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Against High-Tech Global and Grid Approaches to Energy Transition: Post-Liberalism, Open Sourced Metabolism, and the Telos of Local Sustainability

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Abstract: Green political agendas rooted in ecological modernization (EM) are distinguished from antecedent visions predicated on biophysical limits. Net zero is shown to be rooted in a project of global EM. Ecomodernism is analysed in relation to its principal actors, geopolitical context and underlying metaphysics and anthropology. It is driven by non-negotiable societal priorities ('ends') which themselves derive from a particular set of technical 'means'. The top-down version of the 4th industrial revolution (IR4.0) and new paradigm of global net zero constitute an integrated agenda of eco-modernism. Global net zero cannot hope to achieve its own metabolic goals in respect of either energy flows or the circular economy. A competing, bottom-up and distributed model of the IR4.0 could potentially achieve these targets without falling prey to the Jevons paradox. This potential turns on the greater capacity of low-overhead, prosumer models to nurture less materialist cultural priorities that are more communitarian, and family oriented. A smart energy system that emerges in the context of distributed, domestic and informal production is much more likely to mirror the complex, infinitely gradated and granular pattern of oscillating energy transfers that are characteristic of biological systems. From an ecological economic perspective, such a bottom-up approach to the IR4.0 is much more likely to see the orders of magnitude reduction in the unit energetic cost of social complexity envisaged, in principle, by Net Zero.

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1. Introduction

For the last 10 years global climate and energy governance has been dominated by the attempt to entrench hard limits on carbon emissions and effect a top-down transition to renewable energy systems. This regime is encapsulated by the framework of Net Zero and the proliferation of certification and accreditation schemes designed to nudge it into reality [1–4]. Led by the European Union, the emphasis has been on supply side transformations (moving away from coal fired power stations), regulatory leverage to change suites of technologies (as with EVs in relation to automobility) and fiscal incentives to nudge consumer behaviour (EV subsidies; the 'ultra-low emission zones' in UK cities; road taxing; Canada's carbon tax).

This governance regime and these policy priorities emerged in early 21st century in the wake of a 30-year paradigm struggle within the environmental movement. The initial ethical and moral intuitions of biophysical limits to growth [5–7] and the earth systems science that seem to vindicate it [8,9], foundered on the political limits of liberal democracies and developing economies that depended on steady economic growth. With hard limits politically unviable, the emphasis switched to a discourse of sustainable development (née growth) and a vision of ecological modernization [10] for a review of this political standoff and subsequent resolution). Only with work by Steffen, Rockstrom and colleagues [11] did the idea of hard limits reemerge after 2009, this time under the moniker of 'planetary boundaries.' But as it turned out, although all-conquering within academia and the 'third sector', business and geo-politics carried on pretty much as usual. Ecomodernism remains the dominant paradigm. As well as the brutal fact that jobs, internal political cohesion and geo-political stability continue to rely on growth, the burgeoning economy of environmental regulatory services directed at managing the putative energy transition and the emerging circular economy has done more to obscure the underlying tension and trade-offs than effect any substantial decarbonization. When the upbeat insistence that decarbonization could be achieved almost overnight with existing technologies [12] turned out to be Panglossian and even delusional, the predictable response from the left has usually to place the blame on neoliberalism. Fremstad and Paul [13] argue that the putative Green New Deal, resurrecting the spirit of Keynes and Roosevelt, provides an example of

'a decisively anti-neoliberal framework that seeks to wield the power of the federal government to pursue large-scale public investments and binding climate regulations for rapid decarbonization'.

The obvious irony here is that in making open borders and the free movement of labour an article of political faith, social democrats, socialists, green parties, NGO activists and the architects of the EU have together enshrined perhaps the central tenet of neo-liberalism, which is that workers should be able to 'get on their bikes' – as Mrs. Thatcher's infamous enforcer (the 'Chingford Skinhead') Norman Tebbit, said to unemployed Durham coal miners. The truth is that it is only national populism of Victor Orban (Hungary), the A.f.D. (Germany), National Rally (France) MAGA (USA), the Swedish Democrats and more weakly Reform UK,[1] that has been willing to break with global free trade and the neoliberal framework put into place by Thatcher, Reagan, Blair and Clinton from the late 1980s. Needless to say, this break has not been directed with a view to sustainability (although, as we shall see, this is not to say that a more place-bound conservative vision can't end up being more ecologically benign as a biproduct of the concern for social integrity).

