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Can a collapse of global civilization be avoided?

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Environmental problems have contributed to numerous collapses of civilizations in the past. Now, for the first time, a global collapse appears likely. Overpopulation, overconsumption by the rich and poor choices of technologies are major drivers; dramatic cultural change provides the main hope of averting calamity.

1. Introduction

Virtually every past civilization has eventually undergone collapse, a loss of socio-political-economic complexity usually accompanied by a dramatic decline in population size [1]. Some, such as those of Egypt and China, have recovered from collapses at various stages; others, such as that of Easter Island or the Classic Maya, were apparently permanent [1,2]. All those previous collapses were local or regional; elsewhere, other societies and civilizations persisted unaffected. Sometimes, as in the Tigris and Euphrates valleys, new civilizations rose in succession. In many, if not most, cases, overexploitation of the environment was one proximate or an ultimate cause [3].

But today, for the first time, humanity's *global* civilization—the worldwide, increasingly interconnected, highly technological society in which we all are to one degree or another, embedded—is threatened with collapse by an array of environmental problems. Humankind finds itself engaged in what Prince Charles described as 'an act of suicide on a grand scale' [4], facing what the UK's Chief Scientific Advisor John Beddington called a 'perfect storm' of environmental problems [5]. The most serious of these problems show signs of rapidly escalating severity, especially climate disruption. But other elements could potentially also contribute to a collapse: an accelerating extinction of animal and plant populations and species, which could lead to a loss of ecosystem services essential for human survival; land degradation and land-use change; a pole-to-pole spread of toxic compounds; ocean acidification and eutrophication (dead zones); worsening of some aspects of the epidemiological environment (factors that make human populations susceptible to infectious diseases); depletion of increasingly scarce resources [6,7], including especially groundwater, which is being overexploited in many key agricultural areas [8]; and resource wars [9]. These are not separate problems; rather they interact in two gigantic complex adaptive systems: the biosphere system and the human socio-economic system. The negative manifestations of these interactions are often referred to as 'the human predicament' [10], and determining how to prevent it from generating a global collapse is perhaps *the* foremost challenge confronting humanity.

The human predicament is driven by overpopulation, overconsumption of natural resources and the use of unnecessarily environmentally damaging technologies and socio-economic-political arrangements to service *Homo sapiens'* aggregate consumption [11–17]. How far the human population size now is above the planet's long-term carrying capacity is suggested (conservatively) by ecological footprint analysis [18–20]. It shows that to support *today's* population of seven billion sustainably (i.e. with business as usual, including current technologies and standards of living) would require roughly half an additional planet; to do so, if all citizens of Earth consumed resources at the US level would take four to five more Earths. Adding the projected 2.5 billion more people by 2050 would make the human assault on civilization's life-support systems disproportionately worse, because almost everywhere people face systems with nonlinear responses [11,21–23], in which environmental damage increases at a rate that becomes faster with each additional person. Of course, the claim is often made that humanity will expand Earth's carrying capacity dramatically with technological innovation [24], but it is widely recognized that technologies can both add and subtract from carrying capacity. The plough evidently first expanded it and now appears to be reducing it [3]. Overall, careful analysis of the prospects does not provide much confidence that technology will save us [25] or that gross domestic product can be disengaged from resource use [26].

2. Do current trends portend a collapse?

What is the likelihood of this set of interconnected predicaments [27] leading to a global collapse in this century? There have been many definitions and much discussion of past 'collapses' [1,3,28–31], but a future global collapse does not require a careful definition. It could be triggered by anything from a 'small' nuclear war, whose ecological effects could quickly end civilization [32], to a more gradual breakdown because famines, epidemics and resource shortages cause a disintegration of central control within nations, in concert with disruptions of trade and conflicts over increasingly scarce necessities. In either case, regardless of survivors or replacement societies, the world familiar to anyone reading this study and the well-being of the vast majority of people would disappear.

