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Energy Paradoxes

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In the domain of energy systems, paradoxes show that history runs often against what is expected or predicted. This article reviews the paradoxes related with the transition from wood to coal, and then from coal/oil to nuclear, and concludes by lifting a corner of the veil on the paradoxes that have already surfaced in the transition from fossil fuels to renewable energy (green paradoxes).

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INTRODUCTION

Paradoxes unveil surprises: in the domain of energy systems, they show that history runs often against what is expected or predicted; that things are never what they really seem to be. Most fundamentally, paradoxes provide a counterpoint to nested beliefs about energy transitions and groundbreaking technological innovations. Actually, the subtle, discreet and often ironic presentation of “a conclusion that at first seems absurd, but that has an argument to sustain it” Quine (1966), appears as the most adequate form to challenge narrow configurations of expectations, focal goals or inferences from energy systems.

Approached from this perspective, energy paradoxes spark reflexive insights into life-changing periods because they duly call into question the power sources and technologies otherwise deemed to just be superior and more efficient. They provide the interplay between positive and negative imaginings, correlating desirable and desired futures and their tail of unintended and unforeseen consequences. Indeed, statements that run contrary to what most people intuitively expect have constituted a smart means of voicing doubts about visionary energy trances. Within this scope, energy paradoxes display a far-sighted understanding regarding the long-range consequences of energy transitions. Little wonder that the dynamic, multi-layer and interconnected vantage point of paradoxes has occasioned major reconstructions of the very foundations of technical and economic thought.

This paper starts out with an abridged review of the principal energy paradoxes associated with the transition from wood to coal, and then from coal/oil to nuclear, and concludes by lifting a corner of the veil over the paradoxes that have already surfaced in the transition from fossil fuels to renewable energy (green paradoxes).

THE COAL AND THE NUCLEAR PARADOXES

Saving energy through the adoption of efficiency improvements leads to greater energy consumption. In brief, this riddle-“less causes more”-is known as the “Jevons” paradox following the publication of the book “The Coal Question” by the political economist William Stanley Jevons in 1865. Along 380 pages, the author intervenes in the public debate about the danger of exhausting British coal mines and coming out in favour of the shortage thesis. Drawing largely on observations of the history of the steam engine, Jevons noted how successive performance improvements lowered the amount of coal needed to produce one unit of useful motive power (horsepower) but the end result was nevertheless economic expansion and increased aggregate demand for coal: “whatever, therefore, conduces to increase efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam engine, and to enlarge the field of its operations" (Jevons, 1866). Less causes more.

In causal form, the author specified two arguments to sustain this paradox: in practice, enhanced efficiency means energy becomes cheaper. Owing to this, the profits from trade increase thereby attracting still more capital into the industrial sector while allowing individuals to consume more fuel and energy services. Both business and households therefore contribute directly to deepening the demand for cheaper energy. On top of this, Jevons added a second indirect effect: lower energy prices left individuals with more disposable income, which they spend on goods and services from other economic sectors, fostering further demands for energy. Greater efficiency plays out economically through direct and indirect stimuli to the consumption of more energy. Such rebound effects are only going to step up the pace of natural resource exhaustion and hence shortening the time frame until all underground seams end up depleted. Equipped with solid economic arguments, the paradox gave form to collective fears; a fact that explains why Jevons ideas were suddenly thrown into the spotlight.

In summary, an "overall or economy-wide rebound effect represents the sum of the direct and indirect effects and is normally expressed as a percentage of the expected energy savings from an energy-efficiency improvement perspective. Hence, an economy-wide rebound effect of ten per cent means that ten per cent of the potential energy savings are "taken back" through one or more of the abovementioned mechanisms" (Madureira, 2012). The striking shift happens when rebound effects reach 100 percent or more because, in these circumstances, all technical energy savings are offset by growing consumption. Some authors single out this special case of the rebound effect, identifying it as "backfire."

The 1980s brought about a revival of interest in the Jevons paradox, largely based on the likelihood of rebound effects with backfire. Contemporary economists correspondingly extended the Jevons arguments to situations in which there is a spillover of improvements in energy efficiency into the efficiency improvements of other inputs, such as capital, labour and materials, causing a distinct macroeconomic effect that pushes energy consumption increases beyond the landmark of a 100 percent take back (Khazzoom, 1980; Brookes, 1990; Brookes, 1993; Saunders, 1992). These developments were encapsulated in a new definition of the Jevons Paradox: "with fixed real energy prices, energy-efficiency gains will increase energy consumption above what it would be without these gains.".[1]

Most fundamentally, the Jevons paradox cast a long shadow over the smooth transition from wood to coal, recalling how fossil fuels are depletable resources. In this view, technological progress bestows a cornucopian present wrapped up in a hopeless future. The capacity to look ahead and disclose the environmental consequences of present decisions turned the Jevons paradox into a harbinger of 20th century environmental thinking, setting an agenda around two issues: industrialization and the exhaustion of natural resources, and the limits to growth.

