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Review

The Greenhouse Gas Crisis and the Logistic Growth Curve

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Abstract: The greatest challenge of the coming century will be the consequences of an imbalanced atmosphere. Currently, projections of global heating due to an increasingly imbalanced atmosphere are dire, but they underestimate the near-term heating impacts of the growing concentrations of methane. Industrially mediated carbon capture and storage sometimes gets raised as a promising solution on the CO_2 front, but it is presently commercially inviable. Despite these facts, we nonetheless need to act globally to reduce the atmospheric concentrations of greenhouse gases, although our increasingly separate information ecosystems make finding a way to express the reality of the atmospheric imbalance crisis to a wide audience daunting. One approach to presenting the atmospheric imbalances leading to global heating is to strip the discussion down initially to its bare bones with a sharp focus on the variables of the logistic growth equation. Although virtually anything can be politicized, the logistic growth equation's variables are at least apolitical in their origin. After examining those variables, we can proceed to focus on density-dependent mortality factors (DDMFs) and their relationship to visible climatic changes driven by atmospheric imbalances. Both the Global North and the Global South need to do all that we do to reduce atmospheric greenhouse gas accumulation, reducing DDMFs, while paying careful attention to Indigenous rights and to the need for global gender equity, so that our efforts to control DDMFs do not produce a new expression of colonialism.

Keywords: climate change; greenhouse gases; logistic growth carbon dioxide; methane

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1. Introduction

The greatest challenge of the coming century will be the consequences of an imbalanced atmosphere, where carbon dioxide, methane, nitrous oxide, and other greenhouse gases exist in excessive concentrations out of balance with the range of values seen in the last centuries. The current situation is that projections of global heating due to an atmosphere with high levels of greenhouse gases are dire [1], but they underestimate the actual near-term heating impacts of growing greenhouse gas concentrations.

Our computations for projecting the warming impacts of atmospheric gases normally use their average impact over a century, which makes sense for carbon dioxide with an atmospheric residency time of 300–1000 years [2], but methane only lasts in the atmosphere for around ten years, during which time, molecule per molecule, it is much more powerful as a greenhouse gas than carbon dioxide. As the Environmental Defense Fund summarizes [3], "Methane has more than 80 times the warming power of carbon dioxide over the first 20 years after it reaches the atmosphere. Even though CO_2 has a longer-lasting effect, methane sets the pace for warming in the near term. At least 25% of today's global warming is driven by methane from human actions". Using one-hundred-year averages to compute projected climate impacts of greenhouse gases makes the impact of methane look much smaller than it will be over the coming two or three decades [4], which are the period of time during which we need to act effectively to avoid the worst impacts of an imbalanced atmosphere. Additionally, a growing effort to move to natural gas (whose largest component is methane) as a fuel to replace the vast amounts of highly polluting coal used for thermal power generation has often unacknowledged negative impacts. Storrow [5] reports that 3.7% of the methane produced as fuel in the Permian Basin leaks into the atmosphere. That is enough in terms of greenhouse gas impacts to eliminate the global heating avoidance benefits of moving from coal to natural gas for thermal power generation in the coming years. Adding to the complexity of the situation, elimination of coal and petroleum use would also greatly reduce short-lived sulfate and nitrate aerosol emissions, which are cooling, and therefore in the short term moving away from coal especially will "unmask" powerful global heating impacts, this process must also be planned for in the transition away from fossil fuels [6]. We need to acknowledge that using a 100-year time frame in global heating projections involving a gas that remains in the atmosphere for a much shorter period of time is misleading, and stop underestimating how dangerous methane from animal rearing for meat and use for fuel is to the atmosphere.

Industrially mediated carbon capture and storage (CCS) in which we would remove vast amounts of carbon dioxide from the atmosphere sometimes comes up as a promising solution to global heating. However, the proponents of CCS do not acknowledge that it is presently commercially inviable. A recent review of the technical situation in CCS enumerates a range of problems with CCS technology as it presently exists [7]. Only twenty-six experimental CCS facilities are in operation today around the world, capable of storing merely 0.1 percent of global carbon dioxide emissions [8]. We do not have the technology today to remove and store the quantities of carbon dioxide that would be needed in order to rebalance the atmosphere using an industrial process, and the continuing loss of the natural carbon dioxide sinks in rainforests merely exacerbates this problem.

