Sustainability **2013**, *5*, 3368-3381; doi:10.3390/su5083368

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Opinion

Some Challenges to Sustainability

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Received: 12 February 2013; in revised form: 12 July 2013 / Accepted: 15 July 2013 / Published: 9 August 2013

Abstract: The word "sustainability" is often used in business in the belief that the current ways of doing things will be able to be continued with only minor changes to balance economic development with related environmental and social issues. There are, however, immense challenges that threaten the very sustainability of our global society, let alone individual businesses or developments. A few of the most important of these challenges—population growth, clean energy supply, fresh water availability, and global climate change—are discussed. As humanity forms its collective response to these threats, it is concluded that all intelligent people, but especially scientists, have important roles to play, not only in technical innovation, but also in catalyzing political action.

Keywords: sustainable development; sustainability challenges; human population; fresh water; energy; global climate change; scientists' responsibilities

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1. Introduction

As with any era, finding ourselves in the early part of the 21st century, it is prudent to look ahead to see where we are headed, to forecast the environments in which we will be living, to position ourselves for opportunities and to prepare for challenges. For several decades, the word "sustainability" has influenced our thinking about the future. Some businesses and industrial associations have realized that significant changes in their environmental footprints must be instituted in order to sustain production and markets. There exist others, however, that expect our businesses and our ways of living and behaving, with minor tweaking and fiddling, will steadily show continuous improvements and economic growth far into the future. It is the contention of this paper that the latter opinion is wishful thinking and that our future is going to be fraught with many challenges, which will necessitate our changing the way we live and behave, or changes will be imposed on us by Nature.

This paper will summarize some of these challenges and discuss how they might be approached.

2. "Sustainable Development"

Within the business world over the last four decades, sustainability has become a common word. Some companies have changed their organizational structures, renaming what were once called Environment, Health and Safety to Departments of Sustainability, which recognize that protecting environmental and workers' health and respecting the communities in which they operate are core values that help retain a "license to operate". Businesses have joined together to promote larger industrial ventures, such as Sustainable Mining and Sustainable Chemistry, in anticipation that the introduction of certain business objectives or standards of operating will provide a firm basis for being "green".

However it is packaged, the word sustainability means to support and maintain a condition so that it continues without interruption, diminution, giving way, fading, or yielding [1]. It means that we want whatever we are doing to continue to be done in the future. It was, in fact, just such a concern with "business as usual" and the perceived environmental degradation resulting from it, that inspired the Club of Rome in 1972 to issue a report [2], which urged the adoption of a global equilibrium that would be sustainable without sudden and uncontrolled collapse and that was capable of satisfying the basic requirements of all the world's people. This report was one of the first uses of the term "sustainable" aimed at operating modern businesses. It was, however, viewed by most economists and business leaders at the time as being voiced by a fringe group that lacked pragmatism.

2.1. Global Initiatives

In 1983 the General Assembly of the UN created a special, independent World Commission on Environment and Development chaired by Gro Harlem Brundtland. Tasked with formulating a global agenda for change, the Commission proposed environmental strategies for achieving "environmentally sustainable economic development", shortened to sustainable development, by the year 2000 across all nations. While the goal set by the Commission was not met in their desired time frame, the Commission assisted in having most informed people accept that (1) it was impossible to separate issues of economic development from environmental and social issues; and (2) sustainable development was not a final state, but rather was a manner of behavior and a process of decision-making that met current needs without jeopardizing the ability of future generations to meet their own needs [3]. It stated the belief that the process to achieve sustainable development was to integrate aspects of each development with its social issues and with accurate and holistic estimates of its environmental effects and costs.

As a result of growing international concern with ecological degradation, an Earth Summit was held in Rio de Janeiro in 1992. While this Summit succeeded in raising attention on the issue of environmental sustainability, few positive steps to tackle most of the issues on a widespread basis have been successful. An example of one successful initiative was the forum created out of Rio called the Business Council for Sustainable Development, consisting of multi-national businesses which wanted to lay the framework and sustainability principles upon which businesses could operate. In 1995 this forum joined the World Industry Council for the Environment to create the World Business Council for Sustainable Development, which has the potential for significant impact and influence on the philosophy and operating practices of industry in areas of environmental stewardship, maintaining open and competitive markets, in reducing poverty and in maintaining licenses to operate in society.