How likely is such a collapse to occur? No civilization can avoid collapse if it fails to feed its population. The world's success so far, and the prospective ability to feed future generations at least as well, has been under relatively intensive discussion for half a century [33–40]. Agriculture made civilization possible, and over the last 80 years or so, an industrial agricultural revolution has created a technology-dependent global food system. That system, humanity's single biggest industry, has generated miracles of food production. But it has also created serious long-run vulnerabilities, especially in its dependence on stable climates, crop monocultures, industrially produced fertilizers and pesticides, petroleum, antibiotic feed supplements and rapid, efficient transportation.

Despite those food production miracles, today at least two billion people are hungry or poorly nourished. The Food and Agriculture Organization estimates that increasing food production by some 70 per cent would be required to feed a 35 per cent bigger and still growing human population adequately by 2050 [41]. What are the prospects that *H. sapiens* can produce and distribute sufficient food? To do so, it probably will be necessary to accomplish many or all of the following tasks: severely limit climate disruption; restrict expansion of land area for agriculture (to preserve ecosystem services); raise yields where possible; put much more effort into soil conservation [3]; increase efficiency in the use of fertilizers, water and energy; become more vegetarian; grow more food for people (not fuel for vehicles); reduce food wastage; stop degradation of the oceans and better regulate aquaculture; significantly increase investment in sustainable agricultural and aquacultural research; and move increasing equity and feeding everyone to the very top of the policy agenda.

Most of these long-recommended tasks require changes in human behaviour thus far elusive. The problem of food wastage and the need for more and better agricultural research have been discussed for decades. So have 'technology will save us' schemes such as building 'nuclear agro-industrial complexes' [42], where energy would be so cheap that it could support a new kind of desert agriculture in 'food factories', where crops would be grown on desalinated water and precisely machine fertilized. Unhappily, sufficiently cheap energy has never been produced by nuclear power to enable large-scale agriculture to move in that direction. Nor has agriculture moved towards feeding people protein extracted from leaves or bacteria grown on petroleum [43, pp. 95–112]. None of these schemes has even resulted in a coordinated development effort. Meanwhile, growing numbers of newly well-off people have increased demand for meat [44], thereby raising global demand for feedgrains.

Perhaps even more critical, climate disruption may pose insurmountable biophysical barriers to increasing crop yields. Indeed, if humanity is very unlucky with the climate, there may be reductions in yields of major crops [45], although near-term this may be unlikely to affect harvests globally [46]. Nonetheless, rising temperatures already seem to be slowing previous trends of increasing yields of basic grains [45,47], and unless greenhouse gas emissions are dramatically reduced, dangerous anthropogenic climate change [48] could ravage agriculture. Also, in addition to falling yields from many oceanic fish stocks because of widespread overfishing [49], warming and acidification of the oceans threaten the protein supply of some of the most nutritionally vulnerable people [50], especially those who cannot afford to purchase farmed fish.

Unfortunately, the agricultural system has complex connections with all the chief drivers of environmental deterioration. Agriculture itself is a major emitter of greenhouse gases and thus is an important cause of climate disruption as well as being exceptionally vulnerable to its consequences. More than a millennium of change in temperature and precipitation patterns is apparently now entrained [51], with the prospect of increasingly severe storms, droughts, heat waves and floods, all of which seem already evident and all of which threaten agricultural production.

Land is an essential resource for farming, and one facing multiple threats. In addition to the serious and widespread problems of soil degradation, sea-level rise (the most certain consequence of global warming) will take important areas out of production either by inundating them (a 1 m rise would flood 17.5% of Bangladesh [52]), exposing them to more frequent storm surges, or salinizing coastal aquifers essential for irrigation water. Another important problem for the food system is the loss of prime farmland to urbanization, a trend that seems certain to accelerate [53] as population growth steadily erodes the *per capita* supply of farmland.