It is ironic also that the same authors understand the neoliberalism which they oppose, in terms of a thrust to 'decentralize democracy' and 'defund public investment' [13] Their eco-Keynesian vision depends on centralized, top-down governance and public investment. And yet it obviously must be the case that the public sector requires a constant flow of fiscal resources from the private sector. It depends upon economic *growth*. And so very quickly, we are brought back to the continuing tension between biophysical limits and modernity. In the analysis which follows I will argue that it is precisely this commitment to global scale, a centralised architecture of social emancipation, an a priori universalism, metaphysical materialism and an anthropology of atomic individualism – which is to say modernity – that makes both liberal and radical/Keynesian versions of eco-modernization an always receding Fata Morgana mirage.

2. The Dominant Ecomodernist Paradigm

Underlying the ecomodernist regime are a cluster of unstated assumptions. Firstly, with regard to **the principal actors** in the transition, it is taken for granted that energy transition is to be effected by technocratic national and supra-national governance schemes [1,14–17], with suites of technical and market regulations rolled out in cooperation with corporate stakeholders across the largest agro-food [18,19] energy [20], chemical [21]aviation [22], automotive [23], engineering[24,25], electronics[26–28], building and infrastructure [29,30] sectors.

Secondly, with regard to **the geopolitical context** it is taken for granted that the process of globalization will continue to unfold; with a de facto division of labour between China and the West and continuing Chinese dominance in the manufacture of renewable energy technologies. Whilst the West will back-pedal the normative commitment to liberal democracy, the guiding assumption is still that market liberalism will be coupled with an advancing culture of secular individualism, and a common cultural denominator of individualistic consumerism. In this paradigm the influence of leadership (self-designated in the case of the EU) in combination with the imperatives of global supply chains, ensures that the continuing globalization of the economy and the soft pressure of integrated global governance and policy networks will be critical in driving the adoption of green technologies and net zero targets in emerging economies [31–38].

To gauge the depth of this ideological framework, one need only consider the reflexive policy stances of European and North American Green Parties in the Trump era. Support for open borders has become a badge of honour across the green/left end of the spectrum. Thus, the UK Green Party calls for all migrants to be treated as 'citizens in waiting' [39] – which of course makes a nonsense of the category of citizen which is, by definition, exclusionary and membership-based. Green parties have also invariably condemned the idea of tariffs without reservation (e.g. Green Party of Canada, 2025), and attacked attempts to redress Chinese dominance in renewable tech (e.g. Green Party of Canada, 2024).The latter chimes with the consensus on the left in favour of the framework of the open China policy – that China should be fully engaged in the world economy without regard to wider geopolitical, security or human rights issues. This stance was immediately obvious in the policy of Starmer's incoming Labour government in the UK (e.g.[42]) With the political binaries de jour, any serious reversal of policy on China is viewed as irresponsible MAGA extremism.

These first two considerations considered above are largely conscious and at the foreground of strategic consideration at the level of government, NGOs, corporations and universities. The third set of assumptions is less conscious and relates to the underlying **metaphysics and philosophical anthropology** that undergirds late-modern, liberal thinking. The energy/climate problem is treated in strictly instrumental-rational terms as a technical means to a rational end that is itself understood as unquestionable and unimpeachable. This 'end' essentially boils down to material progress. It aligns unreflectively with the spirit of the modern age i.e. secularism, growth, technological capacity. individualism, social and spatial mobility and intergenerational 'enhancement over time.' Understood in terms of 'standards of living' and health, the latter is synonymous with the idea of each cohort of children experiencing better outcomes than their parents. Such ends are entirely in accord with the UN's SDGs which elaborate the same eco-modernist vision[43,44]. The destination is not up for question, merely the means of travel. Automobility is not questioned. The problem is to substitute electric motors for internal combustion engines. Social and spatial mobility is not question. The problem is to achieve that endlessly self-transforming socio-technical division of labour with lower carbon emissions. Materialism and consumption are not up for question. Rather, the problem is to develop the circular economy so as to reduce the metabolic consequences of energy and material throughput. In the liberal ideology of progress, the metric of universalism has narrowed into a preoccupation with the sense that Chinese, America and Nigerian kids do and should all aspire to owning the latest iPhone, and the policy and governance is ultimately about securing such an outcome.