2.2. Inaction Is Rife

It has been 25 years since the World Commission on Environment and Development released its recommendation and it is appropriate to ask how the world has responded. Many people are talking the talk, but walking the talk is more difficult. The reason is no mystery: the relative scarcity of capital. Industries are almost always focused on a relatively short horizon because shareholders want a fairly rapid return on their investment. Truly proper attention to environmental impacts of a new development can be trumped, no matter how progressive and predictive of long-term success those attentions might be, by this quarter's bottom line.

But industry is not alone in this approach. Most social institutions, indeed all governments, are resistant to change and are especially good at equating a go-slow philosophy with stability. It is difficult for governments to rapidly embrace new ways of managing or regulating economic development.

Yet more and more evidence is being amassed that warns of dramatic consequences waiting in the not-too-distant future if certain problems are not addressed very soon. For example, an Earth system framework has been quantified by Rockström and colleagues [4] to define a safe operating multi-dimensional space for humanity. This space is defined by planetary boundaries which, should they be crossed by human activity, would risk irreversible or abrupt environmental changes that would likely negatively impact the sustainability of the entire system. While the location of these boundaries is far from exact, this work provides a framework by which a variety of issues can be debated, refined and acted upon.

It seems that humanity has a dilemma. The continued growth of our collective environmental footprint must change in order for it to be sustainable. But humans, and particularly human institutions, are afraid of changing too much too fast. We are a cautious species and, while this trait may have contributed to our success over the last 10,000 years, our current caution about societal threats and our failure to act on them will likely have drastic consequences that we would do well to fear much more than the fear of change.

History shows that inactions by societies under threat have been linked with their subsequent collapses. Diamond [5] concluded that the factors causing the collapses of many societies have remained constant over thousands of years: (a) local environmental damage (the Mayans and Easter Islanders); (b) climate change (the Anasazi in North America); (c) hostile neighbors (Mycenaean Greeks); (d) weakened important trading partners (Greenland Norse); and (e) the inadequacy of a society's response. The one factor that remained universal was the inability of a society to respond appropriately to the serious challenge(s) it faced. These societies became inflexible, they lost the means to respond, or they did not even recognize the need to respond.

A full litany of all the challenges our global society faces is beyond the scope of this paper. Several challenges are selected for discussion to characterize the breadth and seriousness of what we face: the growing human population, the continued reliance on "dirty" energy sources, the decreasing supplies of fresh water, and global climate change.

3. Human Population

The global population reached 7 billion people in late 2011. It's instructive to look at how we have attained this number. In 8000 BC it is estimated that there were 5 million people alive on Earth. By 1 AD the number was around 200 million, then 275 million in 1000, 1 billion in 1894, 2 billion in 1927, 3 billion in 1960, 4 billion by 1975 and 6 billion in 1999 [6]. The very rapid rise in population has occurred in the last 80 years. It will continue its meteoric rise to 9 billion by the middle of the 21st century and, if birth rates continue to decrease, will likely stabilize at 10–11 billion by 2100 [7].

This population, of course, is not distributed uniformly and neither are its energy consumption or carbon emissions. For example, while greenhouse gas emissions from human activities in 2000 was about 34 billion tons of CO_2 equivalent, which equates to 9.5 tons of CO_2 per person, the highest per capita annual emissions were for North America at 24 t, Australia at 19 t, Japan at 11 t, and Europe at 10 t. The largest geographical population densities in China and India contributed only 4 t and 2 t, respectively, but these per capita annual emissions are increasing at a staggering rate. In addition, the accumulated historical emissions per person per year over the period 1880–2004 show that the U.S. contributed 9 t of CO_2 equivalent compared to only 0.5 t for China and 0.2 t for India [8]. This widely differing historical impact feeds into ethical questions about the responsibility for reducing emissions, and it also feeds into the challenges associated with the much higher rate of pollution to be generated by developing nations like China and India in the short term future. Challenges of providing necessities of not only energy, but also food, and water, and desirables like health care and education, are related directly to population.

