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# From the Paris Agreement to the Anthropocene and Planetary Boundaries Framework: an interview with Will Steffen

Will Steffen[a] and Jamie Morgan[b]

[a]School of Environment and Society, Australian National University, Canberra, Australia; [b]School of Economics, Analytics and International Business, Leeds Beckett University, Leeds, UK

**ABSTRACT**
In this wide-ranging interview, the well-known Earth System scientist Professor Will Steffen introduces and discusses the influential planetary boundaries (PB) framework, the potential for a Hothouse Earth pathway and the relevance of the Anthropocene concept. He elaborates on the role of emergence, complexity, feedback and irreversibility and draws attention to updates for the nine PBs.

**KEYWORDS**
Anthropocene; planetary boundaries framework; Earth System science; climate emergency; Hothouse Earth

Will Steffen is Emeritus Professor at the Fenner School of Environment and Society, the Australian National University (ANU), Canberra. Professor Steffen is an Earth System scientist, known for his advocacy, with Paul Crutzen, of the concept of the Anthropocene and for his collaborative work with Johan Rockström, Tim Lenton, Katherine Richardson and many others, which explores the complex interrelations and dependencies of humans with their environment. In 2009 Steffen, Rockström and a team of researchers published a 'planetary boundaries' framework in *Nature* and their work has been widely cited and used (informing, for example, the Rio+20 summits' work on sustainable development). In addition, Steffen has published numerous other papers over the years and was a contributing author or reviewer of five IPCC reports. He has held a series of significant academic and policy advice positions and been the recipient of numerous honours. He is currently honorary professor at Copenhagen University, a senior fellow at the Stockholm Resilience Centre, a Fellow at the Beijer Institute of Ecological Economics, also in Stockholm, former chair of the Australian Government's Antarctic Science Advisory Committee and sits on the advisory committee of the APEC Climate Centre. Following the dissolution of the Australian Climate Commission in 2013 by then Prime Minister Tony Abbott, Steffen and several of his fellow commissioners crowdfunded an independent Climate Council and he remains a Councillor. He is currently working on the ERC 'Earth Resilience in the Anthropocene' project, jointly coordinated at the Stockholm Resilience Centre and the Potsdam Institute for Climate Impact Research. He holds a BSc from the University of Missouri (1970), and an MSc (1972) and PhD (1975) in chemistry, both from the University of Florida, as well as honorary doctorate degrees from Stockholm University and the University of Canberra.[1]

The following interview with Professor Steffen was conducted by Professor Jamie Morgan for *Globalizations*.

**CONTACT** Jamie Morgan j.a.morgan@leedsbeckett.ac.uk

**Jamie Morgan (JM):** After years of increasingly urgent warnings from natural scientists, ecological economists and activists, it is now widely acknowledged that we have entered a period of 'climate emergency' and cumulative ecological breakdown. The Alliance of World Scientists is now actively promoting the concepts and raising awareness and academics, politicians and the public are increasingly familiar with related language and issues, but many are likely less familiar with Earth System science and the role it plays.[2] So, it might be useful to start with a brief explanation of what an Earth System approach is, what you and your colleagues work focusses on and what a 'planetary boundaries' framework entails.

**Will Steffen (WS):** Basically, the 'Earth System' refers to the interacting physical, chemical and biological processes that operate across, and link, the atmosphere, cryosphere (ice), land, ocean and lithosphere. These processes create 'emergent properties' – that is, properties and features of the Earth System as a whole which arise from the interaction amongst these spheres. Global average surface temperature is a good example – it is a property of the Earth System as a whole.

**JM:** Emergence is a concept that is probably most familiar to philosophically inclined readers (via the work of John Stuart Mill, Jaegwon Kim, etc. and most especially issues in philosophy of mind and the nature of consciousness; see O'Conner, 2020). But, clearly, it refers to any type of system in so far as its properties do not reduce to those of its parts in isolation.

**WS:** The human body is a good analogy for the Earth System. Although we are all made of individual parts – bones, skin, muscle, etc. and contain organs that carry out specific functions – heart, lungs, liver, brain, etc. – we are one single, integrated organism with properties at the level of the entire human. Also, we have intangible features like feelings and emotions which arise from complex interactions within our bodies and between our bodies and the external world. So, in that analogy, the Earth System, too, has intangible, emergent properties that characterize the system as a whole.

