Earth 2020

An Insider's Guide to a Rapidly Changing Planet

Edited by Philippe Tortell

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Earth and Plastic

Roland Geyer

A few months after the first Earth Day, in summer 1970, a handful of researchers at the Massachusetts Institute of Technology (MIT), began to work on a computer simulation that would forever change the way we think about the world. The research was ground-breaking in multiple ways. It used a novel mathematical modeling technique called system dynamics, and an equally novel approach, computer simulation, to study the interactions between human society and the natural environment on a global scale. In particular, the project examined what could happen when exponential growth in human population and economic output is confronted with the finite resources of planet Earth. Today, PhD students run much more complicated simulations on their laptops, but back then, this approach was in its infancy, and non-linear behavior of systems was neither well understood nor studied much.

Results from the MIT study were published in a 1972 book called *The Limits to Growth*, which contained dire prognoses about the consequences of continued exponential growth of the human population and the global economy.[1] The book sparked instant controversy and received fierce criticism, especially from economists. This was perhaps to be expected; claiming that business as usual would lead to global 'overshoot and collapse' is unlikely to make you popular. One widespread criticism was based on the erroneous interpretation of the study as predicting the depletion of non-renewable resources within a few decades — a

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depletion that did not materialize. However, rather than generating any singular predictions, the computer simulations were conceived as a means of exploring many plausible if-then scenarios. Critics also commonly overlooked the fact that many model runs predicted overshoot and decline even when resources were assumed to be limitless. In these model runs, it was Earth's capacity to assimilate human wastes and emissions (represented as pollution in the model), rather than the supply of raw materials and fuel, that became the critical environmental constraint on the continued growth of the economy.

Today, nearly half a century after the MIT study, there is growing consensus that environmental pollution caused by wastes and emissions is of far greater concern than depletion of non-renewable resources. Fossil fuels are the perfect example for this general insight. Since the 1970s, there have been various predictions for the year in which global oil production would peak and then steadily decline. Early predictions were off, since they did not account for unconventional sources of oil, such as tar sands and shale oil, and novel technologies, such as horizontal drilling and hydraulic fracturing (fracking). While the controversy over 'peak oil' continues, it is largely irrelevant; the true environmental constraint on fossil fuel consumption is the amount of carbon dioxide (CO_2) released into the atmosphere, and the effects of this long-lived greenhouse gas on global climate.[2]

In 1970, global atmospheric CO_2 abundance was approximately 320 parts per million (ppm). In 2018 it reached 410 ppm, enough to cause potentially catastrophic climate change.[3] During the same period, global annual CO_2 emissions from fossil fuel combustion had increased from 14 to 34 billion metric tons, or Gigatons (Gt). According to British Petroleum's Statistical World Energy Review, global proved fossil fuel reserves at the end of 2018 were 1,730 billion barrels of oil, 197 trillion cubic meters of natural gas, and 1,055 Gt of coal.[4] 'Proved reserve' here means that the resource could be recovered with reasonable certainty under existing economic and operating conditions. The combined proved fossil fuel reserves contain well over 1,000 Gt of carbon. If all of this carbon were combusted and released into the atmosphere as CO_2, it would further raise the atmospheric CO_2 levels to a point that would make any efforts to avoid catastrophic climate change completely futile. In other words, we will have wrecked the climate long before we run out of fossil fuels.

Not all extracted fossil fuels are burned, though. Today, 14% of oil production and 8% of natural gas extraction is used to make petrochemicals, such as plastics, fertilizers and a multitude of other chemicals. Petrochemicals production as a whole experienced enormous growth since the end of the Second World War, and the rise of plastics, in particular, is its most visible manifestation. As a mass-produced material, plastics are barely seventy years old.[5] In 1970, the year of the first Earth Day, global annual production of plastic polymer resins, fibers and additives was 37 million metric tons, or megatons (Mt). In 2017, global annual plastics production had reached an astounding 438 Mt, an eleven-fold increase in less than fifty years. By the end of 2017, humankind had produced a total of 9.2 Gt of plastic. That is the equivalent mass of 900,000 Eiffel Towers, or 88 million blue whales, or 1.2 billion elephants. If spread out ankle deep as low density plastic waste, it would cover an area the size of Argentina, the eighth largest country in the world. The growth of global annual plastic production has been so large and sustained that half of all plastic ever made by humankind was produced in just the last thirteen years. In other words, in just a little more than the past decade alone, we have doubled the total amount of plastic ever made.