The critical importance of substantially boosting the inadequate current action on the demographic problem can be seen in the time required to change the trajectory of population growth humanely and sensibly. We know from such things as the World War II mobilizations that many consumption patterns can be altered dramatically within a year, given appropriate incentives [54]. If food shortages became acute, then a rapid reaction would ensue as hunger became much more widespread. Food prices would rise, and diets would temporarily change (e.g. the number of meals consumed per day or amount of meat consumed) to compensate the shortage. Over the long term, however, expanding the global food supply and distributing it more equitably would be a slow and difficult process. Even though a major famine might well provoke investment in long-needed improvements in food production and distribution, they would take time to plan, test and implement.

Furthermore, agriculture is a leading cause of losses of biodiversity and thus of the critical ecosystem services supplied to agriculture itself (e.g. pollination, pest control, soil fertility, climate stability) and other human enterprises. Farming is also a principal source of global toxification, as has been clear since the days of Carson [55], exposing the human population to myriad subtle poisons. These pose further potential risks to food production.

3. What needs to be done to avoid a collapse?

The threat from climate disruption to food production alone means that humanity's entire system for mobilizing energy needs to be rapidly transformed. Warming must be held well below a potential 5°C rise in global average temperature, a level that could well bring down civilization [56]. The best estimate today may be that, failing rapid concerted action, the world is already committed to a 2.4°C increase in global average temperature [57]. This is significantly above the 2°C estimated a decade ago by climate scientists to be a 'safe' limit, but now considered by some analysts to be too dangerous [58,59], a credible assessment, given the effects seen already before reaching a one degree rise. There is evidence, moreover, that present models underestimate future temperature increase by overestimating the extent that growth of vegetation can serve as a carbon sink [60] and underestimating positive feedbacks [61].

Many complexities plague the estimation of the precise threats of anthropogenic climate disruption, ranging from heat deaths and spread of tropical diseases to sea-level rise, crop failures and violent storms. One key to avoiding a global collapse, and thus an area requiring great effort and caution is avoiding climate-related mass famines. Our agricultural system evolved in a geological period of relatively constant and benign climate and was well attuned to twentieth-century conditions. That alone is cause for substantial concern as the planet's climates rapidly shift to new, less predictable regimes. It is essential to slow that process. That means dramatically transforming much of the existing energy mobilization infrastructure [62] and changing human behaviour to make the energy system much more efficient. This *is* possible; indeed, sensible plans for doing it have been put forward [63,64], and some progress has been made. The central challenge, of course, is to phase out more than half of the global use of fossil fuels by 2050 in order to forestall the worst impacts of climate disruption, a challenge the latest International Energy Agency edition of World Energy Outlook makes look more severe [65]. This highlights another dilemma. Fossil fuels are now essential to agriculture for fertilizer and pesticide manufacture, operation of farm machinery, irrigation (often wasteful), livestock husbandry, crop drying, food storage, transportation and distribution. Thus, the phase-out will need to include at least partial substitution of non-fossil fuels in these functions, and do so without greatly increasing food prices.

Unfortunately, essential steps such as curbing global emissions to peak by 2020 and reducing them to half of present levels by 2050 [66] are extremely problematic economically and politically. Fossil fuel companies would have to leave most of their proven reserves in the ground, thus destroying much of the industry's economic value [67]. Because the ethics of some businesses include knowingly continuing lethal but profitable activities [68], it is hardly surprising that interests with large financial stakes in fossil fuel burning have launched a gigantic and largely successful disinformation campaign in the USA to confuse people about climate disruption [69,70] and block attempts to deal with it [71].

One recurrent theme in analyses of the food problem is the need for closing 'yield gaps' [72–74]. That means raising yields in less productive systems to those typical of industrial agriculture. But climatic conditions may change sufficiently that those industrial high yields can themselves no longer be sustained [45]. Thus, reducing the chances of a collapse calls for placing much more effort into genetic and ecological research related to agriculture [75] and adopting already known environmental-friendly techniques, even though that may require trading off immediate corporate profits for social benefits or long-term sustainability [3].