In fact, the Earth System exists in well-defined states, the most recent of which is the Holocene, an 11,700-year epoch in the Geologic Time Scale. In terms of an Earth System framework, the Holocene refers to a well-defined, stable state of the system, with a stable climate system, well-defined patterns of atmospheric and ocean circulation, and stable distribution of biomes around the planet. It is in this stable Holocene state that humanity has been able to expand and thrive.

**JM:** And the planetary boundaries (PB) framework?

**WS:** The planetary boundaries is a framework designed to assess what is required to maintain the Earth System in a stable Holocene-like state. We defined the state of the Earth System based on nine processes or features – such as climate stability, biosphere integrity, the water cycle, land-cover change and so on.[3] For each process, we have a control variable which measures the level of human perturbation and a response variable that measures the changes in the Earth System as a result of this pressure. Our present estimate is that four of the nine boundaries have been transgressed, including the two key ones of climate stability and biosphere integrity. This assessment is consistent with the scientific evidence showing that the Earth System has already left the Holocene and has entered the Anthropocene, a proposed new epoch in Earth history.[4]

At present, my work is focussed on the development of scenarios of potential future trajectories of the Earth System, based on a synthesis of modelling studies, observations, process studies and palaeo records. The ultimate question is when could the Earth System be pushed onto an irreversible trajectory towards a much hotter state – Hothouse Earth – and how close are we to pushing it onto that trajectory.[5]

**JM:** And as I understand it you have built into your boundary framework a degree of prudential leeway to ensure that the system stays some ('safe') distance from any given tipping point? For example, for the category of 'Climate Change' in terms of Earth System processes, you use 350 parts per million (ppm) by volume atmospheric carbon dioxide concentration as a proposed boundary. In the 2009 *Nature* paper (Rockström et al., 2009) you noted the current level was 387 ppm and the pre-industrial level 280 ppm. The UK Met Office is forecasting a level varying around 417 ppm for 2021–2.29 ppm higher than 2020, 30 ppm higher than your 2009 figure and around 50% higher than the pre-industrial level.[6] Moreover, according to the UK Met Office, the measurements indicate it took around 200 years for the ppm to increase by 25% but just the last 30 for it to approach 50%. So, the direction of travel does not seem to have changed in this case, quite the reverse. Is the same true of all the 'parameters' you use? In the 2009 paper, three of the planetary boundaries had been 'overstepped' …

**WS:** When we first developed the planetary boundaries framework, we agreed that we should apply the precautionary principle. This meant that when we proposed where a boundary might lie, we wanted to make sure that the 'safe operating space', that is, the 'planetary space' where the control variables for all of the boundary processes are indeed below the boundary itself is indeed safe. By 'safe' here, we mean that there is very little risk that the Earth System will move towards less-stable conditions driven by its own internal feedbacks. That is, the Earth System will be stable and remain in Holocene-like conditions.

In the 2015 update of the planetary boundaries framework, we introduced the idea of a 'zone of uncertainty' to account that there are indeed large uncertainties about where the boundary should be placed, given gaps in scientific understanding as well as intrinsic variability in Earth System dynamics. The boundary itself was placed at the lower end of the zone of uncertainty, based on our assessment that we would be safe if the control variable was placed below that level. However, as the name indicates, the zone of uncertainty is an area within which we don't know whether the Earth System will be safe or stable, or whether we may have triggered a tipping point or driven an unacceptable level of change to the particular Earth System process. Beyond the zone of uncertainty, there is a very high risk of large, potentially irreversible and often abrupt changes to Earth System process. That would indeed be dangerous planetary territory. So staying within the boundary itself, and not entering the zone of uncertainty, is what is required to remain within the Earth System's 'safe operating space'.

The climate planetary boundary is a good example of how this system works. We set the boundary at an atmospheric $CO_2$ concentration of 350 ppm. Both observations and model simulations show that such a boundary would cap temperature rise at much less than 1°C, and the Earth System would remain stable at that level. We set the zone of uncertainty at 350–450 ppm $CO_2$. The idea is that the risks of climate impacts and of triggering a trajectory of the Earth System away from Holocene conditions increases as the $CO_2$ concentration rises. Observations bear this out. At over 410 ppm, we are already experiencing increases in the frequency and severity of several damaging extreme weather events – extreme heat, drought, intense rainfall, wildfires, tropical cyclones. In addition, several tipping points in the Earth System that could drive it towards hotter conditions, even without any further human forcing, are becoming active. These include loss of Arctic sea ice, melting of Greenland and West Antarctic ice sheets, drought and fires in the Amazon forest, melting of Siberian permafrost, and slowdown of the Atlantic Ocean circulation.