In short, the 'ends' or the telos of Western modernity — consumerism, individualism, materialism, intrusive disembedded markets and an over-reaching nanny state — remain sacrosanct, and the overwhelming focus is upon the means by which these ends are achieved. Paradoxically this requires not slowing but accelerating and intensifying many of the underlying drivers, specifically:

- Individual self-actualization remains a prime imperative that is impervious to ecological or communitarian critique
- Individual mobility remains sacrosanct — albeit with electric vehicles and green air travel
- Individual social mobility remains the sine-qua-non of progressive green politics, even as A.I. and the top-down version of IR4.0 tend towards entrenching unprecedented degrees of caste-based inequality [45].
- Ontological meaning is to be achieved through material affluence — but with green supply chains
- There must be continual access to unlimited energy — albeit renewably sourced.

3. The Inversion of Green Metaphysics: From Off-Grid Sufficiency to Hyper-Grid Connectivity

All of these assumptions are rooted in a vision of atomized, self-contained, choice-making 'billiard ball' individuals who relate to each other transactionally and de novo, which is to say episodically, rather than in the context of a web of relationships that precedes and continues forward after any individual life. The latter vision of humans as 'dependent rational animals' [46] was taken for granted until undermined by the disruptive disembedding of social life that accompanied 'the Great Transformation.' Until this point, moral individualism rooted in Imago Dei – the great achievement of Western society – was tempered by a virtue-ethical conception of relationality and mutual obligation [47–50]. The kind of free individuals created by the disembedding of modern societies – severed from the internal and ascriptive processes of conscience formation associated with a pervasive, shared and very public relationship to a transcendent God – have become rendered as the rational transacting agents of both economic textbooks (economic liberalism) and critical theory (social liberalism). From such a perspective, the choices for governance and politics are narrowed to Market versus State, and in the case of the global sustainability, an unlikely combination of both: impersonal free-wheeling global corporations working alongside a proliferating network of quangos, NGOs, charities, governance bodies, institutes, sectoral organizations and the rest. This is what connects what right wing populists refer to as 'the party of Davos' to the activism of 'Occupy' and Extinction Rebellion. At heart, both market liberalism and social liberalism share an anthropological vision of humanity that precludes self-regulating families and communities relating through principles of subsidiarity.

The reason that any of this is notable is that in its origins green politics was predicated on the antecedent vision of medieval Christendom – a perspective crystallized by the idea that 'small is beautiful'. Founding fathers such as E.F. Schumacher, Wendell Berry, Ivan Illich and Leopold Kohr built on social catholic ideas of subsidiarity to advance a bioregional vision of human scale [51–59]. Without exception they adhered to some implicit understanding of Natural Law – that the vector human progress was tied to a God-given telos, that was itself enmeshed in the relational whole of Creation. This sensibility was captured perfectly by the self-limiting conception of 'intermediate' technology – an idea which implicitly nodded to the mythological trope – Icarus, Prometheus, Faust, Eve, and of course Babel – of human pride and hubris coming before a civilizational fall.

Modelled implicitly on the concentric circulating metabolic layers of natural ecosystems and the low-entropy-conservative flow of energy and materials ([60,61]the animating principle of this kind of political economy is to sustain materials and their highest state of complexity and to avoid entropic dissipation. With regard to materials, this involves prioritising reuse, repurposing and remanufacture over recycling whilst maximising proximity and minimising the distances. Such 'proximity power' – discernable in the ATP/ADP energy cycling of individual cells, the internal organization of organisms, the three-dimensional surface area/volume dynamics of ecosystems (e.g. coral reefs, rain forests) – was at the heart of Richard Register's vision for truly ecological cities [62] but goes back to the bio-morphological intuitions of Patrick Geddes [63] and Lewis Mumford's caution about the technics of the machine [64].

In keeping with this tradition, the earliest approaches to what we now call the 'energy transition' were dominated by the metaphysical intuition that tools should always be an aid to human activity and creativity rather than a foundation for life in themselves. Schumacher had read C.S. Lewis's *The Abolition of Man*, and even in the 1950s, there was a deep-seated recognition of the potential for technology to supplant and undermine the meaning of human life. Transhumanism was then, as it is now, a prospective problem of technics and scale. Ivan Illich's conception of 'tools for conviviality' meshed seamlessly with Schumacher's 'appropriate technology' and Gandhi's emphasis on village development [57,65,66]. Informed by Geddes and Mumford, these thinkers understood that the technics of machines – their implications for the scale and texture of human relations – must remain at the centre of any green vision. The pioneering experiments with DIY passive solar, photovoltaics and wind power at the Schumacher inspired Centre for Alternative Technology in Wales, were paralleled by the DIY biogas, manure-fueled cooking technologies developed by Gandhian rural technologists in India. In both cases, the problem was construed as much in the social impact of energy system as the question of quantity and price. Biogas units extended the circular, ecological metabolic flows of traditional agriculture and linked the kitchen directly to the field.