The nuclear energy paradox bore the hallmarks of the scientific manipulation of the atom along with its technopolitical usage: on the one hand, the dawn of a new type of energy, distinguished by its huge energy density and, on the other hand, the cold war's military and technological race and the rapid expansion of the nuclear industrial complex with the concomitant radiological contamination of the planet. Following the studies published by Hagen (1992) and Worster (1994), the destruction paradox served to highlight how technologies prone to destroy the planet also fostered its conservation. Behind this apparent conflict of reasons lies the intermingling of atomic energy with the consolidation of the ecosystem's ecology. Two reasons help explain why the most threatening and concentrated energy ever created by mankind ended up promoting nature preservation: Firstly, the US umbrella organization for nuclear activities, the Atomic Energy Commission, was compelled to sponsor the study of radioactive diffusion in the environment. Unexpected effects from bomb tests in the Pacific, such as the scattered militarized radiation (fallout) that spread globally and fears of contamination from nuclear facilities alarmed the American public Moore (2008), spearheaded the emergence of dissident scientific (anti-bomb) knowledge Kraft (2018) and disturbed US international diplomacy (Divine, 1978). To maintain a free hand for bombs testing, which accounted for a paramount need in nuclear weapons research and development, and defend its public accountability, the AEC commissioned a vast program embracing environmental analysis in the zones adjacent to nuclear laboratories in the United States, in the irradiated Pacific atolls for bomb testing all alongside secret projects worldwide to disclose the impact of radioactive fallout on the biosphere (Gabriel - 1951) and its follow-up project (Sunshine - 1953).

The second reason stresses the proximity of this political agenda with the scientific agenda of emerging ecosystem studies. The goal of the nuclear authorities was to single out patterns of deposition, circulation, and concentration of radioisotopes in the environment. In particular, this focused on the radioactive decay that might be more harmful to human health. On the one hand, ecological studies, a field still seeking to differentiate itself from the academic areas of biology and zoology, were on the verge of accomplishing models of understanding aimed at the integration of both organisms (biotic communities) and the abiotic environment (Bocking, 1995; Golley, 1996). Ecosystem ecology responded fully to uncertainties around radioactive pollution because it "emphasized the movement of energy and materials within self-regulated systems made up of both living and non-living matter, and deemphasized the unique properties of species.".[2]

Putting a face on the ecosystem ecology breakthroughs, the contributions of two brothers, Howard and Eugene Odum, stand out as the pillars of Modern Ecology. Strikingly, the landmark of this

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[1] For a critical review of the Khazzoom–Brookes postulate see (Sorrell, 2009).

[2] Stanley I. Auerbach, staff leader of health physics at Oak Ridge National Laboratory quoted in (Bocking, 1995).

advance was a study sponsored by the Atomic Energy Commisson at Eniwetok atoll, in Micronesia, which had been subjected to repeated nuclear bombs tests: since nuclear explosion tests were being "conducted in the vicinity of these inherently stable reef communities, a unique opportunity was provided for critical assays of the effects of radiations due to fission products on whole populations and entire ecological systems in the field." (Odum et al., 1955) Benefiting from a six week field study, the Odum brothers's work on Eniwetok's coral reefs provided ecologists with a model of a self-regulating ecosystem and the first theorization of the overall metabolism of an "isolated" natural environment. Departing from the biogeochemical approach, the Odum brothers came to see energy flows (the way in which energy gets transferred and transformed from one part of the system to another) as the missing link in ecosystems models and the driving force for all ecological processes such as biogeochemical cycling, respiration and production. In the end, it became clear what ought to be preserved and conserved in the environment: the equilibrium between producers (including primary photosynthetic production), herbivores, carnivores and decomposers (bacteria, blennies, and foraminifera); ecosystem productivity measured in terms of growth by gms/m2/day or lbs/acre/year; the supply and cyclical re-use of chemical nutrients, namely inorganic phosphorus, organic phosphorus, and nitrate nitrogen. This was community metabolism, which had taken millions of years to evolve towards an effective composition-a whole system, analogous to a machine Kwa (1987)-hat ought to be preserved, controlled, managed. The importance of energy flows as the driving force for all ecological processes entailed meticulous care in all measurements of biotic and abiotic communities. Precision measurements, creativity and inventiveness were in effect the trademarks of emergent ecosystems ecology. Suffice to say that, despite the rudimentary and light equipment available at Eniwetok Atoll, subsequent studies have proven the Odum's metabolism measurements to be accurate (Barile¸2004).

Finally, the threat of atomic annihilation also provided a new method for ecological studies (radioecology) through the application of radioactive isotopes as tools for tracing food chains, for determining the mass of nutrients in the various compartments of ecosystems, and for determining the time and extent of transfer of matter and energy among ecosystem components (Odum and Pigeon, 1970).

In keeping with the transition to fossil fuels and nuclear energy, paradoxes have also correlated the imagery of auspicious times with threatening futures. Relocating the analysis to the longer run, the above-mentioned paradoxes pinpointed the exhaustibility of natural resources and the delicate equilibrium of the natural environment.