2. Disinformation

We need to act globally to reduce the atmospheric concentrations of greenhouse gases. The challenges to effective action have been artificially augmented by politically and economically motivated actors. In a world of increasingly separate information ecosystems and extreme polarization, finding a way to express the reality of the atmospheric greenhouse gas crisis to a wide audience is daunting. Highly successful climate change disinformation campaigns [9–11], funded by corporations and by climate change counter-movement organizations with annual incomes summing to hundreds of millions of dollars [12], often steered by think tanks dedicated to this effort, have frequently overwhelmed pathways for rational communication. Corporations such as ExxonMobil, which was the focus of a groundbreaking Union of Concerned Scientists' exposé about the funding of climate change denial published in 2007 (which documented a campaign dating at least back to 1998), have been reported to continue funding climate change denial [13]. As political resistance on the national level in the US to action on climate change has persisted, it has meant that efforts to counter climate change have moved from the federal to the state and sometimes the municipal levels. In response, climate change counter-movement organizations have also developed substantial efforts at the state level [14]. Some state-based climate change denial organizations are reported to have used generous funding, such as The Texas Public Policy Foundation's resources (provided to it over time by fossil fuel companies such as coal giant Peabody Energy, Exxon Mobil, and Chevron, and conservative donors including Charles G. Koch and David H. Koch) to oppose projects such as offshore winds farms off Massachusetts [15]. A recent article in the New York Times [16] says:

"Just as the tobacco industry had front groups and the opioid industry had front groups, this is part of the fossil fuel disinformation playbook", said David Michaels, an epidemiologist at the George Washington School of Public Health who has studied corporate influence campaigns. "The role of these so-called policy organizations is not to provide useful information to the public, but to promote the interests of their sponsors, which are often antithetical to public health".

As with many circumstances where a great deal of money is flowing, political consequences empowering some groups of people and disempowering others have reared their heads around the world. Globally, complex political interactions based on regional concerns have impeded accurate attributions of climate-change-driven extreme weather [17] and also impacted consequent inequalities which stem from socio-political causes [18]. This has led to social fragilities amplifying climate impacts. The potential for both constructive and destructive social feedback loop involvement further complicates the situation, because it is possible for feedback loops toward social disintegration driven by climate-change-induced environmental disasters to occur especially in the Global South, while simultaneously the wealthiest people in the Global North could benefit from transitions to a new zero-carbon economy and develop economically beneficial feedback loops [19]. Largely because of political obfuscation, and the actions of corporations acting out of what they perceive as their narrow self-interest [20], the time to act effectively to avoid the worst projected climate change impacts is now very short.

Despite all of these complexities, there is a practical, ethical, and urgent obligation for stabilizing and subsequently reversing anthropogenic environmental deterioration, and especially for mitigating its impacts on people with limited adaptive capacity [21]. What might be an approach to articulating and conveying accurate information in this often intentionally, and sometimes accidentally, obscured intellectual terrain?

3. The Logistic Growth Equation as a Method to Approach Discussion

One approach to discussing the atmospheric imbalances leading to global heating is to strip the discussion down initially to its bare bones, with as little unneeded complexity as possible in the way. One way to do that is a sharp focus on the variables of the logistic growth equation and curve. These variables were designed to describe animal population dynamics including their relationships to birth rates and death rates, but they are applicable to human populations as well and especially interesting in changing environments. The logistic growth curve can integrate all of the factors impacting human population dynamics, and in an era where atmospheric greenhouse gas accumulations are producing a variety of stresses on human populations globally, this might provide the language we need to carry a more objective discussion fruitfully forward. Although recent history shows that virtually anything can be politicized, the logistic growth curve's variables are at least apolitical in their origin. It is possible to build carefully from those variables to a discussion of what logistic growth can help us see about the global heating crisis driven by the atmospheric accumulation of greenhouse gases, and its human impacts.