Furthermore, we live in a truly global world. No longer are problems encountered in one region limited only to that region. Globalization may have its advantages because people in distant parts of the world can lend assistance to those in trouble in another part, but globalization has the disadvantage that no part of the world is insulated from any other. Other peoples' problems become our problems. The pressure human population puts on the global society, and the concomitant challenges we face and will face when we fail to provide for the essentials for life, permeates and affects every other action we want to take to sustain the way we are living.

4. Energy

Increasing the complexity of a system from a simpler state requires the input of energy. Such a decrease in the entropy in a portion of a system, if done spontaneously, must be carried out far from equilibrium and often is the result of a system having within it extremes of temperature. Thus, the development of life on Earth, obviously where a simple system became more complex, was enabled by conditions far from equilibrium due to large temperature differences between the Sun and the Earth [9], and was sustained by a resulting massive flux of energy to the Earth. Likewise, inputs of additional energy by collections of humans organizing into groups, tribes, settlements and cities resulted in non-spontaneous developments of complexity, which resulted in significant gains in the collective abilities of people to provide for themselves, among other things, food, protection from adverse weather and enemies, and education. The maintenance of even static complex groups requires immense continued energy inputs [10].

Our global society, therefore, requires significant sources of energy just to maintain its current complexity, not even taking into account the increased energy investment that must be made to become even more complex (as, for example, with the increasing network of global systems of trade and with global communications networks such as the Internet). If, for some reason, a human society's supply of energy becomes less than it needs to maintain its complexity, it will collapse, often very rapidly. This is a fact we should look at very seriously for our current reliance on fossil fuels. While some people contend that the current energy situation looks rosy [11], such arguments should not be based on the estimated reserves of oil, coal and natural gas alone, but have to also consider what effects the continued use of these fossil fuels at ever-increasing rates will have on atmospheric constituents that contribute to climate change (see below). The fact is that fossil fuel sources on Earth are large, but they are dirty due to the deleterious effects of their by-products. It is clear that humanity's current reliance on the growth of fossil fuel use has to be, staring now, tempered with a search for (and research on) clean energy alternatives, improving the efficiencies of energy conversion into doing useful work, and reducing the per capita use of energy, particularly in developed countries around the world. Society needs to transform its energy source to one or several that are reliable and clean far into the future. Without such a transformation very soon, our continued uncontrolled usage of dirty energy will cause an environmental crisis with which we will be ill-prepared to contend [12].

5. Fresh Water

Water is essential for life and it has no substitute. Humans can live for a month without food, but most survive only a few days without water. It can be called not only an essential resource but an urgent resource. This resource, however, is taken for granted. Water appears to be plentiful because it covers 71% of the Earth's surface with a volume of some 330 million cubic miles [13]. Because there seems to be a huge amount of water available, we do not treat it as precious. The difficulty with water on Earth is that 97% of it is too salty to drink. Of the remaining 3% that is fresh water, 90% of that is currently frozen, leaving 0.3% of the total inventory as fresh and accessible [14]. However, the issue is further complicated by the fact that only 1% of fresh water is easily attainable in the rivers, streams and lakes of the world [15]. The remainder is underground. So, of the total water on the planet, only 0.003% of it is easily available, and that amount is not spread evenly across the world.

5.1. Drinking Water Supply Is Low

How is the human population doing in sharing valuable fresh water? In 2000, it was estimated that 1.1 billion people lacked safe drinking water [16]. That number has climbed dramatically since then. Just 4 years ago 46 countries with a combined population of 2.7 billion people had contentious water supplies [17]. This number, plus other information, fed into a Pentagon study pointing to fresh water shortages as a special factor in international security [18].

5.2. Diet

Diets influence water use. Increases in the consumption of meat in many parts of the world are requiring increases in water for raising the animals. An example of this is the Chinese, who have increased their meat consumption per capita from 20 to 50 kg/year over the 34 year period of 1985 to 2009. Raising the animals to feed this consumption requires 390 km^3 of water/year. This incremental amount of fresh water use for a change in Chinese diet is nearly equal to the total use of fresh water by all of Europe [19].

