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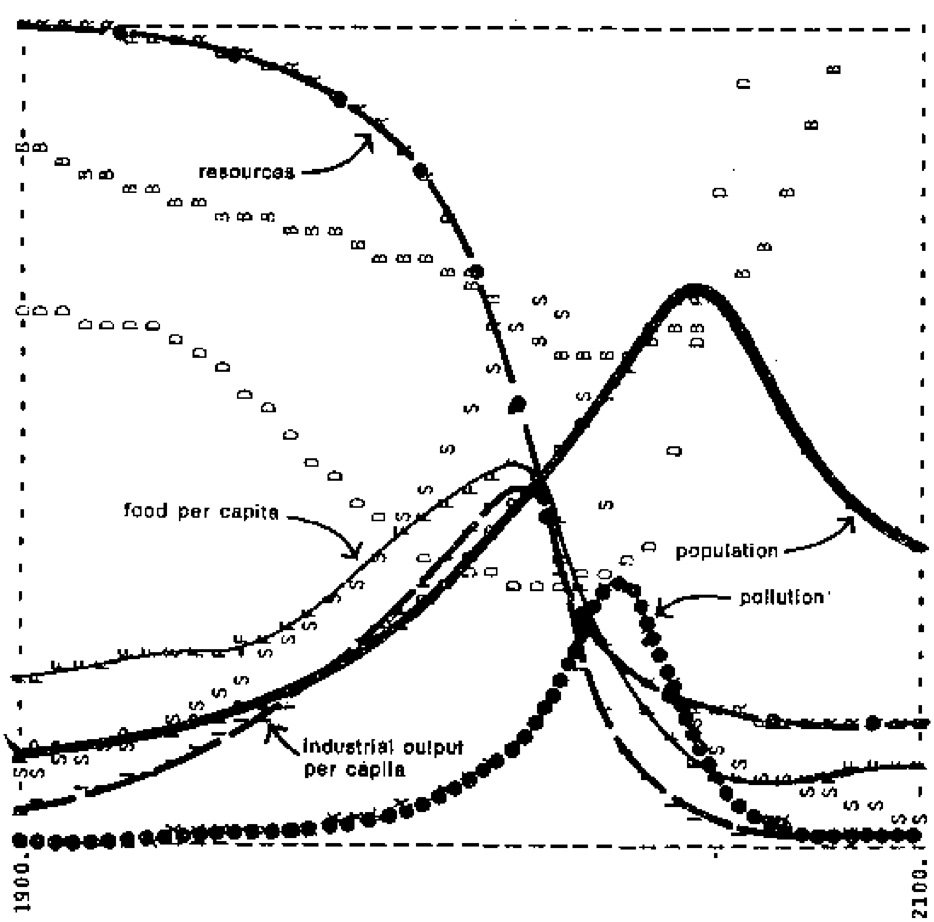
The Limits to Growth at 50: From Scenarios to Unfolding Reality

A half-century ago, the worlds of science, public policy, and economics were rocked by a prominent book, *The Limits to Growth*, authored by four systems scientists (Donella Meadows, Dennis Meadows, Jørgen Randers, and William Behrens III) from the Massachusetts Institute of Technology (MIT). The team produced computer-based scenarios showing that continued increases in population and industrial output would eventually prove to be unsustainable, and that the only path to a stable future was one in which levels of both population and industrial output were deliberately constrained by government policies. If growth continued, the crunch would not come immediately; the team's "standard run" (or business-as-usual) scenario instead showed major disruptions to world systems commencing in the first half of the 21st century.

The Limits to Growth sold 12 million copies, was translated into 37 languages, and remains the top-selling environmental book ever published. However, prominent economists (including Robert Solow, Milton Friedman, and Julian Simon) bristled at the idea that growth might have limits, and issued rebuttals that, while failing to address the core arguments of the book, nevertheless were cited repeatedly over the following years as authoritative refutations (an excellent overview and history of the debate can be found in Ugo Bardi's *The Limits to Growth Revisited*). *The New York Times Book Review* dismissed *The Limits to Growth* as "an empty and misleading work . . . garbage in, garbage out." *Newsweek* (a far more influential publication then than now) called it "a piece of irresponsible nonsense." Policy makers were happy to be relieved of the obligation to grapple with the book and its implications, and have essentially ignored it ever since.