Our species' current situation is that we are riding (or really our voracious consumption of resources that produce carbon dioxide and methane and other greenhouse gas accumulations in the atmosphere, our focus on short-term economic profits, and our increasing population numbers are driving us along) a precarious stretch of the logistic growth curve. The most frequently encountered expression of the logistic growth curve is Equation, $dN/dt= rN((K-N)/K)$. The expression dN/dt represents change in numbers of organisms N over time t. The variable r is the population's intrinsic rate of increase, the increase rate per capita at each instant of time. It derives from the difference between birth rates and death rates. The variable N as already stated is the number of individuals in a population, and the variable K is the environmental carrying capacity, the largest number of individuals of that species that a given habitat can indefinitely support at a given moment in time.

If population numbers N are continuing to increase rapidly in size as the population approaches its environmental carrying capacity K, and therefore N temporarily exceeds environmental carrying capacity K, then $(K-N)/K$ becomes negative, and to determine the upcoming change in population size with time, rN will now become multiplied by a negative number. Simplifying the situation somewhat at this point, we could say that density-dependent mortality factors (DDMFs) that reduce population level N begin to express themselves strongly by increasing the mortality rate in various ways when N exceeds K. The DDMFs are density dependent because the more population N temporarily exceeds carrying capacity K, the larger the negative value of $((K-N)/K)$ that rN will become multiplied by, and the faster the population will begin to die off. Population numbers N can never exceed carrying capacity K except temporarily, but a brief overshoot that may be quite large can occur when a population continues to grow quickly as it approaches the carrying capacity. The problem with carrying capacities in nature (or for humans) is that one never knows exactly what they are at any moment except by observing the consequences of exceeding them.

The environmental carrying capacity of the Earth for humans is a much-debated topic. An Environmental Health Perspectives [22] focus on the topic that surveyed several decades of the thoughts of people often considered the leading experts began:

"Nobody really knows what the planet's human carrying capacity is. Some, like Cornell University ecology and agriculture professor David Pimentel, contend that the Earth has already passed that point. Citing high malnutrition rates in the world, Pimentel estimates that the Earth's carrying capacity—providing a quality life for all inhabitants—would appear to be about 2 billion. Other estimates go to both extremes. In a 1995 Cato Institute essay titled "The State of Humanity: Steadily Improving", Julian L. Simon, the late University of Maryland economist, wrote, "We have in our hands now—actually in our libraries—the technology to feed, clothe and supply energy to an ever-growing population. Even if no new knowledge were ever gained, we would be able to go on increasing our population forever". On the other end of the spectrum, in 1971—three years after writing The Population Bomb—Ehrlich placed the limit at 500 million".

Today, even talking about an ideal population size for humans, or a maximum population size, is a fraught undertaking because of a violent and ugly history. An essay written to mark the estimated moment on 15 November 2022 that the Earth's human population reached 8 billion [23] said:

"Of course, discussions about how many people there should be have never been purely academic. At times, they have been hijacked to justify persecution, ethnic cleansing and genocide. In each case, the perpetrators have been intent on lessening the populations of specific groups of people, such as those from a certain social class, religion or ethnicity—rather than humanity as a whole—but they are nevertheless sometimes seen as examples of the dangers that the very concept of overpopulation can pose. As early as 1834 ... the English Poor Laws were scrapped and replaced with stricter ones ... partly over ... concerns that this social class ... were reproducing too much, and had the result of forcing orphaned children into bleak, unsanitary workhouses ... Over the coming centuries, eugenics was continually disguised as population control—or received support from the movement—such as during the forced sterilisations of people from minority ethnic groups in 1970s America. It was also used to curtail individual freedoms".

4. The Relevance of Density-Dependent Mortality Factors

Realizing that a discussion of optimal or maximum human population numbers for the Earth will produce the opposite of an objective discussion of environmental challenges such as greenhouse gas accumulations in the atmosphere, we can nonetheless focus on some outcomes of logistic growth to promote an objective discussion, by focusing on DDMFs and their relationship to visible climatic changes driven by atmospheric imbalances. DDMFs do not just increase when N actually exceeds K; they also increase in their effect as N approaches K, and $(K-N)/K$ becomes a smaller and smaller positive number, and therefore population increase slows. One does not have to know an actual value for environmental carrying capacity K to discuss the impact of increasing mortality rates due to various DDMFs that are being driven by the consequences of global heating caused by the accumulations of greenhouse gases in the atmosphere.