Rationalizing energy mobilization alone may not be enough to be enough to maintain agricultural production, let alone allow its great expansion. Human water-handling infrastructure will have to be re-engineered for flexibility to bring water to crops in an environment of constantly changing precipitation patterns [51]. This is critical, for although today only about 15 per cent of agricultural land is irrigated, it provides some 40 per cent of the grain crop yield. It seems likely that farming areas now rain-fed may someday need to be irrigated, whereas irrigation could become superfluous elsewhere, and both could change more or less continually. For this and many other reasons, the global food system will need to quickly evolve an unprecedented flexibility, never before even contemplated.

One factor making the challenges more severe is the major participation in the global system of giant nations whose populations have not previously enjoyed the fossil energy abundance that brought Western countries and Japan to positions of affluence. Now they are poised to repeat the West's energy 'success', and on an even greater scale. India alone, which recently suffered a gigantic blackout affecting 300 million people, is planning to bring 455 new coal plants on line. Worldwide more than 1200 plants with a total installed capacity of 1.4 million megawatts are planned [76], much of that in China, where electricity demand is expected to skyrocket. The resultant surge in greenhouse gases will interact with the increasing diversion of grain to livestock, stimulated by the desire for more meat in the diets of Indians, Chinese and others in a growing global middle class.

4. Dealing with problems beyond food supply

Another possible threat to the continuation of civilization is global toxification. Adverse symptoms of exposure to synthetic chemicals are making some scientists increasingly nervous about effects on the human population [77–79]. Should a global threat materialize, however, no planned mitigating responses (analogous to the ecologically and politically risky 'geoengineering' projects often proposed to ameliorate climate disruption [80]) are waiting in the wings ready for deployment.

Much the same can be said about aspects of the epidemiological environment and the prospect of epidemics being enhanced by rapid population growth in immune-weakened societies, increased contact with animal reservoirs, high-speed transport and the misuse of antibiotics [81]. Nobel laureate Joshua Lederberg had great concern for the epidemic problem, famously stating, 'The survival of the human species is not a preordained evolutionary program' [82, p. 40]. Some precautionary steps that should be considered include forbidding the use of antibiotics as growth stimulators for livestock, building emergency stocks of key vaccines and drugs (such as Tamiflu), improving disease surveillance, expanding mothballed emergency medical facilities, preparing institutions for imposing quarantines and, of course, moving as rapidly as possible to humanely reduce the human population size. It has become increasingly clear that security has many dimensions beyond military security [83,84] and that breaches of environmental security could risk the end of global civilization.

But much uncertainty about the human ability to avoid a collapse still hinges on military security, especially whether some elements of the human predicament might trigger a nuclear war. Recent research indicates that even a regional-scale nuclear conflict, as is quite possible between India and Pakistan, could lead to a global collapse through widespread climatic consequences [32]. Triggers to conflict beyond political and religious strife easily could include cross-border epidemics, a need to gain access to food supplies and farmland, and competition over other resources, especially agricultural water and (if the world does not come to its energy senses) oil. Finding ways to eliminate nuclear weapons and other instruments of mass destruction must move even higher on civilization's agenda [85], because nuclear war would be the quickest and surest route to a collapse [86].

In thinking about the probability of collapse, one must obviously consider the social disruptions associated with elements of the predicament. Perhaps at the top of the list should be that of environmental refugees [87]. Recent predictions are that environmental refugees could number 50 million by 2020 [88]. Severe droughts, floods, famines and epidemics could greatly swell that number. If current 'official' predictions of sea-level rise are low (as many believe they are), coastal inundations alone could generate massive human movements; a 1 m rise would directly affect some 100 million people, whereas a 6 m rise would displace more than 400 million [89]. Developing a more comprehensive system of international governance with institutions planning to ameliorate the impacts of such catastrophes would be a major way to reduce the odds of collapse.