5.3. Underground Aquifers

Pumping fresh water from underground aquifers is occurring at alarming rates. The biggest user of water stored underground is agriculture. For example, in 2005 irrigation in the U.S. used 62% of all freshwater withdrawals [20]. And this will only grow with time. The United Nations estimates that 60% more water will be used by agriculture by 2025 [21]. Even though fresh water return to the Earth comes through precipitation, rain and snow events do not occur evenly and are not necessarily in the very places that need fresh water the most. The result is water scarcity in many regions, such as happened in the U.S. Midwest in the summer of 2012 when food production in this major food growing area was cut by severe drought. With 2 billion more people coming into the world by 2025, it is critical that major centers of food production operate at optimum levels because more people and less food and water are a recipe for widespread discontent and potential violence.

5.4. Conflicting Resources

Often resource needs conflict with one another. The Ogallala aquifer in the central U.S. is one of the largest in the world. It lies underneath 8 states and varies in thickness from 30 to 120 m [21]. Its volume of water would cover the continental U.S. to a depth of 0.6 m. Water from this aquifer is being pumped at a high rate. If all pumping were to cease today, it would take 6000 years to refill the aquifer naturally [22]. Plans have been put forward to run a major oil pipeline from Alberta to Texas across land above this aquifer. Oil from Alberta is an important component in North America's energy supply strategy. But the protection of the aquifer from unintended oil spills is also important. These conflicting needs are currently causing other options to be explored.

6. The Energy-Water Connection

6.1. Oil Sands

In mentioning the crude oil expected to come from Canada to be refined in the southern U. S, it is instructive to look at the connections between energy and water. Harvesting the bitumen-rich sands in Alberta is the world's largest energy project. It is expected to add $1 trillion to Canada's GNP by 2020. The oil resources in the Alberta tar sands contain more oil than in Russia, Kuwait, and Norway, combined. Under the assumption that only 10% of it is ultimately tapped, it is still the largest oil reserve after Saudi Arabia. All this sounds very promising. But a challenge is that extracting the bitumen to yield 1 barrel of crude oil takes 3–4 barrels of fresh water [23]. In addition, 280–350 kwh of energy is needed to extract and upgrade the bitumen to a barrel of synthetic crude [24]. This energy is supplied mostly by natural gas at the present time. The energy efficiency of the entire process, often quoted in terms of energy returned on energy invested (EROEI) is only 5–6. Some newly developed oil sands processes transform by-products into fuels, which can replace natural gas as the energy source, but the EROEI is only marginally improved.

6.2. Fracking for Natural Gas

Another example of the energy-water connection is related to the expectation that natural gas will serve as an energy source far into the future. The problem is that 90% of all natural gas wells in North America use hydraulic fracturing as the preferred method to crack open shale where the gas is trapped. The amount of water injected into each well amounts to 3–8 million gallons of fresh water [25]. With more than 450,000 gas wells currently operating in the U.S. alone, and with more being drilled each week, the continuing amount of fresh water consumed by these operations is not insignificant.

As fracking adds chemicals to the water for extraction, there is also concern about the potential for widespread pollution of underground water sources, as well as pollutants released to air.

6.3. Desalination

Many people hail desalination as the answer to supplying fresh water in the future. But that is not without its own set of challenges, namely, that it requires significant amounts of energy and it produces by-product brine that poses difficulties in its proper disposal.

7. Global Climate Change

7.1. The Sun and the Earth

One of the most significant challenges is climate change. In trying to understand climate change, it is important to understand variations in the Sun's and Earth's behaviors. Most energy received by the Earth ultimately is the result of radiant energy received from the Sun. This radiant energy has varied over its history from a somewhat lower luminosity when it was a young star to its luminosity at the present time. This change in luminosity, however, occurs on the scale of billions of years and it is not something that is an important factor in understanding Earth's climate on the scale of thousands or hundreds of years. Sunspot activity, on the other hand, has a much more frequent cycling period of about a decade, and certainly can affect the Earth's climate. We know, for example, that the last 50 years has had an overall decline in sunspot activity and that 2008 was a very low year [26].