Focusing on DDMFs makes even more sense because, uniquely for humans, environmental carrying capacity K could be intentionally increased if resource overconsumption decreased, allowing our numbers to reach a higher population level N without the DDMFs beginning to greatly increase human suffering and mortality. The "Impact = Population * Affluence * Technology" or IPAT expression could be raised here but is dated and controversial, having been criticized in various ways as overly simple [24]. Similarly, humans alone can reduce their intrinsic growth rate r by reducing family size or increasing the intergeneration interval or both. We know that increasing opportunities for the education of young women has often reduced the human population growth rate where the education is available, as young women delay beginning families or decide to pursue other newly possible life options, but the situation is actually quite variable and complex. As Gupta wrote [25]:

"Thus, if the policy focus is on reducing inequality, enhancing income generation for the poor, and making free or affordable access to better health services, water and sanitation services, and education, there is a greater chance that people will choose for fewer children . . . and such a strategy is more consistent with a democratic approach that emphasizes human rights. Having said that, a lower birth rate per family is, in itself, inadequate for reducing population growth. That will depend, as World Population Reports emphasize, on how large the child-bearing population is within a specific population (which depends on the shape of the population pyramid of societies) and how quickly the death rate declines".

Unfortunately, as a species we are also uniquely capable of reducing our own environmental carrying capacity K by large-scale activities that result in diminution of the planet's capacity to support us, e.g., temperature-driven sea level rise that drives people from coastal areas and river valleys, droughts leading to soil degradation that reduces our capacity to grow food, harmful insect populations increasing their range in a warming world, excessive forest loss as drought-driven wildfires diminish all the ecosystem services of forests and perhaps even alter local weather patterns, and other well-known phenomena.

How can you provide evidence for whether, due to the effects of a heating planet, human population numbers have approached or exceeded the current environmental carrying capacity K, and be able to use the language of the logistic growth equation to discuss climate change impacts? One looks for DDMFs whose importance is already visibly increasing in an undeniable way. For humans, increasingly prominent DDMFs are already visible through lived experience or dramatic headlines. The visibility of the DDMFs means that people can be asked to identify them on their own, free from a sense of external political persuasion. These DDMFs include:

(1) Diseases such as ebola, whose vectors prefer warm and wet habitats, which are expected to expand their range [26] as greenhouse gases accumulate in the atmosphere and the climate changes [27], and a wide range of vector-borne parasitic diseases on the move geographically as the planet heats such as Chagas disease, malaria, lymphatic filariasis, hookworm, leishmaniasis, a variety of tick-borne diseases, schistosomiasis, and other conditions [28], which all taken together have led to the use of a new and unpleasant phrase, global worming [29], all of which often involves inexcusable racial inequalities [30].

(2) Insufficient agricultural food production caused by drought driven by climatic shifts. "Oxfam, Save the Children and the International Red Cross are among 260 signatories . . . " [31]: 270 million people, with women and girls most impacted, are " . . . facing hunger, starvation or famine . . . " [32].

(3) Lack of sufficient healthy space to live in, caused by coastal inundations due to sea level rise/global ice loss and in other areas by drought that often leads to human migration [33].

(4) A lack of suitable drinking water, and diseases due to that lack of clean drinking water, caused by shifting patterns of precipitation as greenhouse gases accumulate, the planet heats, and groundwater depletes with consequences that include cholera, typhoid fever, and dysentery. These situations are often rendered especially hazardous for women by social structures [34,35].

(6) Heat that exceeds historical norms or is excessive, which in some areas leads directly to human mortality [36].

(7) Ocean fisheries depletion related in part to overfishing but also due to ocean acidification as excessive atmospheric carbon dioxide dissolves in seawater, and also due to ocean warming that impacts the locations where different fish species can survive [37–39].

