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Tragic triumph

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The publication of the 100th volume of *Climatic Change*—the world's leading policy-relevant inter-disciplinary journal dedicated to the grand theme of anthropogenic global warming—is certainly an excellent occasion for taking stock and taking stance: What has been achieved by the pertinent research community over the 30 years since this communication vessel was launched? What topical challenges need to be tackled and met over the next two or three decades? How can such a journal develop itself for even better advancing the scientific, political, and public understanding of climate change? The people running *Climatic Change* came up with the intriguing idea to have these questions answered by "Anniversary Essays" from all members of the Editorial Board.

When I was invited to contribute back in September 2009 (and happily accepted to do so), I perceived this project as an entertaining, nice-to-have activity, promising to generate a lot of intellectual fun. Yet the dismal COP 15, which took place in Copenhagen in December 2009 and which I attended as a member of the German delegation, has radically transformed that perception of mine: the Copenhagen conference revealed—by assembling crucial, yet scattered and disparate information from various parts of the climate-change universe in a cognitive caustic—the true state of affairs in (1) the relationship between global society and global science, and (2) the (fictive) dialogue between the present and the future (generations). So COP 15 was more than a reality check, this was rather a reality shock.

In the following I will therefore inspect several conspicuous components of the "Copenhagen caustic", notably those that should have an impact on the evolution of *Climatic Change* beyond the anniversary celebrations. And beyond the readership of this journal, there is the climate change science community that has to draw the right conclusions from the recent developments culminating in the Copenhagen

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quasi-disaster. As things stand now, our intellectual enterprise heads towards a *tragic triumph*, as I will try to explain below along three lines of reasoning.

1 The distant goal

As a matter of fact, Copenhagen could have brought about an untainted triumph for science—or rather for an enlightened, rationality-based approach to the management of an eminent global challenge. The notorious "Copenhagen Accord"(CA; UNFCCC 2009), the only tangible result of COP 15, recognizes (although in a muddled and prudish way) the 2°C-guardrail for averting dangerous climate change (Schellnhuber et al. 2006). This means that a most complex body of scientific evidence provides—for the first time ever—the guidelines for political decision-making at a geo-strategic level. Is this the beginning of the age of science-based global governance?

Before I try to answer this seemingly naïve question, let me very briefly review a specific involvement of *Climatic Change* (and myself) in the emergence of the 2°C-target: The First Conference of the Parties (COP 1) to the UN Framework Convention on Climate Change (UNFCCC) took place in Berlin from 28 March to 7 April 1995. At that time, Angela Merkel (now the German Chancellor, i.e., chief of government) was Minister for the Environment and I was Deputy Chair of the German Advisory Council on Global Change (WBGU), a top-level scientific committee supporting "policy making" through scientific advice on all matters of planetary sustainability. As the COP 1 was drawing near, the WBGU focused on the operationalization of the UNFCCC's ultimate goal—to avoid "dangerous anthropogenic interference with the climate system"—and came up with the so-called Tolerable Windows Approach (TWA; Zimmermann et al. 1995, 1996). This was an inverse scheme for climate protection based, inter alia, on some of my ideas which I had developed in applying principles and methods from complex-systems theory to global environmental management (for an overview, see Schellnhuber and Wenzel 1998). The WBGU basically recommended confining anthropogenic global mean temperature (GMT) rise above pre-industrial levels to less than 2°C and the rate of GMT change to less than 0.2°C per decade. These "guardrails" were derived from a combination of arguments, such as the bounded natural variability of GMT during the development of *Homo sapiens* and our civilization, or the estimated averages of migration/recombination/adaptation velocities of crucial ecosystems. The concrete operational intention was to start from the tolerable window in climate phase space and to calculate backwards the admissible global greenhouse gas emissions profiles. It turned out that such an approach requires quite sophisticated mathematical techniques from nonlinear control theory (such as differential inclusions), which were discussed, along with the general concept, in a *Climatic Change* paper in 1999 (Petschel-Held et al. 1999). So it took a rather long time to document the idea in a water-proof way, but we felt it was worthwhile since our approach appeared to be the only genuine alternative to the then-fashionable cost–benefit-analysis of climate protection policies (see, e.g., Nordhaus 1992). Also, we were convinced that the TWA reflects the true objectives of the UNFCCC much better then the overstretched "economistic" schemes. It seems that Steve Schneider, the journal editor, immediately realized the potential of the inverse approach and set up a swift, although challenging, review process for that "outlier" paper, which finally made it to the press.