The Earth's behavior plays a very active role in balancing the energy it receives with the energy it emits. The Milankovitch cycles describe variations in the Earth's distance from the Sun, and in the tilting and precession of its rotational axis, but these have relatively long periods of 20,000 to 100,000 years. Atmospheric gas composition is a very important factor because certain gases, such as CO_2 and CH_4, absorb infrared radiation from the Earth's surface and end up acting like a blanket in preventing this radiation from dispersing into space. The result, which was extremely fortunate for developing life on Earth, is that the climate is warmer than it would be had these gases been absent. Earth's reflectivity varies with the extent of ice and type of plant growth and is an important factor in climate. Also important, but episodic in nature, is the amount of dust in the atmosphere. Such dust, which has a global impact, is usually the result of a meteor impact or volcanic activity and it causes cooling due to its decreasing the amount of radiant energy being received by the Earth's surface.

7.2. The Status of Polar Ice

One of the main ways to monitor temperature change on the Earth is to watch the behavior of ice at the Arctic ice cap, the Greenland ice field, Antarctica's ice fields and the world's glaciers. The evidence being collected is alarming. Arctic ice, for example, floats on water just below water's freezing point. Its average thickness has decreased from about 6 feet 50 years ago to 3 feet currently [27]. The extent of Arctic ice is receding in area each summer at an accelerating rate [28] and it is forecasted that the Arctic could be completely ice free all year within a few years [29]. Very rapid changes in the extent of Arctic ice formation were observed in the summer of 2012. In just 5 days in early August information from satellite images showed that the thickest portions of ice just north of Greenland and north of the Bering Strait had disappeared [30]. This shows how susceptible Arctic ice is to relatively minor variations in temperature.

Another consequence of the Arctic potentially being ice free is that this might interfere with the Gulf Stream and the North Atlantic Drift. These major ocean currents are greatly influenced by thermohaline circulation [31]. If ice does not form off Greenland, then the salt level in surface water will not increase and this water will not sink. Such action, combined with other behavior, could potentially block the Gulf Stream water from bringing warmth to Europe with the result that Europe could experience profound climatic changes [32].

Greenland has an ice field bigger than the area of Mexico. It is second in ice volume only to the ice on Antarctica. Its ice fields are receding in area each year. During one period in the summer of 2012 the complete surface of Greenland's ice field was liquid water [33]. This resulted in significant volumes of water seeping through cracks in the ice and lubricating more rapid movement of glaciers as they transported fresh water to the sea [34]. The importance of Greenland's ice is that the melting of all this ice would raise oceans by 20 feet. This rise is small in comparison to Antarctica's ice fields, which, if melted, would raise the seas by 200 feet [35]. It is clear that not all of this ice is going to melt any time soon. The point of doing these calculations, however, is to recognize that any melting of polar ice raises sea level, and even a modest rise could have enormous impacts on humans living close to the sea. Each 1 m rise of the sea is equivalent on average to a 100 m horizontal spread [36]. Currently 108 million people live on land that is no more than 1 m above current sea level [37].

7.3. Glaciers

Glaciers are another indicator of climate warming. The Athabasca glacier between Banff and Jasper, Alberta, is about 6 km long and is 90–300 m thick. It moves several cm per day. Its nose has receded 1.5 km and it has lost one-half of its total ice volume over the past 110 years [38]. Its rate of recession is increasing. Similar symptoms are being observed for all the world's glaciers. For example, glaciers in Montana's Glacier National Park numbered 150 in 1850, but there are fewer than 30 glaciers still present there today [39]. Himalayan glaciers, which number 15,000 with a combined volume of 12,500 cubic kilometers of freshwater, are melting and receding [40].

7.4. Permafrost

Permafrost, another important frozen state of water, is also rapidly melting. For instance, in 1970 tundra travel could be carried out for more than 7 months each year. That has now been reduced to only 4 months per year [41]. When permafrost melts, it releases stored methane. Atmospheric concentrations of methane taken recently over a large area in Siberia showed that the amounts of methane being released were far higher than was predicted several decades ago [42]. Because methane is 20 times more effective in absorbing infrared radiation than is CO_2, increasing rates of methane emissions will increase the rate of global climate change.

