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Editorial

Deep Reductions in Energy Use: Hobson's Choice in Climate's Last-Chance Saloon

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1. Introduction: Earth's Sustainability Challenges

In 2022, the record of extreme weather events already includes deep droughts in Sichuan province, China, and California, US; floods inundating a third of Pakistan and serious and repeated flooding in Eastern Australia; heat waves and drought in Europe; and wildfires in Europe and the western US. Catastrophic climate change is now either with us or very soon will be [1,2]. Even a temperature rise of 1.5 °C introduces a risk of several climate tipping points [3,4]. The situation is bad but could worsen if the drivers of climate change (CC), greenhouse gas emissions (GHGs), and land-use changes, including net deforestation, are not rapidly reduced.

The first report of the Intergovernmental Panel on Climate Change (IPCC) was produced in 1990 and warned of the dangers of global climate change. Thirty years later, in their sixth report, the IPCC issued the same warnings, except the urgency to respond has increased considerably [5,6]. As Armstrong McKay et al. [3] have observed, we may have very little time remaining to respond if we are to avoid the worst of the warnings we have been given.

What has the world achieved over the three decades since 1990? The emissions of energy-related carbon dioxide (CO_2) (and GHGs overall) have not sharply declined; instead, they have risen from 21.31 gigaton (Gt = 10^{18} ton) CO_2 (or 23.9 Gt CO_2-equivalent) in 1990 to 33.88 Gt (39.0 Gt CO_2-equivalent) in 2021 [7]. Emissions are likely to be their highest ever in 2022 or 2033 as global FF consumption, particularly oil and gas, continues to rise [8]. In 1990, shifting to renewable energy (RE) may have been a feasible strategy, but given the very short time that remains for taking decisive action, it may be, at best, a minor but necessary component of the solution. The following statistics illustrate its slow growth. Over the period covering the last six IPCC climate assessment reports, RE's share of global commercial energy has risen from 7.2% in 1990 to 13.5% in 2021 [7].

However, global CC is not the only serious environmental problem the world faces, and all issues demand urgent action. Some scientists regard the loss of functional biodiversity as just as serious. Today, 99% of all terrestrial vertebrate biomass is either humans or the animals we rear for food, work, or pets. A mere one percent is accounted for by animals in the wild [9]. Oceans are experiencing increasing numbers of hypoxic regions, increasing acidity, and a steady and long-term decline in ocean biomass [10,11]. Both ocean and land pollution from plastics and chemicals is rising and is thought to have already passed safe global limits [12,13]. Some proposed solutions for CC mitigation would help solve these challenges, but others introduce potential conflict [14]. Additionally, of course, continued growth in the global population will make sustainability progressively more difficult to achieve [9,15].

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2. Responding to These Challenges: The Papers in This Special Issue

Charles Hall [16], in his contribution, discusses the relevance of the well-known *Limits to Growth* book, first published 50 years ago in 1972. This book explored future global scenarios using models under the twin constraints of a declining global pollution absorption capacity and the declining availability of resources. Hall regards the book as, even today, a "reasonably accurate assessment" of the predicament we find ourselves in, but he thinks that what is different is that the problems we are facing today are not global in scope but more regional or national. The huge disparities in regional and national freshwater availability is a case in point [17]. He concludes his paper with a terse message: "It is time to acknowledge that there are limits to growth and act accordingly.".

Carlos de Castro and Iñigo Capellán-Pérez [18], in a very detailed analysis, used three different versions of Energy Return on Investment (EROI) analysis to explore the future of RE electricity from wind, solar, and large hydro. When the extended version of EROI was used ($EROI_{ext}$), which accounts for indirect inputs, EROI values were found to be low, except for hydro. $EROI_{ext}$ values were 6.5 for large hydro but under 3.0 for onshore and offshore wind and PV. For solar thermal, they calculated an $EROI_{ext}$ value of only 0.8. Given these low values, they doubt that full reliance on RE could sustain a global growth economy.

The paper by Patrick Moriarty and Damon Honnery [19] also stresses the importance of EROI for the future of RE. It gave four reasons why EROI values for RE are presently over-estimated and why they will decline in the future if RE dominates the global energy supply. These reasons are:

(1) Declining input quality for RE sources such as wind energy (lower wind speeds) and hydropower (fewer suitable sites). Additionally, energy costs of input materials will rise as ore grades decline.
(2) Uncounted environmental costs, mainly for material inputs.
(3) Need for energy conversion and storage as the RE sources with the greatest potential [20] come to dominate the future energy supply.
(4) Removal of fossil fuel "subsidy" as FFs supply an ever-declining share of global primary energy. This subsidy arises because, in the absence of meaningful carbon pricing, FFs are cheaper than renewables (as also found in [18]).

Samuel Alexander and Josh Floyd [21], in their contribution, advocate Tradable Energy Quotas (TEQs) as a means of decarbonizing national economies. They explain this approach as follows: "The TEQs system involves rationing fossil fuel energy use for a nation on the basis of either a contracting carbon emission budget or scarce fuel availability, or both simultaneously, distributing budgets equitably amongst energy-users." TEQs can be traded between parties, which should help maximize the efficiency of resource use. They regard TEQs "as a practical means of managing energy descent futures" and facilitating "degrowth"—the planned contraction of the economy. They regard RE as unlikely to be able to provide present levels of global energy use.

The paper by James Ward and colleagues [22] develops a new technique for assessing sustainability. They propose to either replace or, more likely, supplement the well-known Ecological Footprint (EF) approach to sustainability with a "Renewable Energy Equivalent Footprint" (REEF), which instead "depicts a hypothetical world in which the electricity and fuel demands are met entirely from renewable energy". This assumption of a future with 100% RE was also used in [18,19]. They conclude that a future powered by RE may be possible but caution that future global population growth [23] will make such a future progressively more difficult to attain—or sustain—into the future.

3. Energy Futures: The Remaining Options

If RE cannot prevent serious climate change in the very short time we have left [3], let alone the other environmental challenges we face, the only options are global-scale nuclear energy and the largely untried technologies of solar geoengineering and Carbon Dioxide Removal (CDR). Elsewhere, we and other researchers have pointed out the difficulties facing these options [14,24]. The sole remaining approach is deep energy reductions, by greatly boosting energy efficiency or by significant reductions in the use of energy-consuming devices [25].

Moriarty and Honnery [26] gave several reasons why reliance on energy efficiency improvements may be misplaced, despite its apparently high potential [27]:

(1) The well-known energy-rebound effect [28] lowers the cost, for example, of energy per passenger km for car travel.
(2) Energy efficiency is only one of several desirable efficiency measures. Others include capital, labor and land-use efficiency, and speed (or time-use efficiency).
(3) Global income inequality is reflected in large differences in per capita ownership of cars and domestic appliances. This unmet demand would swamp any absolute energy savings from efficiency gains.
(4) A growth economy is constantly introducing new energy-consuming devices or services (e.g., bitcoin mining), which offset the gains from efficiency improvements.
(5) Device energy efficiency improvement is not enough; it is also necessary to look at whether task-specific primary energy inputs (e.g., energy inputs per vehicle km or kWh of delivered electricity) are rising over time, as discussed in [25,26].

Liu et al. [29], in their eponymous article, have stressed the "*Energy constraints to increasing complexity in the biosphere*". The paper by Hickel et al. [30] is one among many that argue for "degrowth", the idea that the sustainability problems the world faces cannot be solved in a growth economy. As was observed at COP26, decision making about our future climate has arrived at the last-chance saloon, and the time we have available leaves us with little choice; deep reductions in energy consumption are our sole remaining option.

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