The increasing presence of DDMFs has been apparent for decades. The World Scientists' Warning to Humanity (WSWH) of 1992 [40] used different language as it discussed various DDMFs, but it stated, "No more than one or a few decades remain before the chance to avert the threats we now confront will be lost and the prospects for humanity immeasurably diminished". Increasingly urgent 2017 and 2019 WSWH updates followed [41]. The 2017 update [42], which was signed by the authors and 15,364 scientists, says:

"We are jeopardizing our future by not reining in our intense but geographically and demographically uneven material consumption and by not perceiving continued rapid population growth as a primary driver behind many ecological and even societal threats . . . failing to . . . reassess the role of an economy rooted in growth, reduce greenhouse gases, incentivize renewable energy, protect habitat, restore ecosystems . . . humanity is not taking the urgent steps needed to safeguard our imperilled biosphere".

Taken together as a body of knowledge, their "Journal Articles Related To Scientists' Warning", initially published in 2020, is little short of a terrifying compendium of DDMFs [43]. Moreover, the situation is now worse than it was when the first warning was issued in 1992 [44], as the planet has continued to heat due to atmospheric greenhouse gas accumulations, and the values for the variables in $dN/dt = rN((K-N)/K)$ have continued to change in ways dangerous to our species. The human population growth rate has decreased, which buys us some time, but the slowing is uneven geographically, and we have still reached 8 billion people and are projected to reach 9.7 billion by 2050 [45] and greenhouse gases continue to be emitted at a prodigious rate.

5. The Response Needed

Among the affluent component of the people living in the Global North, our immediate response to this crisis needs to focus on decreasing our excessive consumption of resources, which would decrease greenhouse gas production, therefore reducing the global heating that drives DDMFs upwards, and which would also increase global environmental carrying capacity K. Generally, we can achieve this by acting in a way that shows we want to share the necessities of life and not degrade the planet. Globally, we need to make certain that population N does not exceed our environmental carrying capacity K, that we do not reduce our environmental carrying capacity K, and with more rational consumption levels.

Those of us in the Global North need to focus on our own responsibilities for change in overconsumption rates that create the greenhouse gas emissions currently causing imbalances in the atmosphere, and this will require overcoming a frequent lack of ethical analysis, avoiding the language of despair, and reversing moral disengagement [46], rather than focusing on what people elsewhere could do to reduce anticipated DDMFs and help rebalance elements of the logistic growth equation. It is worth noting that a number of nations in the Global South have already begun to reduce their population growth rate, which could reduce all sorts of human impacts, but even this sort of change will lead to complexities and challenges. A recent forecasting analysis for the Global Burden of Disease Study [47] stated:

"Although good for the environment, population decline and associated shifts in age structure in many nations might have other profound and often negative consequences. In 23 countries, including Japan, Thailand, Spain, and Ukraine, populations are expected to decline by 50% or more. Another 34 countries will probably decline by 25–50%, including China, with a forecasted 48.0% decline (95% UI–6.1% to 68.4%). Population percentage declines do not immediately convey the associated profound shifts in age structure in these nations. Our findings suggest that the ratio of the population older than 80 years to the population younger than 15 years will increase in countries with more than 25% population decline, from 0.16 today to 1.50 (0.54–3.25) in 2100. These population shifts have economic and fiscal consequences that will be extremely challenging. With all other things being equal, the decline in the numbers of working-aged adults alone will reduce GDP growth rates".

In both the Global North and the Global South, we need to do all that we do to reduce atmospheric greenhouse gas accumulation, therefore reducing DDMFs, while paying careful attention to Indigenous rights and to the need for global gender equity, so that our efforts to control DDMFs does not produce a new expression of colonialism [48].The science, politics, and economics of none of this will be simple [49], but we really have no good alternative. Noting the urgent need for increasing efforts to improve future projections, Stern writes [50] "Current economic models tend to underestimate seriously both the potential impacts of dangerous climate change and the wider benefits of a transition to low carbon growth. There is an urgent need for a new generation of models that give a more accurate picture". The logistic growth equation does give us a clear way at least of expressing that our only alternative to quick societal and personal action to reduce atmospheric greenhouse gas accumulations is that the DDMFs themselves will reduce the number of humans N across our planet, as we simultaneously reduce environmental carrying capacity K, and these processes will combine in terrible ways we cannot predict.

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