atmosphere in this region. The Early-Twentieth-Century-Warming in the Arctic is an example here.

The existence of natural variability, particularly at regional level, is an argument in favour of a global temperature goal. A global temperature goal is an aggregated measure and consequently less volatile than regional metrics.

A single index of climate-change risk would be wonderful. Such a thing, however, cannot exist. Instead, a set of indicators is needed to gauge the varied stresses that humans are placing on the climate system and their possible impacts. Doctors call their basket of health indices vital signs. The same approach is needed for the climate.

Again, the authors are repeating logical mistakes from above. Due to the cumulative nature of CO_2, what is ultimately needed to avoid potentially disastrous climate impacts is a single target that can be translated into a emissions budget. In fact, there's no such thing as multiple climate risk indicators, since they must, regardless what metric is applied, ultimately be transformable in a globally agreeable emissions budget and thus be transformed into a single metric. What indicators to use and what levels of change should be avoided represent a value judgement that can substantially differ between actors, particularly when differences in responsibilities and vulnerabilities are as pronounced as they are for climate change impacts. The adoption of the 2°C limit already represents a substantial step forward towards a global agreement.

The best indicator has been there all along: the concentrations of CO_2 and the other greenhouse gases (or the change in radiative forcing caused by those gases). Such parameters are already well measured through a network of international monitor- ing stations. A global goal for average concentrations in 2030 or 2050 must be agreed on and translated into specific emissions and policy efforts, updated periodically, so that individual governments can see clearly how their actions add up to global outcomes.

Carbon dioxide concentrations could certainly be an interesting indicator, however this is not the only major greenhouse gas and source of radiative forcing that is changing the Earth's climate. Its use would give rise to the same kinds of problems as one has using global mean temperature, to calculate emissions pathways consistent with achieving concentration targets, including some of the same uncertainties involved. One would have to decide on concentration goals at specific time, and how these are related to the other greenhouse gas emissions and radiative forcing agents at those times. A temperature limit, in this sense, is easier to operationalise. In each case - concentration or temperature limits - emission pathways consistent with the achievement of the limit would need to be re-evaluated regularly.

It is correct that there is a network of international monitoring stations for the measurement of, for example, CO_2 concentrations in the atmosphere. However, the authors seem not to appreciate that radiative forcing is not an observed quantity, but a quantity resulting from model-based estimates. As such the alternative "best indicator" suggested by the authors would be a variable that cannot be directly observed.

A more fundamental issue is what concentration is the goal and on what basis? While several statements above discuss issues connected to climate impacts that, at least from the viewpoint of the authors, are not fully reflected in a global mean temperature target, this issue is by no means resolved by adopting a target based on radiative forcing measures. On the contrary, it could be argued that the 2°C global temperature limit reflects an aggregation of the risks from both rising levels of warming, and rising CO_2 concentrations, the latter leading to ocean acidification. Limiting warming below 2°C, implies stabilizing ocean acidification by the mid 21st-century[15].

Some pollutants that perturb the climate, such as methane or soot, have huge regional and local variations, and important uncertainties remain about the link between human emissions and measured concentrations. Policy initiatives are gaining momentum that would improve measurement and control of those warming agents. For example, the Climate and Clean Air Coalition is a group of countries focused on ways to cut emissions of short-lived climate pollutants.

While tracking those agents is a worthwhile and important scientific endeavor, the last IPCC Assessment Report estimates the influence of CO_2 alone currently at around 75% of total anthropogenic forcing. This forcing is very persistent due to the long residence time of CO_2 in the atmosphere.

Policy-makers should also track ocean heat content and high-latitude temperature. Because energy stored in the deep oceans will be released over decades or centuries, ocean heat content is a good proxy for the long-term risk to future generations and planetary-scale ecology. High-latitude temperatures, because they are so sensitive to shifts in climate and they drive many tangible harms, are also useful to include in the planetary vital signs.

The authors appear to misunderstand the physics of the climate system and the role of the deep oceans. The deep oceans are not going to release any heat at least during the

[15] IPCC WGI AR5 SPM Figure SPM.7

next 1,000 years, because they will be absorbing heat whilst slowly catching up with the much greater surface warming.[16]

In addition, there is little qualitative difference between ocean heat content and global mean temperature as a measure in relation to natural variability. While the radiative forcing increases, this will affect the oceanic as well as the atmospheric component. Aggregated indices of atmospheric and oceanic properties will thus to some extent mirror the effects of natural variability on both systems. Thus, no added value of oceanic heat uptake instead of global mean temperature is apparent (two sides of the same coin) with the notable difference that ocean heat uptake is harder to communicate (e.g. people don't live in the oceans) and global mean temperature is easier to relate to observed changes on the surface of the earth.

In terms of a profound metric providing an indicator of risk to planetary ecosystems, ocean acidification, which is not mentioned by the authors, provides a much more important indicator. Reducing ocean acidification to limits that would e.g. ensure survival of most tropical coral reefs, would likely require faster CO_2 emission reductions than are required to hold warming below 2°C.[17]

What is ultimately needed is a volatility index that measures the evolving risk from extreme events — so that global vital signs can be coupled to local information on what people care most about. A good start would be to track the total area during the year in which conditions stray by three standard deviations from the local and seasonal mean.

Whilst many of these measures/metrics are indeed being observed and reported, and quite apart from whether three or four standard deviations is the best indicator of risk, the major issue here is what relevance does this have for the 2°C limit?