Was it really "empty . . . misleading . . . irresponsible nonsense"? As we'll see, those judgments apply far more fittingly to the book's negative reviews.

Figure 35 WORLD MODEL STANDARD RUN



Caption: This graph, from page 124 of the March 2, 1972 first edition of the book, provoked panic and fury.

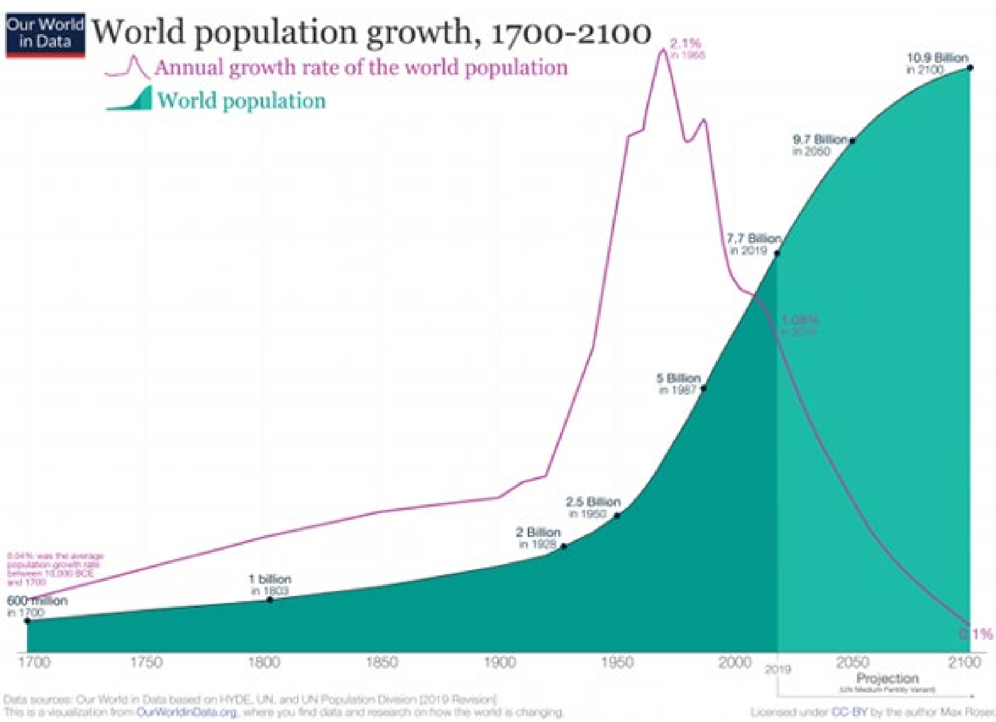
Using a simulation program called World3, the MIT modeling study generated a series of 12 scenarios that showed how resource depletion, population growth, industrial output per capita, pollution, and food production per capita would influence each other under various policy conditions. While the "standard run" scenario (with no policy intervention) showed the disturbing feature of peaks and declines in world population and industrial output in the early-to-mid-21st century, the team had no desire to see such an outcome materialize. Indeed, all the other scenarios were based on efforts to achieve a different and more desirable outcome. What if resources (including minerals and metals) were actually double the levels then estimated to exist? What if growth of population and/or industrial output were limited by government policies? In the best case, the economy could achieve a steady state, at least for the coming century—but that outcome would require substantial policy intervention.

Now we have the benefit of a half-century of hindsight. But we also have the great misfortune of living in a world that closely approximates the "standard run" scenario of the study. In this essay, I'll compare the scenarios with reality in broad terms, discuss what factors the *Limits to Growth* study didn't model, survey later re-assessments of the 1972 study, and explore what can still be done to minimize casualties as the expansive drive of humanity collides with planetary boundaries in real time.

1972 Scenarios

1. Standard run
2. Double resources
3. “Unlimited” resources with maximum recycling
4. “Unlimited” resources plus pollution controls
5. “Unlimited” resources, pollution controls, and increased agricultural productivity
6. “Unlimited” resources, pollution controls, and “perfect” birth control
7. “unlimited” resources, pollution controls, increased agricultural productivity, and “perfect” birth control
8. Stabilized population (equating birth rate with death rate starting in 1975)
9. Stabilized population and capital (capital investment equals depreciation)
10. Stabilized world model 1: technological policies (lengthening the lifespan of industrial capital) added to scenario 9, plus soil restoration
11. Stabilized world model 2: restrictions on growth of population and capital are phased in, to reflect likely delays in implementation
12. Stabilization policies are delayed until the year 2000

The Data Curves—Then and Now



Caption: World population and population growth rate from 1700 to present, with projection to 2100 based only on current demographic trends (i.e., no feedbacks from changes in pollution, per capita food production, or industrial output).