In the meantime, the TWA was sinking—slowly, yet steadily—into the body of climate policy. I recall a meeting with Angela Merkel in early 1995, when we had a chance to explain to her both the rationale and the technicalities of the inverse scheme in some detail—facilitated by the fact that Ms Merkel holds a Ph.D. in Theoretical Physics. In 1996, the Council of the European Union (CEC) adopted the 2°C-target, which was re-affirmed in a CEC meeting in 2004 and eventually became the vanishing point for world-wide deliberations on global emissions reductions measures. (The reader might be interested to peruse the highly critical and quite knowledgeable (although, in my view, not entirely valid) discussion of this subject by Tol (2007). Let me make three comments on the science-policy relationship in this context:

First, the 2°C-guardrail is a *political* objective. It is informed and motivated by a rich, diverse and not completely unambiguous collection of scientific data and insights (see, e.g., EU Climate Change Expert Group 2008), relies on a set of ethical and operational principles (like the precautionary one), and reflects a strategic compromise between desirability and feasibility.

Second, because of the overwhelming complexity of the climate-change problem, neither a credible and comprehensive cost-benefit-analysis is possible nor the identification of a sharp red line that separates global climate comfort from global climate disaster. The 2°C-target has to be perceived like a speed limit within cities, where a trade-off between mobility and safety is a sheer necessity. In the speed-limit context, it is crucial that all actors on the road are instructed (and occasionally "reminded") of that social choice of a threshold. In the global-warming context, it is crucial to set and to comply with the guardrail, since such an attempt to *design* the climate future also allows the global community to anticipate the long-term adaptation challenges. It makes a huge difference whether to cope with a warming by two or by four degrees.

Third, although TWA does not explicitly appear in the climate protection policy documents, its core logics have been implicitly adopted: an adequate strategy for "avoiding" dangerous climate change must depart from considering what potential impacts of anthropogenic global warming are deleterious or even entirely unacceptable for humankind. And planetary mean temperature rise appears to be the only integrated yardstick available for gauging those impacts in a structured way.

Undoubtedly, my comments just cover a minute subset of what could be said about the genesis, intricacies, virtues and deficiencies of the 2°C-target, but I would like to return now to the question what its recognition by the CA really means. In its most recent report published well before Copenhagen (WBGU 2009), the WBGU has calculated global and national decarbonization trajectories consistent with a decent chance ($\geq$50% probability) to hold the 2°C-line. This "budget approach" is based on the latest climate-systems science (Allen et al. 2009; Matthews et al. 2009; Meinshausen et al. 2009; Zickfeld et al. 2009) which confirms that worldwide *cumulative* CO_2 emissions over a long period of time (typically between today and 2050 resp. 2100) are the dominant factor determining GMT response. The most important finding is summarized in Fig. 1, displaying various global CO_2 emissions