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Although there were attempts to incorporate electricity into this vision of place-bound, bioregional, household self-sufficiency, wind powered generators, and even more so photovoltaics, were always going to depend on a relationship with a much wider economic system and a correspondingly extended industrial metabolic system. Nevertheless, the iconography of green technological still centred on 'unplugging' from the grid – with a narrative emphasis on romantic off-grid locations. After a period of innovation and interest against the backdrop of the energy crisis in the 1970s, interest and activity plummeted during the Reagen era and the heyday of liberal Thatcherite economics. When the putative energy transition re-emerged as a central problem of economic governance during the 1990s, the implicit localism of the 1970s was abandoned almost completely [67–71].

Since the 2000s, having defined green politics for decades, the idea of maximal self-sufficiency realized through economic and political decentralization, place-bound community and family life has all but been banished from the green agenda. The commitment to top-down global and supranational structures of regulation such as the European Union is such that the decentralization of democracy and the defunding of public investment are construed, strangely, as 'tenets of neoliberalism'[13].

4. High-Tech Global and Grid Approaches to Energy Transition

With this in mind, the one surprising thing about contemporary green energy politics is the continuing antipathy to nuclear energy [72–76]. That this is a cultural hangover from the cold war and public reaction to the Chernobyl and Fukushima accidents is clear from any reasonable overview of the technics of renewable Net Zero. Wind turbines, photovoltaic arrays and EV batteries depend on a massive global industry which depends on rare earth metals from Africa and Asia, Chinese manufacture, the build-up of mountains of difficult to recycle waste – both during manufacture and at the end of life. And yet the downsides of this proliferating industrial metabolism are almost universally ignored or downplayed by political activists. This is clearly because of the explicit judgement that climate change presents a unique existential threat. But the reaction also depends on: (i.) the less explicit conviction that there is no alternative means (nuclear is discounted on what are manifestly irrational grounds); but also on (ii.) the tacit and unconscious assumption that there can be no other ends. The full repertoire of modern technologies but also the highly mobile, individualized, self-actualising pattern of life that construes citizens as consumers with inviolable rights – are all now construed by Green parties and environmental NGOs as non-negotiable and outside the Overton window of respectable politics. In this way, even the most entropically expensive forms of cultural priorities such as universal availability of sex change surgeries and treatment regimes, are rendered political priors [77,78].

Given this convergence of an inverted green politics and the most sulphuric version of liberal individualism, it is not surprising that sustainability has become synonymous with ecological modernization – the project of sustaining and extending our present way of life to all present and future generations.

In consequence, the supply chains for the green energy sector girdle the earth, stretching in all directions. They both make possible but also depend themselves on a ubiquitous, high-energy transmission and storage of information around the Internet – which has become both the end and the means of global society. Globally, data centers consumed 460 TWh of electricity in 2022 – which, according to the IEA, amounts to 1.4-1.7% of global electricity use, a figure which is likely to double between 2024 and 2026[79] – driven to a great extent by both A.I. and cryptocurrencies[80]. In the most extreme, playing out of the Jevons paradox, dozens of academic articles and industry commentaries are feeding the most predictable idea that A.I. will become the driver of 'energy solutions' [81–83]

What should be obvious is that an energy transition that is dependent on an escalating ratchet of data-driven energy use rather begs the question – underlining the extent to which the modernist sustainability discourse and paradigm is exclusively concerned with 'means' and has banished all

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questions about the 'ends' of human life to the margins of academic and public life. Rather than investigating whether materialism, consumerism and individual acquisition are contrary to the telos of our life in common, the question is: how can we *continue* to live 'like this….only more so'.

From this critical perspective, the defining features of the ecological-modernist approach to energy transition centres on a **grid mentality**: individuals are not defined by their interdependent relation to place-bound communities, but by connection to a placeless and proliferation of episodic transactions and one-dimensional interactions with other individuals (some of which may not be human) who can be located at any one of billions of nodes across the web. Energy provision should be designed to serve topographical connections devoid of local context, specificity and personality. The purpose of power generation infrastructure is service the availability of **'plug and play'** connectivity for households and individuals whenever and wherever they happen to be. In the 20th century, the energy-grid became the pervasive metaphor for modernization. Lenin defined socialism as electrification plus Soviet power. In the 21st century the equation would include seamless digital connectivity, as the information and energy grids mirror each other and drive parallel development.