5. The role of science

The scientific community has repeatedly warned humanity in the past of its peril [90–102], and the earlier warnings [93,103–107] about the risks of population expansion and the 'limits to growth' have increasingly been shown to be on the right track [108–111] (but see Hayes [17]). The warnings continue [109,112–119]. Yet many scientists still tend to treat population growth as an exogenous variable, when it should be considered an endogenous one—indeed, a central factor [120]. Too many studies asking 'how can we possibly feed 9.6 billion people by 2050?' should also be asking 'how can we humanely lower birth rates far enough to reduce that number to 8.6?' To our minds, the fundamental cure, reducing the scale of the human enterprise (including the size of the population) to keep its aggregate consumption within the carrying capacity of Earth [121], is obvious but too much neglected or denied. There are great social and psychological barriers in growthmanic cultures to even considering it. This is especially true because of the 'endarkenment'—a rapidly growing movement towards religious orthodoxies that reject enlightenment values such as freedom of thought, democracy, separation of church and state, and basing beliefs and actions on empirical evidence. They are manifest in dangerous trends such as climate denial, failure to act on the loss of biodiversity and opposition to condoms (for AIDS control) as well as other forms of contraception [122]. If ever there was a time for evidence-based (as opposed to faith-based) risk reduction strategies [123], it is now.

How can scientists do more to reduce the odds of a collapse? Both natural and social scientists should put more effort into finding the best ways of accomplishing the necessary re-modelling of energy and water infrastructure. They should develop better ways of evaluating and regulating the use of synthetic chemicals, a problem that might abate somewhat as availability of their fossil fuel sources fades (even though only about 5% of oil production flows into petrochemical production). The protection of Earth's remaining biodiversity (especially the crucial diversity of *populations* [124,125]) must take centre stage for both scientific specialists and, through appropriate education, the public [126,127]. Scientists must continually call attention to the need to improve the human epidemiological environment, and for control and eventual elimination of nuclear, chemical and biological weapons. Above all, they should expand efforts to understand the mechanisms through which cooperation evolves [128], because avoiding collapse will require unusual levels of international cooperation.

Is it too late for the global scientific community to collect itself and start to deal with the nexus of the two complex adaptive systems [129] and then help generate the necessary actions to move towards sustainability? There are certainly many small-scale science-based efforts, often local, that can provide hope if scaled up [121]. For example, environmental non-govenmental organizations and others are continually struggling to halt the destruction of elements of biodiversity (and thus, in some cases, of vital ecosystem services [7]), often with success. In the face of the building extinction crisis, they may be preserving nuclei from which Earth's biota and humanity's ecosystem services, might eventually be regenerated. And some positive efforts *are* scaling up. China now has some 25 per cent of its land in ecosystem function conservation areas [130] designed to protect both natural capital and human well-being. The Natural Capital Project [131] is helping improve the management of these areas. This is good news, but in our view, many too few scientists are involved in the efforts needed, especially in re-orienting at least part of their research towards mitigating the predicament and then bringing their results to the policy front.

6. The need for rapid social/political change

Until very recently, our ancestors had no reason to respond genetically or culturally to long-term issues. If the global climate were changing rapidly for *Australopithecus* or even ancient Romans, then they were not causing it and could do nothing about it. The forces of genetic and cultural selection were not creating brains or institutions capable of looking generations ahead; there would have been no selection pressures in that direction. Indeed, quite the opposite, selection probably favoured mechanisms to keep perception of the environmental background steady so that rapid changes (e.g. leopard approaching) would be obvious [132, pp. 135–136]. But now slow changes in that background are the most lethal threats. Societies have a long history of mobilizing efforts, making sacrifices and changes, to defeat an enemy at the gates, or even just to compete more successfully with a rival. But there is not much evidence of societies mobilizing and making sacrifices to meet gradually worsening conditions that threaten real disaster for future generations. Yet that is exactly the sort of mobilization that we believe is required to avoid a collapse.