Population. Rather than simply forecasting future population levels based on the then-current growth rate, the authors helpfully discussed the factors and feedbacks that lead to either population growth or decline. In 1972, world population was 3.8 billion and growing at a rate of 2.1 percent per year. In the following decades some nations (notably China) intervened to slow growth, helping to reduce the world growth rate to today's level of 1 percent. Currently, population levels, totaling nearly 8 billion, are actually declining in a growing list of nations, including Japan, Italy, Cuba, and several Eastern European countries. While the "standard run" scenario showed global population peaking around the middle of the current century and declining rapidly, the world appears to be approaching the peak a little more gradually than would have been the case without national interventions, meaning that the peak will be at a somewhat lower population level—though not as low as in scenarios 6, 7, and 8, in which the world was assumed to achieve "perfect" levels of voluntary birth control starting in 1975, or scenarios 9, 10, and 11, in which population is stabilized by aligning the global birth rate with the death rate beginning that same year. Some demographers are now forecasting a population peak soon after mid-century, followed by a gradual decline—which would align with the "standard run" scenario. However, if the trends discussed below are not somehow reversed, the decline could begin sooner and be far more rapid than is generally foreseen.

Energy. The authors of *The Limits to Growth* did not attempt to forecast when or if the world's energy supply would peak. However, they did discuss the central role of energy in industrial production, the unsustainability of our societal reliance on fossil fuels, and the limits of the alternative energy source most frequently discussed in 1972—nuclear power. At the time of the book's publication, world energy production was growing rapidly: from 1960 to 1972, it expanded at 5.4 percent per year on average. Since 1973, that growth rate has slowed, averaging only 2 percent during the past half-century. This is partly a result of waning demand, due to the fact that the pace of world economic growth has likewise diminished (see below), but it's also important to understand that, as fossil fuels (representing about 85 percent of total energy) deplete, more effort is required to identify and extract remaining coal, oil, and gas resources. Since cheap energy is a key factor enabling economic growth, it is difficult to tell which trend is in the driver's seat—whether slowing economic growth is reducing energy demand, or harder-to-get energy is causing growth to slow.

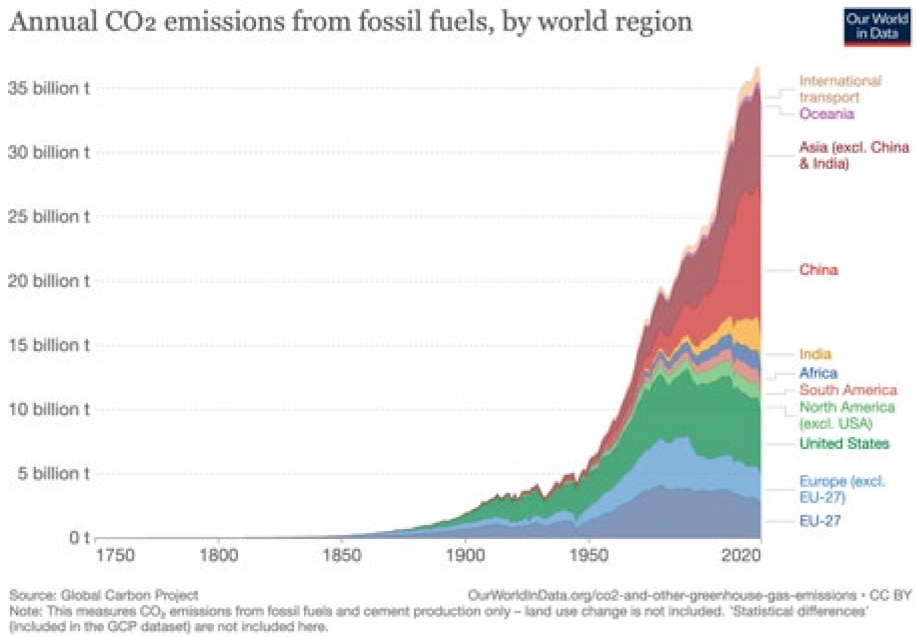
So far, alternative energy sources are not being deployed at rates that exceed overall energy usage growth, and the world continues to be overwhelmingly dependent on fossil fuels. Burning these fuels at growing rates results in increasing levels of greenhouse gas pollution, even though some mitigation efforts have been undertaken (see the section on "pollution" below). As fossil fuels continue to deplete, and as governments and investors sour on coal, oil, and gas due to their carbon emissions and climate impacts, "peak energy" is a realistic prospect sometime during the next 20 years, possibly even this decade. Due to the crucial role of energy in society, its peak in production would probably mark the end of economic growth as we have known it throughout recent decades.