Most innovations in green governance are predicated on the idea that externalities should become visible and accountable to those responsible. Legally responsible for air quality, UK municipal authorities adopt Ultra-low-Emissions Zones (ULEZ) to drive consumer and commercial technical change toward electric vehicles. Consumers likewise become individually accountable for tail-pipe emissions. Blue box recycling schemes encourage individuals to make green choices in the quantity and quality of rubbish generated by households. The EU's WEEE directive attempts to divert electronic garbage from landfill by making manufacturers responsible for end-of-life processing. Household goods and houses are required to have energy ratings designed to spur market innovation and penalize environmental laggards.

National energy policies aim to reduce greenhouse gas emissions across all sectors with the objective of a net-zero economy by 2050. This includes

1. Setting emission reduction targets and regulations:
2. Promoting renewable energy:
3. Sponsoring innovation and technology R&D (e.g. Energy Innovation Program and the Canadian Emissions Reduction Innovation Network)
4. Encouraging energy efficiency:
5. Supporting sector-specific transitions:
6. Encouraging carbon capture and storage in heavy industries such as cement production, iron and steel
7. Building infrastructure for Net-Zero (including smart electricity grids, hydrogen infrastructure, EV charging points)
8. Promoting voluntary initiatives, networks and partnerships which are designed not only to facilitate action but to create a 'structure of feeling' that the energy transition is ongoing and inevitable.

In all areas of intervention, the ostensible aim is to make the environmental impacts of activity visible and so amenable to legal and moral responsibility. This has been the central rationale of ecological and then carbon footprint methodologies – which translate myriad individual and corporate activities into a global metabolic impact or emissions factor. The latter can subsequently be rendered tractable for behavioural nudging, market incentives and regulation and taxation, for example, in areas such as domestic energy consumption [84], hospitality [85], medicine [86] or commercial online activity [87].

In all these areas, the ideas that by making environmental impacts visible, they can be addressed. But this is at best a wildly over-optimistic claim and at best a case of obfuscation.

What becomes visible with the carbon footprint is not an environmental impact per se, but an abstract number. It requires an extended chain of mediating expertise – including government, purveyors of green technology, academics, activists, consumer websites, NGOs, energy companies, consultancies – to tell a given client or consumer whether performance is better or worse (than before, than a competitor, than average), good or bad. The actual externalities remain invisible and can be dealt with by abstract chains of responsibility and provenance. Without specialist expert interpretation -- you can't *see* carbon dioxide. You can't even say with certainty that this or that weather event is a result of your energy footprint. You personally can't really be certain that this FSO certified lumber is more benign for a given ecosystem – or even which ecosystem it came from. You can't really be sure that the more energy efficient and ozone friendly refrigerator is better for the atmosphere than the one going for 'recycling' – or even what 'recycling' really means. You know way of knowing whether the externalities involved in the production of this fridge outweigh the ostensibly better operational performance.

If we step back and look at the last 20,000 years of human history, one striking pattern stands out. With each energy revolution, any given human group became less aware of its long-term ecological impacts. Hunter-gatherers had a good idea of their impact on prey species as the feedback loop was direct and immediate. Having said that migration to new islands or even continents invariably led to massive extinctions in just a few generations [88]. Swidden horticulturalists had a good idea of how their gardens 'used up' the bounty of the earth – such that they would move their whole community every few years and allow the land to regenerate. Agriculturalists began to have long term impacts on the land which were beyond the ken of a single generation – as with the salination of soils as a result of irrigation in the cradle civilizations of Mesopotamia. Traditional rotational agriculture in Europe developed a pretty good intuitive understanding of the relation between manure, grazing, different crops and nutrient depletion. But of course, it was still associated with an almost total transformation of the ecosystem not least with the loss and /or deliberate extermination of large predators, the draining of wetlands, deforestation and the inhibition of the natural movement of rivers. Very little of this was 'available' to the farmers involved. The changes played out over hundreds of years. Informational feedback loops such as there were, were obscured by the noise of much more immediate societal changes in relation to technological and economic change, political conflict, war and religious transformation. Even in the case of massive environmental events such as the Black Death or the late medieval Little Ice Age there was no capacity for human beings to view their own involvement with any detachment as if from without. This was not just a matter of data or scientific understanding, but the fact that most people were too busy simply trying to survive.

