Tipping the scales

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International climate policy needs to induce a socioeconomic tipping to a low or no-carbon economy if we are to avoid climate change tipping points.

The Intergovernmental Panel on Climate Change (IPCC) in its many excellent reports tends to portray climate change as a smooth transition. Although the projections are rarely straight lines, the underlying systems and their responses appear to behave continuously, if not linearly (in mathematical terms). There are, of course, exceptions to this, notable ones being the possible collapse of the Atlantic thermohaline circulation or the irreversible melt of the Greenland ice sheet, which both get significant attention in the latest IPCC report[1]. Such highly non-linear transitions, where "a small forcing can make a big difference", have been described as 'tipping points'. For clarity, we have recently introduced the term 'tipping element' to describe those components of the Earth System that are at least sub-continental in scale and can be switched — under particular conditions — into a qualitatively different state by small perturbations[2]. The term 'tipping point' is then used to refer to the critical threshold at which such a transition is triggered. Our formal definition[2] of a tipping element requires that the factors influencing the system can be combined into a single control parameter; there exists a critical value of this control parameter from which a small perturbation leads to a significant change in a crucial feature of the system, and this state change can be observed either instantaneously or after some lag time. Human alteration of the climate system, especially global mean temperature change due to greenhouse-gas emissions, can potentially shift a control parameter up to or past a critical threshold.

TIPPING ELEMENTS

Climate policy should be concerned with what tipping events might be triggered by human activities in the future, and whether one can stay at a safe distance from their associated tipping points. We consider a tipping element to be policy-relevant if; (1) it has a critical threshold that is accessible this century under IPCC climate change scenarios (which span 1.1–6.4 °C of global warming above the present temperature[1]), (2) it would undergo a transition to a qualitatively different state before the next millennium, and (3) the corresponding impacts would affect many (that is, millions of) people. At least eight tipping elements meet these criteria and could be triggered by global warming[2] (see Fig. 1): the Arctic sea ice, Greenland ice sheet, West Antarctic ice sheet, Atlantic thermohaline circulation, El Niño Southern Oscillation, Sahara/Sahel and West African monsoon, Amazon rainforest, and Boreal forest. The Indian summer monsoon also meets the criteria but tipping is encouraged by aerosol emissions and land-use change rather than greenhouse-gas emissions. The list is most likely incomplete. The Arctic ozone layer, Boreal permafrost, marine methane hydrates, and Antarctic bottom water formation are also important candidates, but they each failed to make our shortlist on at least one criterion.

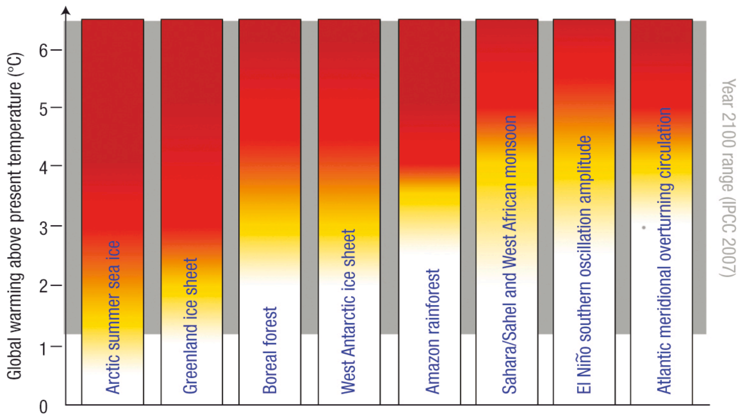

Figure 1 Burning embers. Potential policy-relevant tipping elements that could be triggered by global warming this century, with shading indicating their uncertain thresholds. For each threshold, the transition from white to yellow indicates a lower bound on its proximity, and the transition from yellow to red, an upper bound. The degree of uncertainty is represented by the spread of the colour transition.

Large uncertainty still surrounds the existence of critical thresholds for many of the systems we have identified. For those where a threshold is reasonably well established, there is often scarce information about its proximity (indicated by the 'burning embers' shading in Fig. 1). Hence in some cases their status as 'policy-relevant' is unsettled. However, at the very least, the existence of policy-relevant tipping elements cannot safely be ruled out. Rather, the current understanding of Earth System dynamics based on a rapidly increasing body of evidence about disruptive events in the geological past (like the 'browning' of the Sahara some 5,000 years ago) indicates that the possibility of large-scale tipping events needs to be accounted for in future climate considerations. An important additional dimension of complexity — and concern — arises from the analysis of potential interactions between candidate tipping elements identified so far. From our assessment of the pertinent literature and expert opinions, there are more ‘positive’ causal connections — whereby tipping one element enhances the probability of activating another switch — than ‘negative’ connections, where tipping one element reduces the probability of tipping another.