Physical resources. Humanity currently extracts nearly 100 billion tons of raw materials each year, up from roughly 30 billion tons in 1972 (according to UNEP). *The Limits to Growth* offered a lengthy discussion of the rate at which various minerals were being depleted, and the likely limits to extraction of these resources. Renewable resources can be harvested faster than they can regrow, and this has been the case with forests and fish during recent decades. Nonrenewable resources simply deplete as they are mined. In all of the book's scenarios, available nonrenewable resources decline, though they decline more quickly in the "standard run" scenario than in those in which policies limit population and/or consumption. Negative reviewers of the book seized upon resource estimates on pages 56 through 60 (which were drawn primarily from publications by the US Bureau of Mines), claiming that more resources certainly exist, awaiting discovery. However, the authors anticipated this criticism by including a scenario in which available resources turn out to be double then-current estimates. In this double-the-resources scenario, industrial production reaches higher levels and collapse is delayed (though only by a decade or two), triggered by higher pollution levels. The authors even included a third scenario, in which energy is unlimited and all resources are recycled. Again, pollution was shown to trigger a somewhat delayed collapse.

Among policy makers today, relatively little attention is devoted to the dilemma of resource depletion. During the first decade of this century, there was a lively discussion about "peak oil;" however, intensive petroleum production methods (hydrofracturing and horizontal drilling) and higher rates of investment delayed the decline in world oil production by roughly a decade, leading to a widespread, though unfounded, perception that the problem of oil depletion had been solved or was unworthy of serious interest. Another critical nonrenewable resource, however, is receiving considerable concern: mined phosphorus, which is an essential input to industrial agriculture (scarcity is possible later this century, and there are no known substitutes). Gold and uranium are also likely to become scarce later this century, as known deposits are being drawn down rapidly. Also, some analysts have sounded an alarm with regard to future resource demand triggered by the planned shift to renewable energy sources such as solar and wind. Renewable energy and battery technologies will require enormous amounts of copper, silica sand, cadmium, gallium, germanium, lithium, and rare earth elements. Even assuming high rates of recycling, scarcity later this century for some or all of these materials is likely.

One frequent and predictable consequence of resource depletion is the need for higher investment per unit of output. This is an unavoidable dilemma that can be only partly or sometimes resolved through higher rates of recycling or the development of new technologies. Typically, the effects of depletion (including the need to rely on continually lower grades of ore) are countered by the application of more energy to mining efforts. But this strategy will likely become problematic as our major sources of energy also become further depleted.