Exactly the same is true of the present energy/ecology crisis. We know, in the abstract, that the concatenation of environmental problems really derive from the scale of human activities relative to the natural energy and metabolic processes upon which they depend [89,90]. But despite the overwhelming and saturating flow of data-collection, information processing and narrative-framing directed towards the problem of GHG emissions – in policy briefings and government white papers; in schools and university curricula; on consumer white goods labels; in compulsory realtor information; in food labelling; on all new vehicles; in travel advisories; in corporate strategy rooms; in the rising flood of grey literature from ever more niche sustainability consultancies – despite all of this knowledge, one really important truth is avoided at all costs. GHG emissions, chemical pollution, ecosystem disruption, species extinction, resource depletion and pollution sink-saturation are all a function of how we live, what we value and the metaphysical ends prioritised by liberal modern societies. The problem is our way of life per se, not how we deliver it. The problem is not about technology or governance but meaning. A philosophical way of expressing this, drawing upon the tradition of Aristotelian -Thomist virtue ethics and rooted in natural law, is to say that the telos of ecological modernization is progressive, materialist, secular, individualist and, with regard to moral philosophy, relativist – which is to say modernist. In other words, ecological modernization does what it says on the pot. It matters not a whit, how much data is gathered and processed under the aegis of this paradigm. The guiding premise is that our current way of life is non-negotiable, should be extended to rising nations from the global south (as far as possible) and delivered in a green way.

5. The Circular Economy from Above

It from this point of view that globalising perspectives on the 4th industrial revolution (IR4.0) combined with the putative (and now still born) 'green new deal' understand the 'circular economy' [93–95]. Far from accepting limits, the progressive constituency automatically assumes a virtuous relationship of mutual facilitation between the technical and market solutions for perpetual recycling of materials and the limiting of 'entropic dissipation'[94–96] .The idea of entropic dissipation is implicit in the green hierarchy of: (Reduce), Repair, Reuse, Remanufacture and Recycle. The priority is to preserve units and sub-units of metabolic complexity or 'negative entropy' that have been achieved only with an antecedent process of expensive metabolic production. It takes a great deal of energy and complexity for a rain forest ecosystem to concentrate phosphorus. Luckily combined processes of predation, digestion, decomposition are enormously efficient at ensuring that rare elements don't leach into the water system and down to the sea becoming unavailable to the wider ecological community. The same principle holds for rare earth metals in human electronics. But when an iPhone or any chip enabled device enters a land fill this is the equivalent of a haemorrhagic even of entropic dissipation – the loss of embodied energy [61,99]. The circular economy is, in essence, an attempt to stem these losses and make human society operate with the metabolic efficiency of a rainforest.

So of course, the notion of the circular economy itself is common sense. It has from the start been the central idiom of ecological economics. But modelled on biological life systems, much depends on the scale at which it is articulated and expressed. In nature energy cycling at its most basic level is subcellular and involves the oscillating balance of ATP/ADP production in the processes of photosynthesis and cellular respiration. In a multicellular organism the problem of temporary or long-term storage of energy and just-in-time delivery is solved with a complex range of chemical storage molecules (glycogen, blood sugar, subcutaneous fat etc.), transportation infrastructures (semi-permeable membranes between cells, blood tissue, arteries, the heart etc.) and an even more complex mechanisms of hormonal controls. Just as cellular processes are nested within larger cycling at the level of organs and whole organisms; energy cycling within any organism contributes to metabolic and informational flows cascading through whole ecosystems and ultimately the biosphere. However, the system as a whole is granular and involves uncountable levels and subsystems with their own topography and temporal rhythms – from nanoseconds to millions of years in the case of the carbon cycle (and what we know as fossil fuels).

This begs the question: if the circular economy is to be global in reach, what are the granular subsystems and the temporal and spatial feedback loops regulating it. In a more fundamental ontological sense, what is the unit of analysis. What takes priority – the individual, the family/community, the nation state or global society.

Industrial Revolution (IR) 1.0 was organized around coal which facilitated steam power and highly mechanized and centralized forms of factory manufacture. IR 2.0 was driven by the internal combustion engine, electricity grids and the revolution in synthetic chemicals. Founded on computers and the information economy IR 3.0 came of age with universal personal computers and the Internet or what was called to begin with the information super-highway. As with previous paradigm shifts, the IR 4.0 now underway doesn't displace these previous architectures but rather re-integrates them in new ways. A paradigm of synthesis and convergence, the 4th Industrial Revolution is blurring the lines between the physical, digital and biological worlds with the suite of emerging technologies including quantum computing, artificial intelligence, the so called 'Internet of Things', 3D printing and additive manufacturing (applied to every more substrates and domains) and finally, the miniaturization and modularization of manufacturing and fabrication technologies that were hitherto capital-intensive and necessarily large scale. These innovations are reducing the cost of manufacturing and making possible boutique economies of scope involving complex alloys, printed circuit boards, plastic extrusion and even synthetic biology.