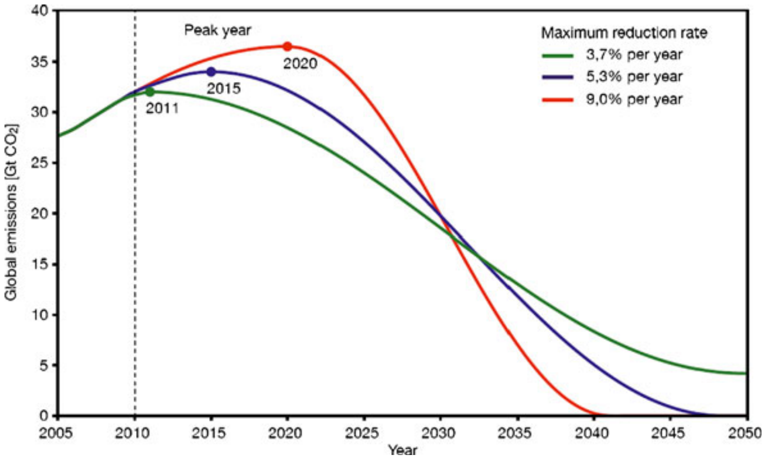

Fig. 1 Examples of global emission pathways for the period 2010–2050 with cumulative global CO_2 emissions capped at 750 Gt during this period. At this level, there is a two-in-three probability of achieving compliance with the 2°C-guardrail. The figure shows variants of a global emissions trend with different peak years: 2011 (*green*), 2015 (*blue*) and 2020 (*red*). In order to achieve compliance with these curves, annual reduction rates of at maximum 3.7% (*green*), 5.3% (*blue*) and 9.0% (*red*), respectively, would be required. Source: WBGU (2009)

profiles that generate a two-in-three chance to respect the 2°C-guardrail. The chart highlights the critical importance of an early peak year in order to spare us unfeasible emissions-reduction rates (up to 9% p. a. if culmination is not achieved before 2020) in the decarbonization period afterwards.

Figure 1 provides an unequivocal litmus test for every global climate protection strategy which deserves this name. Unfortunately, the COP 15 failed that test and thus rather epitomizes real decision-making in the "knowledge-infested" societies of the twenty-first century: do not argue with the scientific mainstream (at least not in public), but ignore its recommendations when it comes to practical purposes. In fact, the CA comes with an appended subscription sheet where all nations are supposed to enter their voluntary mitigation efforts by 31 January 2010 according to an undisguised pledge-and-review scheme. A preliminary analysis of the national offers made so far reveals that our planet is heading for a medium anthropogenic warming of 3.5°C (Climate Action Tracker 2010). The "G2" bears a crucial responsibility for this high-risk development, since the US emissions will probably not peak before 2020, while the Chinese emissions may even grow until around 2050 as a consequence of the country's conventional cost-benefit approach to climate protection measures (as presented at COP 15 side events).

So there is a huge hiatus between the recognized science-based aspirations and the expected/accepted politics-driven outcome: the 2°C-guardrail appears as a goal in nowhere land, at least for the time being. The COP 15 venue prompts me to the following metaphorical conclusion: According to the "Copenhagen Interpretation" of quantum mechanics as championed by Nils Bohr, a mixed-state wave function will only reveal its value with respect to a specific "observable" (position, momentum, spin etc.) if forced to do so by an appropriate (anthropogenic) experiment (see, e.g., Merzbacher 1970). The Copenhagen conference can be likened to such an experiment in the macro-world of "realpolitik", which tested the true worldwide mitigation commitments and made the climate protection wave function collapse unto its "ground state", representing the lowest-ambition eigenvalue. In my view, a quantum leap to an excited state (i.e., a level of ambition compatible with the 2°C-target) could still happen if a fair and feasible vision for a global climate regime (perhaps along the lines of the WGBU budget approach (WBGU 2009)) would be introduced and pursued in the multilateral debate.

As far as I can see, however, there is no powerful political "laser" which could stimulate that quantum leap. So the climate problem may become the precedent for global inaction in spite of compelling global evidence for action. Are we entering an era of planetary cognitive dissonance instead of planetary enlightenment?

2 Earth roulette

The other day, I talked about anthropogenic climate change to an engineer who is board member of a world-leading technology company. Trained in control theory, he was particularly interested in stability aspects as determined by feedbacks, memory effects, and hysteresis loops in the Earth system. This business man was deeply impressed by the complexity of the subject, worried about our persisting scientific ignorance of many nonlinear processes in the planetary machinery, and truly terrified by my assertion that the most aggressive global emissions reduction strategy we can possibly get will ensure only a three-in-four chance to hold the 2°C-line. For him, it would be unthinkable to construct a bridge, let alone a nuclear-power station, based on failure odds worse than those faced by Russian roulette players. See, it's not a bridge, it's only our planet, I sighed…