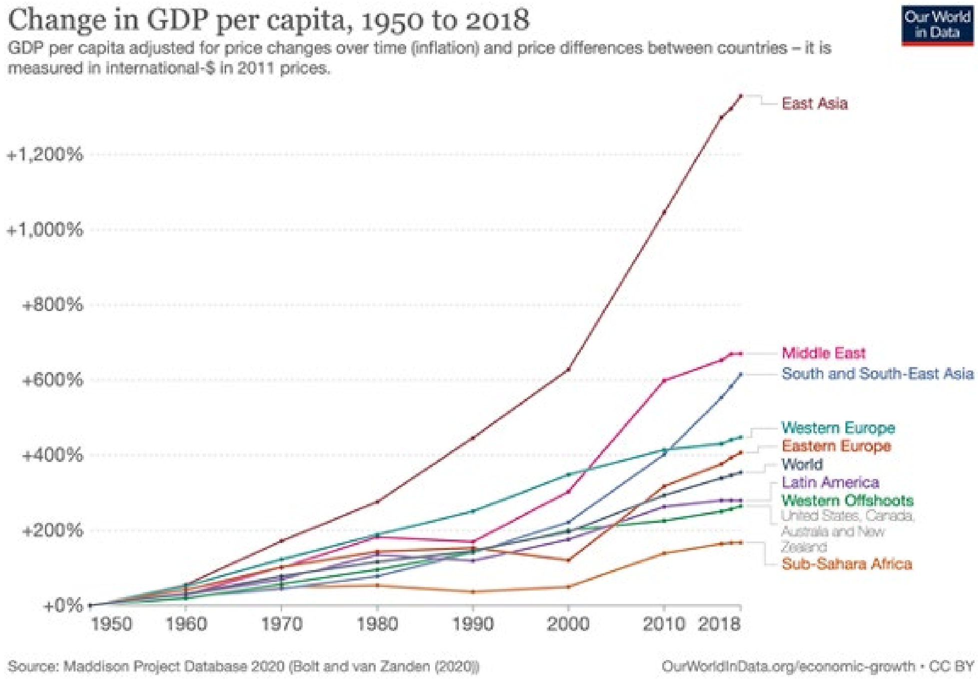
Of all our natural resources, freshwater is arguably the most crucial for the maintenance of human life, let alone advanced civilization, and localized water scarcity seems extremely likely in the coming decades. Aquifers are being depleted, mostly for irrigation, and the glaciers that provide water for up to 2 billion people are melting. Soil is also being depleted and degraded through accelerated erosion and salinization driven mostly by modern industrial agriculture. Together, the loss of freshwater and the ruination of soil threaten future food production (see "food production" below).



Caption: World greenhouse gas emissions. Source: Our World in Data; data from Global Carbon Project.

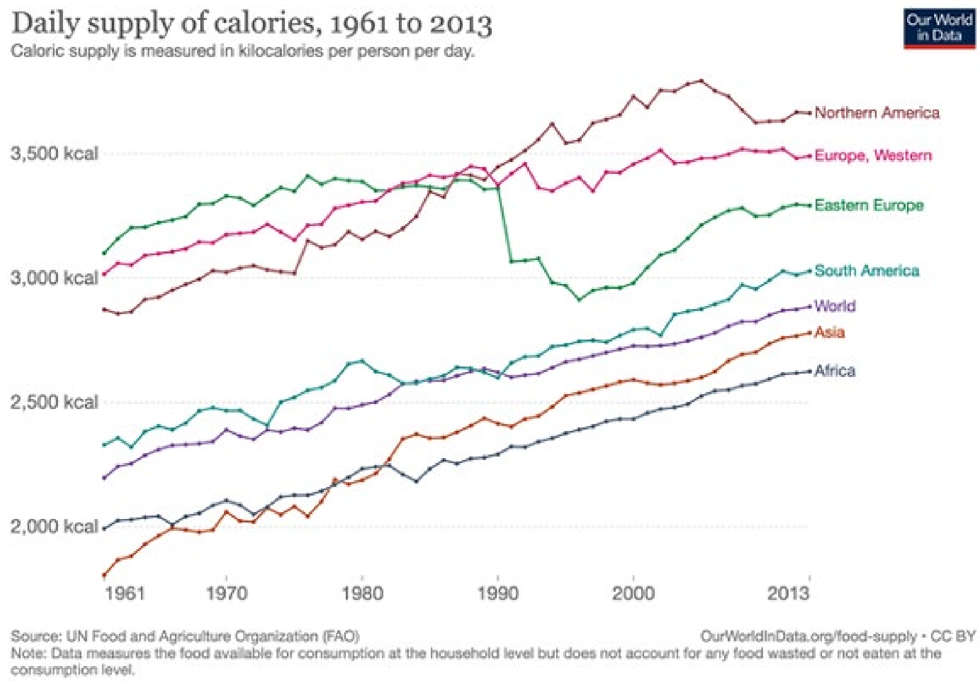
Waste/pollution. The authors of *The Limits to Growth* viewed pollution as an important limit to economic expansion. Already, in 1972, serious adverse consequences were being attributed to pesticides such as DDT, artificial fertilizers, and many industrial chemicals. Since then, some success has been achieved in banning or regulating a few toxic chemicals, including DDT (at least in most countries), thus preventing some environmental harms. However, newer neonicotinoid pesticides appear to be decimating populations of bees and other beneficial insects, and endocrine-disrupting chemicals appear to be causing alarming reductions in sperm counts in humans and other animal species.