4IR as conceived by the World Economic Forum [3,100–103] is explicit in conceiving of the unit of analysis and the principle metabolic container for the circular economy as the global economy. The accounting process and account clearing – whether in terms of energy or rare-earth metals, or biodiversity or ecosystems – is global. Many have criticized the project for its failure to evidence any real transformation of social, political, cultural and economic institutions, locally and globally [104]. Moll is not untypical in seeing the World Economic Forum's mission as running cover for global corporate and liberal elites.

But although this is true, the problem is more specific and technical. Attending only to the scale of a putative global society, the economic ecosystem is conceived very simply in terms of a small number of actors: massive corporations, pliable and compliant supply-side nation states and billiard ball individuals. This of course, reflects the traditional liberal conception of Homo economicus. But it also greatly underplays the complexity of the nested hierarchy of energy processing units operating within, across, in cooperation/competition with each other that make the circular economy of the biosphere function so efficiently. The WEF understanding of the global economy is something akin to a biologist imagining the energy flows of the Serengeti by referring only to the sun, the grass and lions or of a Pacific ecosystem with only sharks and plankton. In fact, the oscillating chain of energy exchanges and transformations that mediate solar energy and the ambient heat escaping into the universe involve billions of interdependent entities -- from individual bacteria to mitochondria and chloroplasts, whole cells, multicellular organisms, communities of species, coral reefs and forests, right up the biosphere – whose isolated categorical autonomy as things in themselves is only a function of human analysis. It is the multiplicity and complex interdependence of these 'levels of integration' (to use Joseph Needham's term [105] that make possible the continual balancing of supply and demand for nutrients and energy across so many spatial, topographical and temporal scales. The accounting process isn't done at the year end, or at one organizational scale – but continually, and at every scale.

Perhaps in some specific areas the ecological modernization project of the World Economic Forum will lead to some 'demand reduction.' There have certainly been some notable successes – for instance in relation to CFCs and the ozone layer. But even this example is indicative to the degree that the ozone friendly HFCs (hydrofluorocarbons) that replaced CFCs, contributed greatly to the next problem of industrial society because of their high global warming potential. The campaign to preserve the ozone layer characteristically focused on the supply and demand of a single class of chemicals (a MEANS of refrigeration) rather than demand for refrigeration itself (the 'END') and the modern lifestyle that required ubiquitous cold food storage.

But what if this eco-modernist paradigm is not taken for granted? Specifically, what if global ecomodernism cannot deliver and endless materialist bonanza within limits? The results so far are not promising. It seems highly unlikely that consumer society can be made 'green.' The idea that circular economy can deliver the micro/granular re-circulating throughput of energy and materials, eliminating entropic dissipation and delivering super-complexity with a 90% reduction in metabolic cost seems more like science fiction the more that we understand of the analogous processes in the biosphere. Given the exponential dependence on computing and servers, rather than sustainability, the attempt to deliver this future seems likely to put an unbearable strain on the resources and carrying capacity of the biosphere.

6. Populist Rejection of Net Zero and Green Energy

Because it has become the goal, the metaphor of grid – stemming from the universal and topographical approach to the delivery of electricity, sewage, water, postal systems, transportation and Internet – has become itself a massive problem. The idea of the electrification grid was in the 20th century a powerful symbol of modernization with the image of cheerful pylons marching across the countryside delivering clean power to far flung rural communities. As noted above, exactly the same iconography was picked up in the Soviet Union.

What if, within erstwhile coherent national societies, this trajectory unravels the shared 'we-identities', perceptions of common destiny, place-bound obligations and communitarian commitments that combine to secure social cohesion? The previously unthinkable prospect of

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European civil wars driven by mass migration, class tensions and ethnic and religious fragmentation is now emerging as a possibility even within mainstream discourse [106,107]. Such unravelling is likely to generate the kind of internal conflicts that often generate external bellicosity. It is entirely possible that the same trajectory of eco-modern material progress unleashes a new phase of geopolitical conflict over scare/rival resources including land, minerals, water and energy [108–112]

In the 20th century energy and infrastructure grids were territorially bound – pertaining to coherent national societies and economies. The project of Net Zero – tied to increasingly global targets and agreements overseen by abstract global bureaucracies such as the EU or the WEF – has in many ways come to bear against national interests and the place-bound 'we identity' of citizens in particular countries. From the outset, commentators such as Matt Goodwin warned that costly green taxation would be perceived as unfair and provide impetus to populist revolt [113].