While some might regard the global rise of plastic as a fantastic economic success story, others see an environmental tragedy. Many plastic products are short lived — plastic toys, household items, or fast fashion made from synthetics, for example. But it is packaging that has the shortest lifetime of all plastic products. Packaging accounts for around 36% of plastic production, most of which is used once and then disposed of. As a result, much plastic becomes waste soon after it was produced, and plastic waste generation can thus be expected to closely track plastic production. Unfortunately, solid waste generation data are much harder to come by than material production data — clear evidence that we consider the generation of solid waste an inconvenience, and treat it as an afterthought.

We love buying new things, in alluring and convenient packaging, but we also seem to expect that the old stuff will just disappear once we throw it into our garbage bins. This may have been true at some point in the past, when the majority of our trash would rot or corrode away. It is certainly not true for the plastics we have made so far, since they do not biodegrade on any reasonable timescale. In fact, all of the plastic we have made and did not burn, or otherwise destruct thermally, is still present on this planet. This is estimated to be 86% of the plastic waste humankind has thus far generated. An estimated 6 Gt of plastic waste is therefore present somewhere on this planet: in landfills, or open dumps, or in the natural environment. Another estimated 3 Gt is currently in use and will become waste as soon as we're done with it, which won't be long.

While we can estimate how much plastic currently resides on the planet, we do not know where exactly it is. Conventional plastic polymers don't biodegrade, but become brittle and disintegrate into smaller and smaller pieces, which then disperse in the environment as so-called micro-plastics. Wherever we look for plastic we find it. Plastic has been found in ocean creatures of all sizes and trophic levels, from plankton and seabirds to fish and whales. It's on the ocean surface, in the water column, and on the world's beaches, river beds and ocean floor, including its deepest point, the Mariana Trench, more than 11 km below sea level. Plastic has been found in arctic sea ice, in snow, rain, tap water, bottled water and beer. In the year 2010 alone, 5 to 13 Mt of plastic entered the world's oceans from land due to littering or mismanagement of plastic waste.[6] Terrestrial plastic pollution has so far received less attention than plastic marine debris, but we know that plastic is also everywhere in the soil. In fact, due to its ubiquity, plastic has recently been proposed as a geological indicator of the proposed Anthropocene, the period in which many geological surface processes started to be dominated by humans. A sediment core taken off the coast of Southern California shows the first appearance of micro-plastic in its sedimentary depth layers around 1950, with a subsequent doubling about every fifteen years thereafter. The long-term consequences of such pervasive and near-permanent plastic pollution are unclear at this point, but there are many reasons to expect significant adverse ecological and human health effects.

Traditional approaches to solid waste management are unable to cope with the ever-growing amount of plastic waste. Developed economies rely on a mix of landfill, incineration and collection for recycling. Landfill of plastic is essentially permanent storage of the waste material. Apart from the land, money and overall effort required, landfill also raises concerns about the generation and emission of hazardous substances. On average, about 8% of finished plastic consists of so-called additives; complex chemicals such as plasticizers, flame retardants and stabilizers, some of which are known to be hazardous. Many developed economies are aiming to reduce landfill rates by increasing incineration and collection for recycling. While plastic incineration rates are high in many European countries, waste incineration remains unpopular in the United States. The environmental and health impacts of waste incinerators very much depend on their emission control technology, as well as incinerator design and operation. Recycling delays rather than avoids final disposal, unless it reduces virgin plastic production (i.e. synthesis of plastics from hydrocarbon building blocks). European countries and the US used to send up to 60% of their plastic waste collected for recycling to China and Southeast Asia, but these countries are accepting less and less of it. In addition, plastic recycling suffers from poor environmental and quality control or poor economics, since it has to compete against cheap and abundant supply of virgin plastic. It is estimated that only 9% of all plastic ever made has been recycled. Many developing economies lack solid waste management infrastructure and have high rates of mismanaged plastic waste.[7] Considering all of these challenges, it is perhaps not surprising that a sizeable fraction of our plastic ends up in the natural environment.