Yet apart from the obvious risks of missing the 2°C-target by inadequate political action there are also the less evident, but significant, risks for nature and society in an up-to-two-degrees-warmer world: In 2000, the WGII Synthesis Chapter team (co-chaired by me) of IPCC-TAR invented a semi-quantitative way of indicating "dangerous" impacts of climate change: the reasons-for-concern chart, now widely known as the "burning-embers diagram" (Smith et al. 2001; Schneider 2009). An update of that chart in the peer-reviewed literature (Smith et al. 2009) summarizes two major conclusions from the bulk of more recent impacts studies, namely (1) that the risks tend to slip down the GMT scale quickly with the advancement of the pertinent science, and (2) that fairly disastrous effects are likely to kick in already below the 2°C-line, especially in the marine biosphere (see the comparison in Fig. 2).

To make things worse, the really strategic concerns, i.e., the "large-scale discontinuities" sitting in the fifth column of the charts, are shrouded in the biggest scientific uncertainties. In particular, state-of-the-art analyses are largely unable to constrain the activation temperatures of the so-called tipping elements in the Earth system (Lenton et al. 2008) in a satisfactory manner. Similar uncertainties prevail for the relevant positive (CO_2, see e.g. Frank et al. 2010, and CH_4, see e.g. Bloom et al. 2010), and possibly negative (stratospheric H_2O, see e.g. Solomon et al. 2010) feedbacks, let alone the potential interactions between all these nonlinearities. In fact, the co-dynamics of reasonably investigated and still under-researched systems components

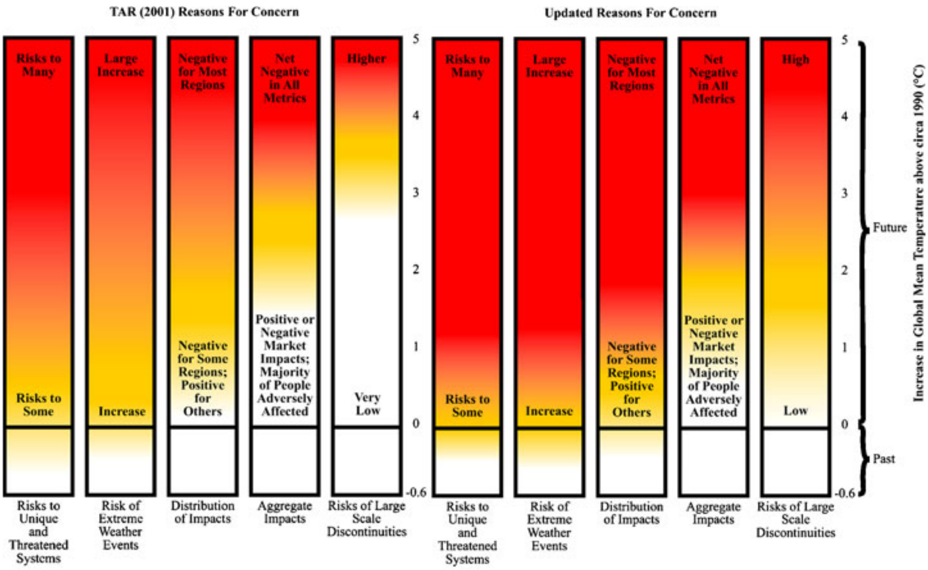

Fig. 2 Evolution of the burning-embers diagram. *Left* IPCC TAR version (Smith et al. 2001). *Right* PNAS version (Smith et al. 2009)

(like certain marine biogeochemical processes) could be much more sensitive to anthropogenic interference than we usually think. Quite recently, some light has been shed on this overwhelmingly important issue by Schneider and Schneider (2010) through the Pliocene lens (see also Pagani et al. 2010 and Lunt et al. 2010). Therefore, it seems that the scientific elephant in the global warming room cannot be ignored forever: are there realistic scenarios for anthropogenic interference with our planet that could trigger "runaway effects", i.e., self-amplifying Earth-system responses of at least episodic character? Such an episode would be characterized by the rapid transition of the total system through a "forbidden temperature range" where energy gain (determined by positive feedbacks such as the release of organic carbon from multiple sources) overwhelms energy loss (driven by the Stefan-Boltzmann radiative damping and negative feedbacks). A caricature of this idea *in statu nascendi* is given in Fig. 3.