Perhaps the biggest challenge in avoiding collapse is convincing people, especially politicians and economists, to break this ancient mould and alter their behaviour relative to the basic population-consumption drivers of environmental deterioration. We know that simply informing people of the scientific consensus on a serious problem does not ordinarily produce rapid changes in institutional or individual behaviour. That was amply demonstrated in the case of cigarettes [68], air pollution and other environmental problems [69] and is now being demonstrated in the obesity epidemic [133] as well as climate disruption.

Obvious parallels exist regarding reproduction and overconsumption, which are especially visible in what amounts to a cultural addiction to continued economic growth among the already well-off [134]. One might think that the mathematics of compound interest would have convinced everyone long ago that growth of an industrialized economy at 3.5 per cent annually cannot long continue. Unfortunately, most ‘educated’ people are immersed in a culture that does not recognize that, in the real world, a short history (a few centuries) of exponential growth does not imply a long future of such growth.

Besides focusing their research on ways to avoid collapse, there is a need for natural scientists to collaborate with social scientists, especially those who study the dynamics of social movements. Such collaborations could develop ways to stimulate a significant increase in popular support for decisive and immediate action on the predicament. Unfortunately, awareness among scientists that humanity is in deep trouble has not been accompanied by popular awareness and pressure to counter the political and economic influences implicated in the current crisis. Without significant pressure from the public demanding action, we fear there is little chance of changing course fast enough to forestall disaster.

The needed pressure, however, might be generated by a popular movement based in academia and civil society to help guide humanity towards developing a new multiple intelligence [135], ‘foresight intelligence’ to provide the long-term analysis and planning that markets cannot supply. Foresight intelligence could not only systematically look ahead but also guide cultural changes towards desirable outcomes such as increased socio-economic resilience. Helping develop such a movement and foresight intelligence are major challenges facing scientists today, a cutting edge for research that must slice fast if the chances of averting a collapse are to be improved.

If foresight intelligence became established, many more scientists and policy planners (and society) might, for example, understand the demographic contributions to the predicament [136], stop treating population growth as a ‘given’ and consider the nutritional, health and social benefits of humanely ending growth well below nine billion and starting a slow decline. This would be a monumental task, considering the momentum of population growth. Monumental, but not impossible if the political will could be generated globally to give full rights, education and opportunities to women, and provide all sexually active human beings with modern contraception and backup abortion. The degree to which those steps would reduce fertility rates is controversial [137–139], but they are a likely win-win for societies [140].

Obviously, especially with the growing endarkenment, there are huge cultural and institutional barriers to establishing such policies in some parts of the world. After all, there is not a single nation where women are truly treated as equal to men. Despite that, the population driver should not be ignored simply because limiting overconsumption can, at least in theory, be achieved more rapidly. The difficulties of changing demographic trajectories mean that the problem should have been addressed sooner, rather than later. That halting population growth inevitably leads to changes in age structure is no excuse for bemoaning drops in fertility rates, as is common in European government circles [141]. Reduction of population size in those over-consuming nations is a very positive trend, and sensible planning can deal with the problems of population aging [142].

While rapid policy change to head off collapse is essential, fundamental institutional change to keep things on track is necessary as well. This is especially true of educational systems, which today fail to inform most people of how the world works and thus perpetuate a vast culture gap [54]. The academic challenge is especially great for economists, who could help set the background for avoiding collapse by designing steady-state economic systems [107,134,143], and along the way destroying fables such as ‘growth can continue forever if it’s in service industries’, or ‘technological innovation will save us’. Issues such as the importance of comparative advantage under current global circumstances [144], the development of new models that better reflect the irrational behaviour of individuals and groups [145], reduction of the worship of ‘free’ markets that infests the discipline, and tasks such as making information more symmetrical, moving towards sustainability and enhancing equity (including *redistribution*) all require re-examination. In that re-examination, they would be following the lead of distinguished economists [146–148] in dealing with the real world of biophysical constraints and human well-being.