As mentioned above, the most widely discussed pollution problem of our time is the release of greenhouse gases from the burning of fossil fuels. Some efforts have been made to curb carbon dioxide emissions, especially in wealthy countries—though such efforts are not nearly sufficient, as total emissions are still growing. *The Limits to Growth* discussed CO_2 emissions on pages 72-73, projecting that, if then-current trends continued, the atmospheric concentration of carbon dioxide would reach 380 parts per million by 2000. In fact, with somewhat reduced rates of growth in energy usage in the years after 1973, CO_2 concentration in 2000 reached only about 370 ppm; the current level is nearing 420 ppm. So, the situation with regard to carbon emissions is not quite as bad as it might have been, but grim indeed nevertheless. The last time atmospheric CO_2 amounts were this high was more than 3 million years ago, during the Mid-Pliocene Warm Period, when temperature was 2°–3°C (3.6°–5.4°F) higher than during the pre-industrial era, and sea level was 15–25 meters (50–80 feet) higher than today.



Caption: GDP per capita, 1950-2018 for World and regions. Source: Our World in Data.

Industrial output. The "standard run" scenario showed a peak and decline in per capita world industrial output occurring roughly simultaneously with a peak in food production. Industrial production tracks closely with inflation-adjusted GDP, data for which are readily available, so it is fairly easy to compare recent trends with the 1972 scenarios. Growth slowed in older industrial countries starting in about 1999, while the economies of China and India have leapt ahead. Growth in energy usage and greenhouse gas emissions has likewise largely shifted from Europe and America to Asia. Future increases in industrial output will, of course, depend on the prices and availability of energy and raw materials, and on the impacts of greenhouse gases and other pollution.



Caption: Food supply in kilocalories per person, 1961-2013. Source: Our World in Data, data from UNFAO.

Food production. In the 1970s, ecologist Paul Ehrlich voiced concern that population growth would lead to famine before the commencement of the 21st century. That did not happen. Instead, the amount of land under cultivation expanded, and more intensive agricultural methods (based on the expanding use of fertilizers and pesticides, as well as increased irrigation and more productive breeds of wheat and other grains) led to soaring harvests and per capita food supplies that more than kept pace with population growth. However, there are ongoing costs associated with these strategies, including soil degradation, habitat loss, and pollution. In many parts of the world, adding new increments of artificial fertilizer is now yielding diminishing returns. Further, there are limits to the continued expansion of arable land, and climate change could impact industrial agriculture by, for example, melting the snowpack and glaciers that supply irrigation water to large and populous regions of the planet.

As of 2022, world food prices are at the highest levels in two decades due to supply-chain issues partly related to the COVID-19 pandemic. This fact highlights the problem of interacting trends: not only do they make predictions more problematic, they also often make systems more brittle than they might otherwise be. A financial crisis, for example, can reduce investment in energy production; resource depletion can hobble industrial agriculture; higher energy prices can hike the cost of transporting food and raw materials from one region to another. If even one of the major components of the world food system fails significantly, the entire system can be hobbled. As we have just seen, each of those components is facing a sustainability crisis.

What the Report Left Out

The authors of *The Limits to Growth* could not hope to model all of the possible future constraints on society's ability to continue expanding. For example, it was well known in the early 1970s that a major war, especially a nuclear war, could greatly influence the trajectory of growth in population and industrial output. However, the authors of the report noted that "we have . . . ignored discontinuous events such as wars or epidemics, which might act to bring an end to growth even sooner than our model would indicate. In other words, the model is biased to allow growth to continue longer than it probably can continue in the real world."

It was for this reason, among others, that the authors insisted that their "standard run" scenario should not be regarded as a forecast of future events. Many may think of it as a worst-case scenario, in that it did not reflect policy interventions that could slow population growth, pollution, or resource depletion. But really, it was a better-than-worst-case scenario, because it did not reflect the impacts of hard-to-predict events such as the COVID-19 pandemic.

There was understandably no attempt by the 1972 team to model the possible interactions of finance and debt with trends in material factors such as resources, industrial output, and population. In the years after the book's publication, the industrial world began inflating a debt bubble, based on expectations of perpetual growth, that almost popped in 2008; since then, that bubble has reinflated to unprecedented proportions. It is clear to many economists that an uncontrolled deflationary debt crisis could cause immense damage to the physical economy, but no one knows if or when the bubble will burst.