In general, most of the control variables for the boundaries are moving away from the safe operating space, or, if they were within, are moving closer to the boundary itself. An exception to this trend is atmospheric ozone depletion, where the banning of CFCs had led to a stabilization of ozone levels with a good prospect of increasing ozone concentration over the southern hemisphere polar regions over the coming decades. For all of the other boundaries, however, the control variable is moving in the wrong direction. When the next major update of the PB framework is published, hopefully later in 2021, it is likely that at least six of the nine boundaries will be transgressed.

**JM**: Interesting, reference to the precautionary principle raises a whole set of issues regarding the nature of objectivity and how others interpret and use evidence, including that drawn from your own work. As I am sure you are aware, Article 3 (3) of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) is:

> The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be ***cost-effective*** so as to ensure ***global benefits at the lowest possible cost***. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties. (UNFCCC, 1992, p. 4 [emphasis added])

Though well-intentioned perhaps, this places prudential action in the context of economic systems and thus opens up policy choices and timing to a whole set of additional considerations that have seemingly affected if and when to address changes to the different control variables your work uses – cost effectiveness, benefits (to who and where?), etc. Do you worry about the misuse and misinterpretation of your work and your colleagues work?

**WS:** Yes, misrepresentation is indeed a problem. But I think we need to differentiate misrepresentation by those who are using the science and some misrepresentation within the scientific community itself. As an example, there has certainly been misrepresentation of the planetary boundaries framework, and also some possible misuse, at both levels.

The most prominent case of misinterpretation – an apparently deliberate misinterpretation – is the claim by some critics within the scientific community that not all boundary processes have well-defined thresholds or tipping points. That is, there has been a conflation of a boundary with a tipping point. We were very clear that not all boundary processes had tipping points, and even if a boundary process had a tipping point, the boundary itself would be set well upstream of the tipping point. Some critics attempted to discredit the framework by arguing that not all boundary processes had tipping points, despite the fact that we explicitly pointed out that some processes were more gradual, with no discernible tipping point, but nevertheless pushing the process too far would move the Earth System out of Holocene conditions.

Potential misuse, in my view, can occur when the planetary boundary framework is applied to uses or situations for which it was not designed. This type of misuse occurs in the user community, rather than in the scientific community itself. The primary issue here is the framework is explicitly designed to operate at the global level. This has not stopped the 'down-scaling' of the framework to be applied at the level of individual countries or corporations or other economic entities. The problem here is that not all boundary processes scale linearly as one goes down from the global to smaller scales, so setting the portion of the safe operating space that country X, for example, can 'use' is fraught with many difficulties. In terms of corporations, trying to match supply chains with the planetary boundary framework can quickly become extremely difficult to implement.

**JM:** There is an important issue here that a great deal of business school work on 'sustainable development' tends to neglect. While it is potentially constructive for each and every significant entity to have 'sustainable development' policies, whether in fact an activity is 'sustainable' is not set at the level of that entity, but of the totality of them in so far as the level of activity and its consequences are within the tolerance of systems. Of course, one might think that enough entities undertaking change might mean that change is sufficient to place the aggregate within that tolerance and this seems, for example, to be basic to the 'bottom up' approach adopted for the nationally determined contributions (NDCs) of the Paris Agreement. Your planetary boundaries framework is more broadly based than the main focus on emissions and temperature in Paris Article 2 (1a) (UN, 2015). What scope do you see for that broader based approach to inform the implementation of the Paris Agreement, given that, as you say, the situation seems to have moved from 3 to 4 and perhaps 6 Earth System processes exceeding boundaries – and perhaps you might mention which these others are and what their significance might be?

**WS:** The two additional boundaries that probably have been transgressed are ocean acidification and freshwater use. In the 2015 assessment of the PBs, ocean acidification was virtually on the boundary itself. Since then, emissions of $CO_2$ have continued to increase, with the oceans absorbing about 25% of these emissions, thus causing ocean acidification to increase, most likely beyond its boundary value. The other PB that is likely to have been transgressed now is freshwater use. It continues to increase and, along with that issue, we are re-examining where that boundary should be set based on new analyses in the peer-reviewed literature. That is a work-in-progress and we hope to have an update later in the year.