At the global level, the loose network of agreements that now tie countries together [149,150], developed in a relatively recent stage of cultural evolution since modern nation states appeared, is utterly inadequate to grapple with the human predicament. Strengthening global environmental governance [151] and addressing the related problem of avoiding failed statehood [152] are tasks humanity has so far refused to tackle comprehensively even as cultural evolution in technology has rendered the present international system (as it has educational systems) obsolete. Serious global environmental problems can only be solved and a collapse avoided with an unprecedented level of international cooperation [122]. Regardless of one’s estimate of civilization’s potential longevity, the time to start restructuring the international system is right now. If people do not do that, nature will restructure civilization for us.

Similarly, widely based cultural change is required to reduce humanely both population size and overconsumption by the rich. Both go against cultural norms, and, as long feared [153], the overconsumption norm has understandably been adopted by the increasingly rich subpopulations of developing nations, notably India and China. One can be thrilled by the numbers of people raised from poverty while being apprehensive about the enormous and possibly lethal environmental and social costs that may eventually result [154,155]. The industrial revolution set civilization on the road to collapse, spurring population growth, which contributed slightly more than overconsumption to environmental degradation [136]. Now population combined with affluence growth may finish the job.

Needless to say, dealing with economic and racial inequities will be critically important in getting large numbers of people from culturally diverse groups [156] to focus their minds on solving the human predicament, something globalization should help [157]. These tasks will be pursued, along with an emphasis on developing 'foresight intelligence', by the nascent *Millennium Alliance for Humanity and the Biosphere* (the MAHB; http://mahb.stanford.edu). One of its central goals is to try to accelerate change towards sustainability. Since simply giving the scientific facts to the public will not do it, among other things, this means finding frames and narratives to convince the public of the need to make changes.

We know that societies can evolve fundamentally and unexpectedly [158, p. 334], as was dramatically demonstrated by the collapse of communist regimes in Europe in 1989 [159]. Rather than tinkering around the edges and making feeble or empty gestures towards one or another of the interdependent problems we face, we need a powerful and comprehensive approach. In addressing climate change, for instance, developing nations need to be convinced that they (along with the rest of the world) cannot afford (and do not need) to delay action while they 'catch up' in development. Indeed, development on the old model is counterproductive; they have a great opportunity to pioneer new approaches and technologies. All nations need to stop waiting for others to act and be willing to do everything they can to mitigate emissions and hasten the energy transition, regardless of what others are doing.

With climate and many other global environmental problems, polycentric solutions may be more readily found than global ones. Complex, multi-level systems may be better able to cope with complex, multi-level problems [160], and institutional change is required at many levels in many polities. What scientists understand about cultural evolution suggests that, while improbable, it may be possible to move cultures in such directions [161,162]. Whether solutions will be global or polycentric, international negotiations will be needed, existing international agencies that deal with them will need strengthening, and new institutions will need to be formed.

7. Conclusions

Do we think global society can avoid a collapse in this century? The answer is yes, because modern society has shown some capacity to deal with long-term threats, at least if they are obvious or continuously brought to attention (think of the risks of nuclear conflict). Humanity has the assets to get the job done, but the odds of avoiding collapse seem small because the risks are clearly not obvious to most people and the classic signs of impending collapse, especially diminishing returns to complexity [28], are everywhere. One central psychological barrier to taking dramatic action is the distribution of costs and benefits through time: the costs up front, the benefits accruing largely to unknown people in the future. But whether we or more optimistic observers [17,163] are correct, our own ethical values compel us to think the benefits to those future generations are worth struggling for, to increase at least slightly the chances of avoiding a dissolution of today's global civilization as we know it.

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