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[16] Solomon, S., Plattner, G.-K., Knutti, R. & Friedlingstein, P. Irreversible climate change due to carbon dioxide emissions. *Proc. Natl. Acad. Sci. U. S. A.* **106,** 1704–9 (2009).

[17] Frieler, K. *et al.* Limiting global warming to 2 °C is unlikely to save most coral reefs. *Nat. Clim. Chang.* **3,** 165–170 (2012).

Given that the purpose of 2°C limit is to attempt to avoid undesirable and very damaging changes, and given the nature of the climate system, the utility of these observational metrics would have to be in relation to whether or not the 2°C limit is sufficient or not. For example, what does the early emergence of three sigma heatwave events, as has happened in recent years in Europe, the United States and Russia tell us about climate policy and the 2°C limit? One cannot seriously answer this without looking at the projected changes in the future. Having done that, one is still left with the basic political decision as to whether the widespread emergence of three-sigma heat extreme events by the time that the Earth has warmed to 1.5 to 2°C above preindustrial is "dangerous".

Consequently, a volatility index cannot be used to replace a long-term global goal, unless the purpose is just to document carefully and methodically the rapid and wide spread exceedance of historical extremes, and the arrival of dangerous episodes of extreme climatic changes.

The window of opportunity for improving goal-setting is open.

What is more fundamentally important, is that the window for taking sufficient action to limit warming below 2°C is rapidly closing. There will always be room to discuss goals, but re-opening this issue at this stage would be a recipe (no doubt welcomed by some Governments) for simply deferring action on greenhouse gas emissions until a later time by launching into a years-long discussion on measurements.

This autumn, a big push on climate policy begins — with the aim of crafting a new global agreement by late 2015 at the UNFCCC's Conference of the Parties in Paris.

Getting serious about climate change requires wrangling about the cost of emissions goals, sharing the burdens and drawing up international funding mechanisms. But diplomats must move beyond the 2 °C goal. Scientists must help them to understand why, and what should replace it.

Getting serious and agreeing on emission goals, economic costs and funding fundamentally means having an understanding about the scale of the mitigation task the confronting the planet. The proposal for considering multiple metrics made in this commentary does not advance this cause, and certainly not on the Paris 2015 timeframe. The 2 °C limit already provides strong guidance on the required level of mitigation action globally and regionally, and recent scientific assessments place bounds on economic costs and technological changes required to achieve this.

Recent research on multiple climate targets achieved simultaneously may not provide the results that the authors wish to see: a relaxation of the present pressure on short-term emission reductions to meet pathways required to limit warming below 2°C. Simultaneously meeting multiple climate goals: global mean warming, sea level-rise due to thermal expansion, ocean acidification in different regions, changes in the net primary production of the terrestrial biosphere and loss of carbon from cropland soils indicates that emission reductions (and hence budgets) would be smaller than in the 2°C limit case.[18] This means that the emission reduction would need to be more rapid than presently assessed.

New indicators will not be ready for the Paris meeting, but a path for designing them should be agreed there.

It is unclear whether the authors mean that the Paris meeting should defer emission reduction commitments until the issue of indicators is resolved. Because this is the risk.

Such a clear international mandate would spur research on indicators of planetary health, just as the United Nations' Millennium Summit on extreme poverty gave political momentum to the MDGs. The Paris agreement should call for an international technical

[18] Steinacher, M., Joos, F. & Stocker, T.F., 2013. Allowable carbon emissions lowered by multiple climate targets. *Nature*, 499(7457), pp.197–201..

conference on how to turn today's research measurements into tomorrow's planetary vital signs.

There is no need to burden the Paris meeting with this issue, which could adequately be dealt through scientific research coordination entities. In addition, there's already quite some vital discussion about going beyond a global temperature limit alone. However, these discussions about "planetary vital signs" by no means aim to replace a global temperature limit, but rather extend it to other vital functions of planet earth as it is done e.g. in the planetary boundary approach[19].

The public needs to understand what it is being asked to pay for. On this score, 'CO_2 concentration' or 'ocean heat content' are not nearly effective as 'temperature' in conveying to the person in the street what is at risk. Yet patients have come to understand that doc- tors must track many vital signs — blood pressure, heart rate and body mass index — to prevent illness and inform care. A similar strategy is now needed for the planet.

A doctor examining planet earth would very likely diagnose a variety of serious threats. Not all of them are solely climate-related and some are global biodiversity loss, land-use change and changes in the nitrogen-cycle that pose serious risks by themselves. Broadening the perspective to several indicators tracking vital signs of planet earth is certainly a key challenge that is addressed by the scientific community under the planetary boundaries framework.

However, this does by no means undermine the validity of the 2°C limit, in fact the opposite is the case. The approaches put forward by the authors fall short of addressing the multi-faceted questions of a "safe and just operating space" for humanity by only focusing their debate on replacing a single indicator for reasons that remain unclear even after careful examination of the article.

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[19] Rockstrom, J. *et al.* A safe operating space for humanity. *Nature* **461,** 472–475 (2009).

As in medicine, there are several indicators addressing different aspects of the vitality of the planet, but each of them would call for action if it reached a critical state. No doctor would refuse to provide treatment to a patient with a body temperature exceeding 40°C because his blood pressure might be close to normal or cannot be measured.

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