7.5. Greenhouse Gases Increasing

The most watched greenhouse gas continues to be CO_2. Prior to 1750 and the industrial revolution, CO_2 concentrations in air varied narrowly around 275 ppm [43]. It then began a steady increase due to humanity's increasing reliance on burning fossil fuels for energy, and it is widely held that this combustion has played and will continue to play a dominant role in influencing atmospheric CO_2 levels. The best record of its concentration in air is from Mauna Loa in Hawaii, which has 50 years of data [44]. In 1960 atmospheric CO_2 was 315 ppm; by 2013 it had reached 400 ppm [45]. Its rate of change is also increasing to its current 2.5 ppm per year. It is likely that CO_2 will reach 450 ppm before 2033. As shown by ice coring results, CO_2 is higher today than at any time in the past 420,000 years [46].

Predictions of future CO_2 levels and the concomitant warming that will occur depend on future global economic activity and CO_2 emission rates, as well as the timing for significant uses of non-carbon energy sources to replace fossil fuels. Such predictions are difficult to make and have uncertainties. Despite this, it has been widely accepted that a 2 °C rise in average global temperature is associated with a CO_2 concentration of about 450 ppm. This level became a target by which strategies for controlling emissions could be formulated. Even with this seemingly small rise in global temperature, the negative effects on the environment and humans are predicted to be significant. These include a disruption in productivity of farms, forests and fisheries, a potential decrease in the resilience of plant and animal species that would cause some species extinctions and significant alterations in biodiversity, increased risks for coastal areas caused by sea level rise, increased erosion and flooding, increases in extreme weather events, particularly damaging storms and high localized rainfall, alterations in the spatial distribution of infectious diseases, increases in malnutrition and more stresses to drinking water supplies [47].

However, since only marginal actions have occurred on the world stage for controlling emissions to the amount needed not to exceed 450 ppm by 2030, a target of 450 ppm CO_2 is in great danger of becoming obsolete. What is a meaningful new target? If a business-as-usual scenario is considered, taking into account expected changes in population and extending current demographic and economic trends, it is estimated that a doubling of pre-industrial CO_2 levels (to 550 ppm) will occur by 2060 and would result in a 3 (±1) °C temperature rise [48]. If a leveling off at 550 ppm were to be targeted, global emissions of CO_2 would have to level off at 40 billion tons/year by 2035 (from 23.5 billion tons/year in 2000) and then be reduced to 22–26 billion tons/y by 2100 and further reduced to 11–14 billion tons/y by 2200. This kind of adjustment, while not impossible, would take, given the current lack of meaningful actions, a Herculean effort by the entire world.

We should not fool ourselves. Expecting to attain a target of 450 ppm CO_2 is rapidly becoming a fantasy. Even a higher target of 550 ppm CO_2 will be extremely difficult to achieve and will result in a world close to being roasted and unlike anything humans have experienced thus far. These predictions put into context just how dangerous and challenging our situation is.

7.6. Barriers to Action

If the scientific information about global climate change or any of the other societal threats is so compelling, and if the consequences that are certain to arise are so dire for the human condition, then why are humans unable or unwilling to take action? While certainly not an exhaustive list, there appear to be both psychological and societal reasons behind inaction [49]. On the psychological side, humans have, like other animals, an ability to respond rapidly to an immediate crisis. However, despite our brain capacity for analysis and planning, we are not adept at recognizing crises that take a long time to develop. One obvious reason for this is that we are too busy taking care of the multitude of minor problems that happen in daily living. Another reason is that a slowly developing crisis, particularly one that has not happened before, and one that will significantly alter the view of our security on which we have come to rely, can be too easily dismissed as an unlikely fiction. This enables us to keep putting off attending to this kind of potential crisis while it inexorably advances to becoming a reality.

On the societal side there are an enormous number of institutions and groups of powerful people who are heavily invested in propagating the current socio-economic model of continued growth. Governments of all sizes and types adhere to this paradigm and society in general embraces rules and personal behaviors that promote this as the best possible way for the world to function. Responses to societal threats would likely cause a serious readjustment of this world view. Furthermore, needed actions would cause deployment of massive financial attention to dealing with such threats. Neither of these results are favored by this paradigm. It is much easier and less worrisome to brush aside the threats and focus on continued economic growth.