The issue of novel entities will also be updated in our 2021 analysis. At present, there is no suggested boundary. This is an extremely complex process to deal with, starting with the definition of novel entities themselves. Much of the focus so far has been on chemical pollutants, and we are using that as a model for how one sets boundaries for such substances. Late in 2020, we ran a workshop bringing together experts on chemical pollutants and their impact on the environment. An interesting suggestion, which is getting quite a bit of support, is that the boundary for chemical pollution should be set at zero. As the name indicates, a 'novel entity' is something entirely new to the Earth System so the system has no experience in dealing with or metabolizing such materials. This makes sense from a scientific perspective, but it would be very confronting for the chemicals industry. In essence, a PB set at zero for chemical pollution would mean that we would have to develop circular economies and industrial systems, where there are no pollutants or effluents released to the environment. They are all captured and re-used.

**JM:** Yes, this seems likely to be controversial – not because it is unreasonable, but because of the ingrained problems of industrial processes and uses.[7] Over the last thirty years, plastics producers, for example, have placed considerable resources into convincing the public that recycling has been relatively effective in addressing some of the problems of plastics production and use – yet, as I am sure you know, only a small fraction of plastics are recyclable and are recycled and of these a great proportion are 'down-cycled' rather than 'closed-loop' (a bottle becomes something else rather than a bottle stays a bottle). The level of plastics in our environment, especially micro-plastics, is, of course, now a matter of growing concern and awareness. But, given this is something readers probably already know something about it might be worth illustrating a slightly different issue here in order to reinforce understanding of some of the key issues your PB approach highlights. The idea of feedback seems extremely important, would it be possible to provide an example of a feedback process? Moreover, complexity seems to be an important facet of the Earth System and uncertainty seems to be a key issue arising from interactions which influence feedbacks, so perhaps you might comment on this too. Clearly, uncertainty should not be taken as grounds for complacency, as though it amounted to 'we don't know, so there is no need for concern' – this is intrinsic to the adequacy of a precautionary principle isn't it?

**WS:** You've certainly raised some important issues here. First, the fact that the Earth System is a complex system is very important but also widely misunderstood. Here, the term 'complex system' is used in a technical sense and not simply to mean a system that is highly complicated with many 'moving parts'. Rather, complex systems are systems that typically exist in well-defined states that are stable and resilient to external forcing agents or internal dynamics. Their resilience is often built around 'negative', or dampening, feedback processes that act to maintain the system in its existing stable state. For example, over half of the human emissions of carbon dioxide to the atmosphere are absorbed by the ocean and land, thus reducing the amount that remains in the atmosphere and acting to maintain the climate in a stable state. In general, the Holocene – the most recent 11,700-year epoch in Earth history – was a stable, resilient state of the Earth System because of these intrinsic negative feedbacks.

However, once complex systems are forced too far away from their stability domains and their dampening feedback mechanisms are overwhelmed, they can move rapidly and irreversibly towards a new state as 'positive' (reinforcing) feedback mechanisms take over. This is the risk that we currently face with the accelerating trajectory of the Earth System away from the Holocene. At present, dampening feedbacks still dominate the overall behaviour of the system, but positive feedbacks are being activated. These include melting permafrost, increasing drought and fire in the Amazon rainforest, and a slowing of the Atlantic Ocean circulation.

The second important issue you've raised above is how to deal with uncertainty. We know, with a high degree of certainty, that many positive feedback processes exist, but we don't know – with a high degree of certainty – where the tipping points for these processes might lie. That is, where is the level of forcing (e.g. temperature rise) beyond which permafrost melt becomes self-reinforcing and thus unstoppable? Even more uncertainty surrounds the interactions among these feedback processes, interactions that could lead to a global tipping cascade. In effect, this is the process that would drive the Earth System from one stable state – the Holocene – into another stable, but much hotter, state, sometimes called 'Hothouse Earth'. Large uncertainties remain regarding the point at which such a global tipping cascade, if it exists, could be initiated. So this is the ultimate challenge for humanity in terms of dealing with the uncertainty-complacency issue, and in applying the precautionary principle. And, of course, the planetary boundary framework is designed to err on the side of safety. That is, if the boundaries are respected, we argue that there is only a very low probability of initiating a tipping cascade.