Elsewhere, I (among many others) have written about the loss of social cohesion that appears to be occurring in many countries, notably the United States. Though it was not modeled in the *Limits to Growth* study, social cohesion is essential if societies are to respond proactively to threats such as climate change. However, it is difficult to quantify social cohesion, or to forecast trends in it (though ecologist Peter Turchin has made efforts to do both of these things, using data and methods that were unavailable in 1972). In Turchin's view, declining social cohesion is tied to increasing economic inequality (among other factors).

The authors of *The Limits to Growth* discussed inequality on pages 147 and 178-180 of the original edition of the book, pointing out that "present patterns of population and capital growth are actually increasing the gap between the rich and the poor on a worldwide basis. . . ." The dramatic growth of the economies of China and India has reduced world poverty and inequality by some measures; however, by other measures inequality has deepened substantially in the last two decades. How increasing inequality might interact with other trends was not explored in the 1972 book.

While the book discussed impacts on nature from increasing levels of pollution, it did not attempt to model the extent of future loss of wild nature (the word "wildlife" was not mentioned, and the word "biodiversity" had not yet come into common usage). In actuality, this loss constitutes one of the most significant global trends of the past few decades. Recent assessments show that, since 1970, roughly two-thirds of wild mammals, birds, amphibians, reptiles, and insects have disappeared. Species are going extinct at roughly 10,000 times the rate that occurred in pre-industrial times. The full impact on human society of this ongoing biological holocaust has yet to land.

Although *The Limits to Growth* mentioned climate change as a likely possibility, it did not attempt to forecast specific impacts. The authors noted (on page 81): "It is not known how much $C0_2$ or thermal pollution can be released without causing irreversible changes in the earth's climate." Now we have a much better idea. A broad scientific consensus has emerged that global temperatures are increasing, weather extremes are growing worse, glaciers are disappearing, and sea levels are rising. Hundreds of millions of climate refugees are forecast by the end of the century, and food systems could be profoundly impacted. Unfortunately, discussions about threats to our future have tended to become narrowly focused on carbon emissions to the exclusion of any other growth limits.

A few critics of *The Limits to Growth* decried its lack of critical commentary on politics and economics. Johan Galtung, the Norwegian father of peace studies, wrote in 1984: "The book gives its message in what looks like a 'non-political' form: at no point are political constants and variables introduced. It presents the world, with rich countries and poor countries, with oppressors and oppressed, with all of us, as if this were an ecological system with some animal and some non-animal components, a thermodynamic system. . . ." When interviewer Christian Parenti asked Dennis Meadows about this in 2012, the latter conceded the point: "It was outside the scope of our work. We didn't talk about the political and economic aspects of the problem because politics—states—are too diverse. Lumping all states into a single variable is not plausible."

Later Re-assessments

The *Limits to Growth* team produced two subsequent books, *Beyond the Limits* (1992) and *Limits to Growth: The 30-Year Update* (2004)*,* both authored by Donella Meadows, Dennis Meadows, and Jørgen Randers. In each, the team discussed progress in systems science, and updated the data trends that were modeled by World3 back in 1972. In both follow-up books, the authors concluded that humanity has overshot the limits of what is physically and biologically sustainable, and that overshoot will lead to industrial collapse if we do not act rapidly and effectively to reduce resource extraction, pollution, and population growth.

Sadly, with the untimely death of Donella Meadows in 2001, further book-length efforts by the original team to update its methodology and data have not been undertaken. However, a book that will be published later this year, *Limits and Beyond: 50 Years on from The Limits to Growth, What Did We Learn and What's Next?* (Exapt Press, April 2022)*,* will bring together two of the original authors from the 1972 book, Dennis Meadows and Jørgen Randers, along with an array of other world-renowned thinkers, scientists, analysts, and economists to grapple in much more depth with the issues explored in this article.

Meanwhile, several researchers have made independent efforts to assess the methodology and results of the 1972 study. Two are especially noteworthy.

In 2008, Graham Turner of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) published a paper titled "A Comparison of 'The Limits to Growth' with Thirty Years of Reality." It assessed scenarios laid out in the 1972 book in light of the past three decades of data and found that changes in industrial production, food production, and pollution are all roughly congruent with the "standard run" scenario. "The data do not compare well," wrote Turner, "with other scenarios involving comprehensive . . . stabilizing behaviour and policies."