EARLY WARNING

Given their large-scale impacts and the uncertainty as to exactly where their thresholds lie, an important question is whether we can detect an approaching tipping event well before it actually happens? In principle, a critical threshold can be anticipated, because a system that is approaching a tipping point becomes more and more sluggish in its response to perturbations caused by natural variability[3]. This should become apparent in time-series data. It requires a sufficiently long and highly resolved record to extract the longest imminent timescale, which diverges at the transition point of the system in question. Unfortunately, for the tipping elements on our shortlist, the necessary time-series data are currently lacking. However, by deploying well-designed monitoring systems, building on existing ones — for the Atlantic thermohaline circulation for example — and obtaining improved palaeo-records, a global early-warning system could, and we argue should, be put in place. Such a system would ideally combine advanced monitoring, data analysis and simulation modelling in a fully integrated fashion.

It seems wise to assume that we have not yet identified all potential policy-relevant tipping elements. A systematic search for further candidates should be undertaken. Increased efforts to assemble palaeo-evidence for multiple modes of operation of the Earth System should be complemented by studies that search for tipping elements in comprehensive Earth System models. The rapid development of the Antarctic ozone hole, after all, teaches us many lessons about the surprises that non-linearity can hold in store.

RISK AVERSION

Tipping any of the elements identified so far would represent “dangerous anthropogenic interference with the climate system”[4] carrying high-casualty and high-cost impacts. This, combined with the uncertainty surrounding the existence and location of tipping points, qualitatively changes the context for climate policy making. The problem becomes one of risk management demanding a subtle precautionary approach, where the tipping events to be averted can act as ‘knock-out criteria’ for decision making, that is, climate protection strategies that clearly do not avert the risk of reaching a tipping point can be excluded from policy decisions.

The prospects of large-scale impacts from each tipping event and the amplification of impacts from causal interactions between events provide strong arguments for mitigation, that is, massive reduction of greenhouse-gas emissions. Mitigation action can be seen as taking out an insurance policy against the threat of tipping particular elements. Unfortunately, if our assessment of the literature and expert opinions is correct, present policy targets may not represent sufficient insurance. Even the EU target of restricting global warming to 2 °C above pre-industrial levels (1.2 °C above present) may not avoid the loss of most Arctic summer sea ice, although it could protect the Greenland ice sheet from irreversible melting.

After the extraordinary success of the Stern Review[5] of climate-change economics, there are high expectations about the ability of cost-benefit analysis to guide climate protection strategies. Yet providing useful and credible socioeconomic assessments of policy trajectories involving potential discontinuities is rather challenging. In the global warming context, the difficulties are aggravated by the long-term nature of the problem to be solved, where the question of how to value the well-being of future generations needs to be tackled[6]. Fortunately, some eminent economists are developing a theoretical framework that can handle the non-linear behaviour of abrupt environmental changes[7], such as the jumps associated with the transgression of tipping points. Their analysis suggests that the magnitude of uncertainty about tipping events, the time scales involved in reinstating the pre-tipping state and the spatial extent of the consequences of exceeding a tipping point are crucial in assessing appropriate policy options. However, one sobering conclusion is that there may be no optimum climate policy under certain highly non-linear circumstances.

IGNITING CHANGE

So, what can we do? The best choice is to avoid tipping events at acceptable social costs. This can be achieved by inducing a fast transition to a low/no-carbon economy which will have to materialize eventually anyway with the depletion of the fossil fuel resources. When we say ‘fast’, we envisage a Third Industrial Revolution in the sense of a socioeconomic tipping event. As in the biogeophysical planetary machinery, there should be aggregated control parameters in civilization, which can bring about highly non-linear changes. In fact, many political scientists and economists argue that there is an obvious counterpart to global mean temperature as the prime natural control factor, namely the global carbon price. Macro-economic models demonstrate that the decarbonization of modern societies can be triggered by increasing that price (through an international trading system for auctioned emissions permits, for instance) until a self-amplifying technological and institutional innovation process is ignited[8].

We recommend that the international community take out insurance in the form of strong binding mitigation targets, starting along the lines of Germany’s policy of a 40% reduction in greenhouse-gas emissions from 1990 levels by 2020, continuing to an 80% reduction by 2050, and ultimately reducing emissions to zero. Adaptive capacity should also be increased, in particular for the possibility of sea-level rises at rates considerably in excess of current IPCC projections[1] and of eventual magnitude exceeding 5 m. A planetary early-warning system for tipping elements should be designed and put in place. Finally, assuming early warning can be achieved, the international community should critically evaluate what climate engineering options (if any) it could reasonably deploy, at short notice, to protect certain elements from tipping.

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