Speculations about the existence of self-accelerating global warming dynamics are usually shrugged off as "unscientific". The growing external pressures on the climate-change research community in the wake of recent incidents like the illegal dissemination of CRU-emails and the IPCC Himalayan glaciers blunder will certainly not push projects in that direction: taking shelter in the mainstream is an instinctive reaction of individuals under such circumstances. However, it is not just a matter of intellectual civil courage but also our responsibility as a scientific community to research those distant and muddy waters where presently unthinkable risks might—or may not—lurk. I think that *Climatic Change* should provide a conspicuous forum for such a venture, which is more relevant, in my view, than the current "geo-engineering" debate.

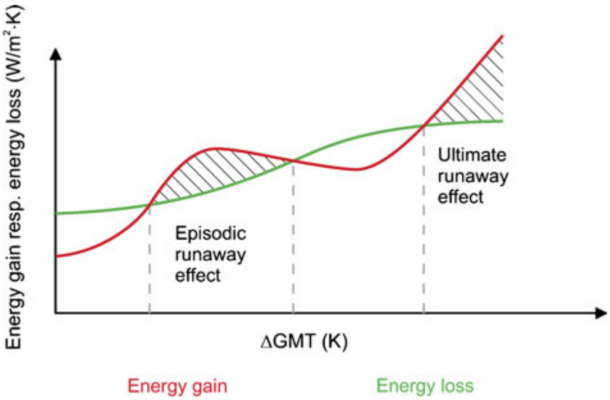

Fig. 3 Conceptual sketch of an "episodic" runaway greenhouse effect. As humanity pushes the system towards higher global mean temperatures (GMT) energy gain (*red*), determined by positive feedbacks, may exceed energy loss (*green*), driven by the Stefan-Boltzmann radiative damping and negative feedbacks, for a limited temperature range. The resulting self-amplification may cause a rapid "jump" towards the upper bound of the temperature range, at which energy loss once again outbalances energy gain. Source: after Levermann and Schneider von Deimling (pers. communication)

3 Being right and relevant

Pascal's wager on the existence of God (Jordan 1994) has been discussed many times in the climatic-change context: if anthropogenic global warming comes with a non-zero probability for truly devastating impacts on nature and society ("hell"), then it is worth while to protect the climate system ("believing"). We will hardly ever learn whether Blaise Pascal (1623–1662) actually made the right bet and received the well-deserved award ("paradise"), but we can use the analogy as a starting point for an extremely simplified, yet revealing reflection on humankind's climate wager in the twenty-first century.

Let us, however, not focus on the bet's pay-off matrix, which would involve the (ill-constrained) costs and benefits of worldwide climate protection measures, but rather on a joint-probability matrix for the following two assertions:

A_1 Unabated global warming will generate dangerous, if not disastrous, impacts
A_2 Humankind will respond, with appropriate mitigation and adaptation measures, to the challenge as sketched by science

If we assign plausible subjective probabilities to both assertions (in recognition of the tolerably high state of the research art and our less brilliant understanding of the political world), namely

p_1 $(A_1 \text{ is correct}) = 0.9$,
p_2 $(A_2 \text{ is correct}) = 0.1$,

and assume, in a first-order approximation, that these are independent probabilities, then we end up with the likelihood structure for all combined statements displayed in Table 1.

Table 1 Joint-probability matrix for the global warming predictor–corrector problem

		A_2 Correct	A_2 Incorrect
A_1	Correct	$p \equiv p_1 \cdot p_2 = 0.9 \cdot 0.1 = 0.09$	$0.9 \cdot 0.9 = 0.81$
	Incorrect	$0.1 \cdot 0.1 = 0.01$	$0.1 \cdot 0.9 = 0.09$

Evidently, there are two possible negative and two possible positive outcomes within this simplified climate-change world, yet their respective probabilities differ hugely.