**JM:** Coming back to the core focus of Paris via Article 2 (1a), all of this seems to suggest that climate and ecological breakdown is a more complex set of issues than Paris alone can and does address.

**WS:** Yes, it certainly is. We use the term 'biosphere degradation' for ecological breakdown, and give it core boundary status along with climate change. Core PBs, according to our definition, can change the state of the Earth System on their own. This is clear for climate change. But in the past, major changes to the biosphere have also marked different states of the Earth System as a whole, and many of them have acted as feedback processes that have pushed the Earth System from one state to another. Examples include mass extinction events and the evolution of new life forms. Today there are multiple threats to the biosphere, including the potential for the sixth mass extinction event in Earth's history.

There have been several assessments of how humanity is changing the biosphere now, irrespective of climate change. For example, the big international assessment effort called IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) in 2019 came up with a number of overarching conclusions on human-driven degradation of the biosphere. Three of the most prominent ones are: (i) Nature is declining globally at rates unprecedented in human history; (ii) around one million animal and plant species are now threatened with extinction, many within decades, (iii) the web of life on Earth is getting smaller and increasingly frayed.[8]

Palaeo-botanist Mark Williams and his collaborators have examined human degradation of the biosphere in a very long-term perspective and suggest that our impact on the biosphere could represent the third major stage in the evolution of the biosphere in Earth history. They suggest four criteria: (i) global homogenization of flora and fauna; (ii) humans commandeering 25%–40% of the net primary productivity (NPP) of the biosphere and the mining of fossil NPP (fossil fuels); (iii) human-directed evolution of other species; and (iv) increasing interaction of the biosphere and the technosphere (e.g. chemical pollutants).

Although there are certainly some connections between these changes to the biosphere and climate change, often through the carbon cycle, it is absolutely clear that dealing with these profound changes to the biosphere are well beyond the remit of the Paris Accord.

**JM:** Your comments on degradation, mass extinctions, etc. all speak to issues of conditions and cause and thus evoke the concept of an 'Anthropocene', in so far as our species is not a mere bystander or observer in events but is, rather, the prime mover in them. But before we come to that, given we have raised the issue of Paris, and you had some role in the 2018 IPCC *Global Warming of 1.5°C* report (IPCC, 2018), I am curious as to your opinion on its subsequent reception. On the one hand, it has precipitated a significant increase in awareness of the need to urgently tackle climate change and GHG emissions (targets for 2030, net-zero by mid-century, the UN 'Race to Zero campaign, etc.).[9] On the other hand, there was considerable wrangling regarding what status to give to the report (bearing in mind it had been invited/commissioned) within the COP process – at COP 24 in Katowice the US, Saudi Arabia, Russia and Kuwait objected to the phrase 'welcomes the report' and preferred 'noted'. Did you find this 'disappointing'?

**WS:** The reception to the IPCC SR1.5 report was generally very good, despite a few countries apparently not wanting to 'welcome' it. The report has indeed supported the growing calls for much more urgent action on climate change and has also focussed on near-term action with interim emission reduction targets for 2030 becoming much more prominent. The report also provides a stark assessment of the large increase in risks and impacts that will occur at 2°C of warming compared to 1.5°C. A decade or so ago, a 2°C target was thought to be adequate or even 'safe', but the IPCC SR1.5 report seriously challenged that assumption.[10] In addition to the urgency message, the SR1.5 report also hammered home the message that the more we learn about climate change, the riskier it looks.

**JM**: This brings us to the Anthropocene. When did you and others start thinking about using this term and what exactly do you mean by it?

**WS:** The term 'Anthropocene' was introduced by Paul Crutzen in February 2000 at a meeting of the IGBP (International Geosphere-Biosphere Programme) Scientific Committee in Cuernavaca, Mexico. Paul was becoming agitated at continuing references to the Holocene in our discussions of impacts on the Earth System, and he finally interrupted the discussion and forcefully said that we are no longer in the Holocene; we are in the … Anthropocene. He coined the term at just that moment.