GREEN PARADOXES

Renewable energies display the greatest potential to overcome the challenge of concentrations of greenhouse gases in the atmosphere and subsequent global climate change. In recent decades, a significant stream of research has already highlighted prospective paradoxes regarding the transition towards a green economy: that renewable energy might itself be exhaustible. It is no accident these paradoxes have come to light in the literature that assesses the global technical potential of solar, wind, ocean, hydro, biomass and geothermal energy. Indeed, a thoughtful formulation of the depletion paradox states the existence of technological and economic limits to renewable energy expansion. Rather than taking for granted that some such sources of power appear "unlimited," some authors have pointed out that tapping into these sources is likely to become increasingly difficult. In the first place, the successful deployment of a range of new energy technologies substantially raises the demand for a range of metals and rare metals, some of which are currently in short supply. Fast growing demand is likely to be particularly acute for gallium, used in semiconductors and in photovoltaic cells, and indium, also involved in some forms of solar-photovoltaic technology (Kleijn and van der Voet, 2010). Likewise, the known reserves of this last metal are running quickly towards depletion (Fridley, 2010). In the short run, Garcia Olivares et al. (2012) points out that supply (and the reserves) of tellurium and indium are currently limiting the scaling-up of thin-film, amorphous silicon and amorphous-nano silicon photovoltaic technologies over 0.1 TW. More generally, the present "reserves of iron, non-metallic minerals, aluminium, copper, nickel and platinum are sufficient to initiate a Renewable Energy (RE) transition but they may constrain the growth of an RE mix of over a mean power of 12 TW," thus creating a barrier to inexhaustible economies of scale. A final argument stresses that the monetary, energy and environmental costs of supplying minerals will necessarily rise in the future. This situation particularly affects scarce elements in the crust (an abundance of less than a 0.01% concentration or 100 ppm -parts per million) because these elements are chemically challenging and energetically expensive to extract from ore bodies. Palladium and platinum, applied in the catalysts for fuel cells, and the abovementioned indium, rank in this respect as low-concentration minerals whose extraction will probably entail growing environmental and economic costs (Moriarty and Honnery 2011). To sum up with Bardi (2011) words: "is it correct to assume that minerals are limited resources? The answer is yes, provided that we understand that the limits we are facing are not limits of amounts, but limits of energy."

Under the scarcity scenario, rare metals have become entangled in geopolitical strategies, national security machinations and speculative finance. Since China accounts for 95% of global rare Earth production, limits on exports were deployed as a weapon to stymie the development of foreign green energy and as a leverage of power and diplomacy (Raman, 2013). In this sense, Raman (2013) claims renewable technologies are "already being fossilized in the sense of becoming akin to the political economy of fossil fuels" with nation-states competing for resource control, national security policies designed to secure supply and environmental damage from the mining, dressing, smelting and separating of rare earth-containing ores. Another similarity between renewables and fossil fuels is the decline in output as premium sites are used up and resource quality worsens (e.g. average wind speeds, or geothermal steam temperatures). Moriarty and Honnery (2012) have shown that as global wind energy production increases (and the best sites are engaged), the ratio of gross energy output to energy inputs and the marginal capacity factor of wind turbines decreases.

Certainly, with proper economic incentives renewable technology might adopt alternative materials, provided there is scope for some direct substitution of resources by capital inputs (Solow, 1974; Solow, 1997). Bio-economics and thermodynamic analysis nevertheless suggest there are geochemical and physical limits to such a substitution process (Ayres, 2007). And the clock remains ticking. In the meantime, a second generation of emerging green technologies is already pursuing alternative paths for clean and sustainable development (Hussaina et al., 2017).

The merit of the green paradox is to countervail the idea that there are no technological limits in the necessary energy transition to renewables, forewarning how the first generation of renewable energy displays "technological and sustainability limits much closer than thought" and that . . . "scenarios of the future must contemplate them" (Castro et al., 2013).

Beyond Energy

Energy paradoxes bring to light paired antinomies combined in powerful riddles: saving entails more consumption; destruction entails conservation; boundless energy entails depletion. To explain these riddles, we must overstep the closed system of energy production and embrace the broader context in which energy is consumed, appropriated, tapped. Paradoxes return critical insights into energy's long run embeddedness in society, broadening narrow expectations formed around the development of energy systems.

Indeed, changes brought about by energy transitions set in motion a nexus of interrelated events that are not reducible to a single specialized dimension: emergent phenomena with non-linear dynamics may trigger an effect of consumer behaviour and micro economics into macroeconomics; effects that have feedbacks to causes may involve unforeseen geopolitical and techno-political developments; occurrence of unexpected results may transform the goal-oriented course of events. "With increasing complexity, problems of society" display "a self-referential nature, that opens the door to paradox." (Klein et al., 2001). According to Klein (1996), the proper way to tackle complex issues that occur across contexts is to take into account all these contexts through a transdisciplinary approach in which all disciplines contribute fully and on equal standing, "leaning towards the restructuring of the disciplines themselves."

If we want to unveil paradoxes' surprises, we need a shared understanding.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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