In 2020, an analysis by Gaya Herrington (Sustainability and Dynamic System Analysis Lead at KPMG, though acting in a personal capacity) was published in Yale's *Journal of Industrial Ecology*. The study, which examined models from *The Limits to Growth: The 30-Year Update,* looked at data on population, fertility rates, mortality rates, industrial output, food production, services, non-renewable resources, persistent pollution, human welfare, and ecological footprint, and concluded that the "business-as-usual" scenario is a close fit, though a couple of other closely aligned scenarios also track the data well, and that, if major changes to resource consumption are not undertaken, economic growth will peak and then rapidly decline by around 2040.

What to Do—Then and Now

The authors of *The Limits to Growth* tried to model the results of various government policies that would affect the interacting parameters of World3 (population growth, resource depletion, pollution, and industrial output). The policies that were found to shift trends away from peaks and declines, at least for the current century, were these:

Stabilizing population by setting the birth rate equal to the death rate in 1975, with an average desired family size of two children. The book contained little discussion of population growth reduction methods, aside from full access to contraceptives.

Implementing radical efficiency in resource usage, so that resource consumption per unit of industrial output is reduced to one-fourth the 1970 value. This could be achieved by recycling as much material as is physically possible.

Shifting from encouraging consumption to fostering human development. Instead of maximizing manufacturing and sales of products, focus economic and priorities and policies on education, health care, and cultural activities.

Reducing pollution per unit of industrial and agricultural output. This requires identifying and adopting less-polluting technologies, methods, and materials.

Diverting capital to making food affordable for everyone. The authors anticipated that the above conditions would result in changes to the food system that might increase levels of malnourishment, absent policies to make food more affordable.

Prioritizing sustainable agriculture. Devoting more capital to food production would likely result in more soil erosion and pollution, unless steps were taken to reform agricultural practices.

Increasing the lifetime of industrial capital. The authors note: "The drains on industrial capital for higher services and food production and for resource recycling and pollution control under the above six conditions would lead to a low final level of industrial capital stock. To counteract this effect, the average lifetime of industrial capital is increased, implying better design for durability and repair and less discarding because of obsolescence. This policy also tends to reduce resource depletion and pollution."

These have been the key policy recommendations issued by environmental organizations ever since—in addition to ecosystem protection and restoration, and energy source switching.

However, timing is of the essence. In the final 1972 *Limits to Growth* scenario, stabilizing policies are introduced later (in the year 2000) rather than sooner (1975); in that scenario, "population and industrial capital reach levels high enough to create food and resource shortages before the year 2100." Sadly, as of 2022, those stabilizing policies still have not been fully implemented.

Today, policy options are highly constrained: in order to avert peaks and substantial declines in food and industrial production later this century, so much would have to be done that the policies themselves would be extremely disruptive to society. Over the past decade, the world's efforts to avert environmental harms have become focused primarily on climate change; resource depletion and overpopulation are now largely ignored. And the fight against global warming is not going well.

Still, while policy makers have failed to prevent sustainability crises that have already begun and will almost certainly worsen throughout the remainder of the century, further inaction just ensures the worst possible outcome. We can do things to minimize casualties and leave the survivors with more options. As Dennis Meadows put it to me in a recent email:

> "The challenge in any retrospective on *The Limits to Growth* is to make it more than just 'I told you so, and now comes doom.' The last time greenhouse gas concentrations in the atmosphere were this high, the sea was 20 meters higher. There were no *Homo sapiens* around then, and I fear there won't be any around a few centuries from now. But in the meantime, let's try to spur constructive action. For me that means exploring the options and means for a peaceful and equitable decline and strengthening the resilience of all our critical systems."

For suggestions that might lead us toward a peaceful and equitable decline, see Howard and Elisabeth Odum's *A Prosperous Way Down* (2001), my own book *The End of Growth* (2011), and innumerable articles published at www.resilience.org. In the near-absence of government efforts to implement stabilizing policies, organizations such as the Transition Network are fostering people-powered sustainability change at the community scale. Meanwhile, governments and the mainstream think tanks that advise them are beginning to invest in resilience-building strategies, since it is clear even to them that hard times are coming.

Thanks to Anna Ostermeier for help with data in the preparation of this article.