The term 'Anthropocene' had two distinct meanings from the beginning. One was clearly based on the Geologic Time Scale, in which the geological history of Earth is divided into time units – eras, periods, epochs and so on. The Anthropocene was suggested as a new epoch to terminate the Holocene, based on the mass of evidence that was being gathered by the IGBP and other research efforts. The second – closely related – meaning was that the Earth System has left the

11,700-year relatively stable Holocene state and was now in a rapid trajectory away from the Holocene into significantly new and different conditions. The term Anthropocene also implied that this trajectory away from the Holocene was not being driven by natural forces within or external to the Earth System (e.g. volcanic eruptions, changes in solar intensity, meteorite strikes) but rather by the activities of *Homo sapiens*. As the Anthropocene concept became more broadly known, its interpretations multiplied, primarily in terms of unpacking what aspects of the 'human enterprise' and what segments of the global human population were primarily responsible for the Anthropocene. The start date for the Anthropocene is also an interesting topic for discussion, with the geologic and Earth System science communities agreeing that the most appropriate start for the Anthropocene is the mid-twentieth century.

**JM:** This raises a whole set of important issues for how one develops and applies the concept of an Anthropocene and perhaps we could start to draw the interview to a close by inviting you to comment on this? Early on you referred to measures of 'human perturbation' for each of the 9 processes in the PB framework in relation to response variables. And as you say, there is a great deal of unpacking to do in terms of the nature of human enterprise that underpins the concept of an Anthropocene. Insofar as humans have become a primary influence on the Earth System this evokes the subsequent questions, what human systems, what places, practices, organizations, and policies are producing 'human perturbation'? Some combination of answers to these questions lead to the kinds of consequences the PB identifies. Clearly, the nature of explanations of human systems bears on the adequacy of explanation of how our species has found itself in a period of climate emergency and ecological breakdown, and as a corollary, this must have some bearing on how we view the scope and adequacy of solutions, and conversely, it bears on where we might expect to find impediments to adequate solutions – a subject that ranges across knowledge/theory and its framing effects as well as its influence on research applications, politics and policy.[11]

Ecological economists, of course, are distinguished from other economists by their focus on an economy as a set of material processes, involving thermodynamic consequences, entropy, waste creation, and basic bio-physical modification of the world. This approach brings into question standard economics, which focuses primarily on the exchange value of goods and services, that, in turn, supports an idea of an economy as a circular flow of income, targeting *continual* economic growth. The standard economic approach disembeds an economy and then, 'environmental economics' tries to adapt standard economics to the real-world problems this has produced, by adding on environmental concerns as modifications to the core of the economics. For an ecological economist, this is insufficient to address the generalized problem that human systems are dependent on and consequential for a material world i.e. that there are limits to what can be safely done.[12] However, once this distinction has been made ecological economics starts to divide as the political economy of causation comes to the fore and the problem of 'what is to be done?' is evoked. There is, for example, work that modifies the concept of an Anthropocene as a 'Capitalocene', there is renewed debate over limits to growth, but now in the context of 'green new deals', there is scepticism regarding the kinds of integrated assessment models that have dominated debate in environmental economics (the social cost of carbon approach), there is scepticism regarding the influence that faith in solutions stemming from future technology, etc. might have on the 'net' in net-zero (what it will mean in practice), there is a host of work on 'social ecological economics', 'postgrowth' and 'degrowth', which argues that fundamental changes are required in the way society and economies are organized and motivated (and this is different than just massive investment in infrastructure organized around a transition, since it begs the question of, 'from what and to what?'), etc.[13]

I am not sure how familiar you are with this kind of work, so perhaps you might comment on that. Clearly, the importance of your work is not reduced by any of these issues noted above, but they do seem to have some bearing on the timing of an Anthropocene (the subjective aspects perhaps), but more importantly on how we might move towards the 'Alternative Stabilized Earth Pathway' your work draws attention to – one that avoids crossing thresholds that lock us into a 'Hothouse Earth pathway'. And this seems especially so once one starts to think of the focus of Paris as vital yet partial from a more holistic PB perspective …