The virgin plastics industry frequently states that using plastic is actually environmentally beneficial, since it replaces heavier and more impactful materials, including metal and glass. This argument not only implies that the environmental impacts of plastic production, use and disposal are lower than those of alternative materials, but also that plastic is being used instead of these other materials. Unfortunately, global production of all human-synthesized materials has been increasing, so we're actually using plastic in addition to everything else, not instead of it. In the fifty years since the first Earth Day, global annual production of hydraulic cement increased seven-fold, while primary aluminum and crude steel production grew by factors of five and three, respectively. Along with our increasing use of various materials, solid waste generation in general is also increasing year over year. Producing and using more materials each year does not just mean that there will be more waste when these materials reach the end of their useful lives. Materials cause environmental impacts throughout their life cycles, such as ecosystem disturbance during extraction, and wastes and emissions all along their supply chains. What we throw into our garbage bins is just the tip of an ever-growing 'wasteberg'.

Material recycling, which has recently been repackaged as part of the 'circular economy', is unlikely to be a panacea.[8] Collection and reprocessing of solid waste into secondary material has its own environmental impacts. These impacts are typically much lower than those of making the same material from primary resources, like ores, but they are still significant. Recycling therefore only decreases environmental damage if it significantly reduces primary material production. So far this has not happened. The currently empty promise of recycling is perfectly illustrated by a petrochemical engineer, who stated that 'we passionately believe in recycling' while overseeing the construction of a brand-new, 'as big as you get' virgin plastic plant that will be fueled by abundant Marcellus Shale gas.[9]

Another proposed solution that is not going to work on a global scale is the so-called 'bio-economy', in which fuels and materials are made from biomass rather than non-renewable resources. Utilizing waste from agriculture and forestry for fuel and material production is certainly attractive, but there is nowhere near enough biowaste for a large-scale replacement of non-renewable fuels and materials. Instead, this would require vast amounts of dedicated crop production and thus agricultural land. It is now clear that the climate change and land use impacts of global food production are imposing significant stress on Earth's terrestrial ecosystems.[10] Imagine how much those impacts would increase if we produce biomass not just for our food and feed, but also to supply all our fuels and materials. To make things worse, some bioplastics and biofuels, such as polyhydroxyalkanoates (PHAs) and corn-based ethanol, have been shown to have greenhouse gas emissions that are similar or even higher than those of their fossil-based competitors. A global bio-economy would also massively increase other environmental impacts, such as eutrophication from fertilizer runoff, where excess of nutrients leads to harmful algal blooms and oxygen depleted 'dead zones' in water bodies.

At this point, the only meaningful path forward will have to include substantial reductions in the amount of materials we produce and use, unless we are willing to see further increases of CO_2 in the atmosphere, plastic in the oceans, nitrogen in our estuaries and coastal waters and so on. It is telling when the CEO of Recology, a major resource recovery company, publishes a newspaper op-ed entitled 'It is time to cut the use of plastics'.[11] I have no doubt that a large reduction in our material footprint is compatible with a good life. If anything, maintaining the latter will require the former, since the relentless growth of the global economy seems to be finally hitting the environmental limits of this big, but finite, planet. This brings me back to *The Limits to Growth* study, conducted almost fifty years ago. One final error of its critics is the belief that history proved it wrong a long time ago. But the standard scenario in the report made projections well beyond the year 2050, finding that global population would peak around that time and decline sharply thereafter. It remains to be seen whether history will falsify this grim prediction.

Endnotes

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