7.7. Adaptive Cycles

There is, however, the question of whether the present cycle of growth can continue far into the future. Studies by Holling and his colleagues [50] about the natural adaptive cycles that exist for all living systems describe the repetitive phases of growth, collapse, regeneration, and the start of growth again. While growth is a phase we mostly associate with good health, Holling's message is that growth inevitably will result in a system that is characterized by a highly integrated complexity and a loss of redundancies. Such a system, given a shock from the outside, can rapidly collapse. While not necessarily a bad thing for the very long term health of the system because the collapse liberates enormous capabilities for creative reorganization and another phase of growth, a system collapse is not a happy situation for the components of the system suffering a collapse.

One of the more important aspects of Holling's work is panarchy theory, which views all living systems as having a nested combination of many adaptive cycles with varying periodicities. This means that while some parts of the system are nearing the end of growth, others may be able to build in overall resilience so that the inevitable collapse, when it occurs, may not be as deep or as calamitous as it would have been without the resilience in place. If global society is a panarchy of adaptive cycles with many economic and technological aspects operating in their late growth cycles, humans should anticipate that the system will collapse at some point. We need to be taking steps now to improve the resilience of our society so that we can best set the stage, when the current cycle of growth ends, for rapid creativity, reorganization and new growth.

8. Conclusions

Attending to the threats discussed above, as well as to other ecological and social concerns, requires an immense effort along multiple avenues. An agenda for action would certainly include some of the following:

(a) There must be an international commitment very soon to stabilize CO_2 in the atmosphere at 450–550 ppm. This would include a reduction of carbon emissions through international frameworks and funding strategies. Since fossil fuels as energy sources are likely to be used by humanity for a long time, there must be increased research on efficient capture and sequestration of CO_2 from burning fossil fuels. Research should be increased on storage options for spent fission reactor fuels and on using fusion reactors. There should be increased attention on how to harvest energies present in ocean currents, in atmospheric winds, and in solar energy.

(b) Research on climate change and other planetary boundaries must be funded to better define where thresholds exist for irreversible ecological changes. This work would increase the understanding of mechanisms and kinetics of the world's natural CO_2 sinks. It would also improve models for predicting the way human parameters adversely affect ecological systems. In the issue of fresh water, more research is needed on how to effectively interact with the global weather system to provide precipitation events where they are most needed.

(c) There must be an international plan to reduce population growth. This should include research on and implementation of the most effective approaches for educating people on family planning worldwide.

(d) There must be international actions to address the widening economic inequality across the world. As these inequalities are often the seeds of civil unrest, violence, and further ecological destruction, improving the lives of people in developing regions in areas of education, health, and social welfare is an alternative to solving these issues eventually by wasteful and destructive military means.

As can be seen by the repeated emphasis of international attention in this partial agenda, separate national or geographical policies and institutions are no longer able to cope effectively with the complexity and enmeshed issues of security and sustainable development for human society. However, it appears that the political leaders of the world are not inclined to act rapidly or meaningfully on this agenda, let alone on a more comprehensive list of challenges. The world needs another kind of leadership and passionate dedication on these issues. Another group of people, scientists from many disciplines, must step forward in large numbers to catalyze world action. Scientists cannot be silent waiting for leaders to come forward with appropriate strategies or for the international community to engage in prolonged debates about priorities. Scientists have been educated to honestly evaluate information and form it into reliable knowledge. While we must continue to apply this knowledge to create technical innovation in our fields of expertise, our obligations to society go much deeper. Our society needs its scientists to recognize the challenges society faces, to prioritize them, develop ideas and options for dealing with them, and to courageously articulate opinions and conclusions to others in plain language. Scientists can do this as individuals, but more importantly as groups using the professional and technical societies to which they belong. Lone individuals can be dismissed as mavericks, but a call to action by important and large scientific institutions would be far harder to dismiss. In doing this we would be using our talents to help define how all of us should behave in business and in our personal activities so that the people who come after us will have the best chance to enjoy the wonder of being alive.

Conflict of Interest

The author declares no conflict of interest.

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