**WS:** You've raised a number of very important issues above, and I'll start with the last one first – the timing of the Anthropocene. If we go back to the original sources of the Anthropocene concept – basically Earth System science and geology/stratigraphy, we have two different criteria for determining the start of the Anthropocene epoch. The Earth System science definition is based on the time at which the trajectory of the Earth System clearly left the 11,700-year stable Holocene epoch, and there is a mass of evidence that points to the mid-twentieth century for that start date. Stratigraphers examine changes in the Earth's stratigraphic record – e.g. ice cores, tree rings, lake and coastal sediments and so on. Can they see a clear line of demarcation where the indicator in the core – isotopic signature, pollen record, nitrate concentration, etc. – clearly changes from one level to another? Again, there is a mass of stratigraphic evidence that shows a break in the stratigraphic record around the mid-twentieth century. Consistent with this bio-physical evidence, historian John McNeill, in his landmark book *Something New Under the Sun*, has described the changes in the human component of the Earth System – governance, technology, economies, international relations – that led to the explosion of human activity from the mid-twentieth century onwards, a phenomenon he labelled the 'Great Acceleration'.[14]

A very interesting point of discussion and debate is just which humans have been most responsible for the Great Acceleration, and hence for driving the Earth System out of the Holocene. And this question has led to some variants on the Anthropocene, such as the 'Capitalocene' and the 'Manthropocene'. The basic point here is that not all humans have been equally responsible for the Anthropocene. In our original analysis of the Anthropocene data, we had lumped all of humanity together as one whole. But in an update of the data to 2010, we divided humanity into three groups – the OECD (wealthy) countries, the so-called BRICS emerging countries (Brazil, Russia, India, China, South Africa) and all the others – the poorer countries. The outcome of this analysis was striking. From 1950 to 2010, nearly all of the population growth was in the BRICS and developing countries, who accounted for about 80% of the global population, yet 74% of the world GDP, and hence consumption, occurred in the OECD countries. That is, the data showed huge inequalities within the human component of the Earth System. These data are from 2010, so the rapid rise of China, for example, would probably change this analysis somewhat if it was taken to 2020. Nevertheless, the analysis of the rapidly changing characteristics of the 'human enterprise' – if I can call it that – are an important feature of the Anthropocene narrative.

So where is the Anthropocene going? Can we quickly change the trajectory of the Earth System away from its current pathway towards Hothouse Earth and onto a Stabilized Earth pathway? There is no clear answer to that question, but perhaps the various attempts to answer it can be grouped into two very broad, contrasting approaches. One is that technology is the solution – switching to renewable energy systems, smart grids, electricified transport systems, high-tech agriculture and so on – will create a sustainable future. Economies can grow and we can become wealthier, but decoupling will reduce our imprint on the Earth System. The other broad pathway is that we require a much deeper transformation, one that is based on a fundamental shift in core values – degrowth, less consumptive lifestyles, from 'wealth' to 'well-being', living much simpler but more satisfying lives, reconnecting with the biosphere, and so on. As of yet, there is no clear answer to these questions, and opinions and debates continue. Probably the only sure thing we can say about the future is that it hasn't happened yet.

**JM:** Taking stock then, do you see grounds for optimism?

**WS:** I think we are at a critical point in human history. There are grounds for both optimism and pessimism. The pessimism is fuelled by the power of the incumbents (e.g. the fossil fuel industry) and the conservative political ideologies that hang on to power. Breaking this toxic power structure can seem impossibly hard at times. On the other side of the coin, social tipping points are notoriously difficult to foresee and predict.

**JM:** And yet 2030 is fast approaching and 2050 is sooner than we like to think. We cannot, seemingly, afford to wait and must begin to provide answers and we need governments to begin to act – to mobilize akin to 'war-footing', as it has been put.[15] The rhetoric around COP26 makes much of this urgency. Moreover, whatever uncertainty pertains, given we are talking about high impact and irreversible processes there seems to be a policy asymmetry situation that the precautionary principle implies, but politics does not always fully embrace: it is better to overrespond rather than under since the consequences of underreaction are surely greater?

**WS:** But there appears to be mounting pressure across many societies for fundamental change. This, of course, gives one hope for the future. For me, a critical question is timing. There are tipping points in the Earth System and we could be approaching a planetary tipping point that could lead to Hothouse Earth and a dismal future for humanity. So it is a race against time. Can we transform our societies (and ourselves) fast enough to avoid a Hothouse Earth future? That is the critical question, and nobody knows the answer, but it will depend on us – the values that we hold and the choices that we make.