3.1 Scenario 1: disgrace

Let us start with the least probable ($p = 0.01$) constellation, i.e., that climate-change science grossly exaggerates the risks of anthropogenic global warming, yet manages to fool humankind into strenuous and costly mitigation measures. Being *wrong and relevant* would be a truly embarrassing outcome for our research community. On the other hand, strong mitigation action may prove to be a no-regret option anyway since the global industrial metabolism cannot be sustained with fossil fuels forever. So this end of the story would be devastating for science, yet good for the world - by instigating accelerated decarbonization under benign and stable climatic conditions.

3.2 Scenario 2: tragedy

The opposite scenario, where science is *right and irrelevant*, is by far the most likely ($p = 0.81$). In this case, the political world insists on ignoring the scientific wake-up calls and therefore has to cope with the anthropogenic disruption of the Holocene mode of planetary operation. Climate-change research could hardly rejoice such an outcome that might serve as the plot for a Greek tragedy: being vindicated by disaster of unprecedented dimensions is something nobody should desire. Cassandras cannot win by construction.

3.3 Scenario 3: farce

A fairly improbable outcome of our climate-change game ($p = 0.09$) is the quite ridiculous multiplication of failures for co-generating a happy ending: science is *wrong and irrelevant*, as decision makers do not heed the unwarranted claims about dangerous anthropogenic global warming and neither invest in substantial mitigation measures nor longer-term adaptation activities. At second glance, such a scenario looks less amusing since it would (1) shatter the public confidence in the scientific system altogether, and (2) demonstrate the inadequacy of the contemporary multilateral political system—what if a true global crisis eventually emerges and needs effective management?

3.4 Scenario 4: glory

A comparatively unlikely (yet not impossible) outcome ($p = 0.09$) is that climate-change science turns out to be *right and relevant*, convincing societies around the world of the correct insights that rapid decarbonization is necessary and also feasible.

In such a scenario, the scientific system would trigger the global transition towards sustainability (Potsdam Memorandum 2007), averting the dangerous, unmanageable consequences of climate change.

Although the majority of authors/readers of *Climatic Change* probably favor scenario 4 over all the others, it comes with pitfalls and could even set the stage for triumphs as tragic as the one sketched by scenario 2. Two different types of tragedy are conceivable. First, once mitigation measures will have taken their effect, the scientific community might be retrospectively accused of alarmism and gloomy exaggeration. In fact, it may quickly slip from the public memory that the worst outcomes could only be forestalled because of rigorous warnings of the scientific community in the first place. Second, if the glorious role of science was acknowledged, the scientific system could - not less tragically - establish itself as a quasi-political super-power for the twenty-first century. I personally feel that a "new contract between science and society" (Jasanoff 2005; Potsdam Memorandum 2007) has to be crafted and signed. However, I also think that this should primarily imply stronger and better interactions between science and society according to proper rules, not a clandestine or open merger of those entities which need to be separated.

Take an obvious example: Mining a deep ice-core from Antarctica and scrutinizing it with the most advanced methods from physics, chemistry and biology will hardly benefit from involvement of (or even supervision by) government representatives from, say, Venezuela and Kuwait. I guess that almost all researchers will subscribe to the principle that the politicians should stay out of the proper generation of scientific data and insights. But how about the reverse—shall scientists also stay out of politics? My answer is yes when it comes to the core business of political institutions—establishing laws and regulations, allocating resources, designing strategies, declaring war or peace. This does by no means discharge the scientific community from the obligation to provide the best possible information and advice to the legitimate decision makers and to civil society. In turn, stakeholders should by all means communicate their challenges to the pertinent scientific communities and provide them with the necessary topical and contextual information for identifying valuable response options. In other words, we need *dialogue, not monolithicity*. The latter would inexorably lead to the distortion of truth. So here is another grand topic that *Climatic Change* needs to keep addressing.

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