## Notes

1. For further information and access to Professor Steffen's work visit:
   https://en.wikipedia.org/wiki/Will_Steffen
   https://climate.anu.edu.au/about/people/academics/professor-will-steffen
   https://www.stockholmresilience.org/meet-our-team/staff/2009-08-24-steffen.html
2. Note from JM: see Ripple et al. (2020, 2021) and "The Climate Emergency: 2020 in Review": https://bit.ly/3nk4QXt
3. Note from JM, the original full list of 9 Earth system processes each with a boundary, parameters, measurement status and comparison to a pre-industrial level (phrased here in terms of foci for potentially adverse effects) comprises: 1. Climate Change; 2. Rate of biodiversity loss; 3. Nitrogen cycle/Phosphorous cycle – jointly comprising the biogeochemical flow boundary; 4. Stratospheric ozone depletion; 5. Ocean acidification; 6. Global freshwater use; 7. Change in land use; 8. Atmospheric aerosol loading; 9. Chemical pollution (Rockström et al., 2009, p. 473). For tipping points discussion see also Lenton et al. (2008) and Lenton et al. (2019).
4. Note from JM: see, for example, Steffen et al. (2011); Robin and Steffen (2007); Crutzen and Steffen (2003). See also Waters et al. (2015) and Zalasiewicz et al. (2010).
5. Note from JM: see, for example, Steffen et al. (2018, p 2016, 2015, 2005).
6. Note from JM: see the 10 year summary of UNEP emissions gap reports for the general trend increase in global emissions (Christensen & Olhoff, 2019).
7. Note from JM: this, of course, does then raise the issue of what fully circular means and whether this is possible (which is a different issue than whether it is unreasonable for corporations to address the problem of pollutants in good faith).
8. Note from JM: see IPBES (2019), note also there is considerable debate regarding the use of standard economic theory to provide commensurable values as the basis of policies to protect, preserve and use ecosystem 'services', as the recent UK Dasgupta Report indicates.

9. Note from JM: Visit Race to Zero at: https://unfccc.int/climate-action/race-to-zero-campaign
   And for the Climate Ambition Alliance see: https://cop25.mma.gob.cl/en/climate-ambition-alliance/
10. Note from JM: moreover, (and noting Professor Steffen's previous comments on the climate planetary boundary) in the 'Trajectories of the Earth System' paper, Steffen and colleagues suggest that Paris climate targets may be insufficient to prevent a Hothouse Earth pathway: "This analysis implies that, even if the Paris Accord target of a 1.5°C to 2.0°C rise in temperature is met, we cannot exclude the risk that a cascade of feedbacks could push the Earth System irreversibly into a 'Hothouse Earth pathway. The challenge that humanity faces is to create a "Stabilized Earth" pathway that steers the Earth System away from its current trajectory toward the threshold beyond which is Hothouse Earth. The human created Stabilized Earth pathway leads to a basin of attraction that is not likely to exist in the Earth System's stability landscape without human stewardship to create and maintain it. Creating such a pathway and basin of attraction requires a fundamental change in the role of humans on the planet." (Steffen et al., 2018, p. 3). For similar concerns see Hansen et al. (2017); Bradshaw et al. (2021).
11. Note from JM: this is the subject matter of many of the contributions to the original special issue of *Globalizations*. See the introduction, Gills and Morgan (2020b). See also Lamb et al. (2020); Røpke (2020); Oreskes and Conway (2010).
12. Note from JM: compare Daly (1997) and Nordhaus (1991).
13. Note from JM: for indicative range see, for example, Hickel and Kallis (2020); Parrique et al. (2019); Dyke et al. (2021); O'Neill et al. (2018); Moore (2015); Asefi-Najafabady et al. (2020); Keen (2020); Spash (2020); Gills and Morgan (2020a).
14. Note from JM: see McNeill (2001).
15. Note from JM: see, for example, Newell and Simms (2020) on 'just transition' and also some of the essays in the edited collection Fullbrook and Morgan (2019).

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Notes on Contributors

*Will Steffen* is Emeritus Professor at the Fenner School of Environment and Society, the Australian National University (ANU), Canberra. Additional detail is given in the interview.

*Jamie Morgan* is Professor of Economic Sociology at Leeds Beckett University. He co-edits the Real-World Economics Review with Edward Fullbrook. He has published widely in the fields of economics, political economy, philosophy, sociology and international politics.

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