Even as recently as 2023, Paterson et al. [114] were able to argue that the populist assault on net zero had failed to dismantle the basic aim of UK climate policy – although they did add the rider 'not yet'. Since then, such optimism has evaporated[115]. Across the Western world, populist parties are challenging incumbent liberal and social democratic establishment [116]. Longstanding scepticism in East and Central Europe is no longer an outlier. In the UK, having been propped up by Boris Johnson, Kemi Badenoch's conservatives have finally turned their back on Net Zero arguing that the upfront cost can't be borne by consumers. But much more significantly has been the astonishing rise of Nigel Farage's climate skeptic Reform party – now quite possibly in a position to form the next government. Even Tony Blair – the cheer-leader extraordinaire for the liberal global order and the 'party of Davos' – has warned against rushing the phasing out fossil fuels. And perhaps most strange is that even the Green Party under Polanski has adopted a version of consumer-centric eco-populism that throws Net Zero under the bus [117]. On the ground, there is clear evidence of voter fatigue with imposed green limitations, not least with respect to the much hated Ultra Low Emission Zones [118,119].

Clearly Trump's election in American speaks for itself as to changing public attitudes towards the top-down sustainability agenda. But even against the backdrop of an ostensible trade war and a marked upsurge in Canadian national sentiment based on a self-image of adult responsibility and international civic-mindedness, Carney's new government has dropped Trudeau's unpopular carbon tax – a far cry from the heady atmosphere of 2020 [120]. Aside from the impact on prices [121], the Liberals have been sensitive to clear evidence – very well communicated by the opposition – that Canada has underperformed the American economy for two decades, in part because of the much greater regulatory overhead.

The bottom line is that global ecomodernism is not succeeding even in its own terms. Green tech is not delivering growth and political stability, but nor has it made a dent in anthropogenic impacts on the biosphere. Advocates on the inside have always insisted on the need for trust and citizen acceptance (Kitt et al., 2021).But the polarising logic of culture war has seen putative consensus positions on climate policy linked inextricably with the most partisan extremes of race and gender politics, and currently – in the case of Greta Thunberg – antisemitic and far left activism against Israel and the entire body politics of western society.

7. IR4.0 from Below: Decentralized, Open Source, Disruptive

For the last 50 years, eco-modernist approaches have dominated mainly because of the real benefits to the global south brought by globalization and modernization, and because of the political impossibility, in Western countries, of challenging a social compact that depends upon growth. To advocate for localism was necessarily, and sometimes overtly/deliberately, to embrace poverty, simplicity, and the disavowal of technological development and innovation. Limits to growth localism seemed necessarily to be Luddite, backward looking and atavistic. Even technological progressives could not square self-sufficient localism with the economies of scale and the throughput of artefacts necessary to drive productivity and innovation. The iPhone depends for its existence on a cyclical process of technical revision that requires hundreds of millions to be thrown away as a matter of design. With regard to local energy systems, although renewable energy technologies have

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been presented as opening up avenues for community life 'off the grid' – in fact for market and technical reasons depend very much on networked economies of scale. In this sense, green technologies – particularly in relation to energy and information – have moved communities into much closer reliance on global grid systems in terms of manufacture, the circulation of raw materials, the ecosystem of training and expertise and the constant hum of, now ubiquitous and automated information exchange (not least as artefacts talk to each other via the 'Internet of Things').

On the other hand, the same technical developments associated IR4.0 are making at least conceivable, for the first time, forms of high-tech and networked manufacturing/consumption localism. Sometimes called social manufacturing [123,124], commentators are identifying the disruptive potential of additive manufacturing in particular, for a paradigmatic transition to economies of scope. In essence the new technology makes possible a kind of just-in-time immediacy that was evoked but never achieved by advocates of the Third Italy model in the 1980s [125]. Although they don't spell it out, specialists in this new political economy are spelling out a degree of modularity, distributed activity, granularity and complex nested presumption levels that is analogous in a very real way to the hierarchy and connectivity of natural systems [126–133]. This highly granular 'nano-mode' organization allows for exactly the 'tightening of the loop' on the circular economy that would be necessary to lower the entropic unit cost of complexity [132]

In the history of humanity, 'prosumption' was the norm. Peasant households would routinely heat their houses and cook using their own or locally sourced wood, grow their own meat and vegetables, producing dairy products or perhaps make clothing. Slightly higher order domains of production might involve the wider community – furniture making, metal work, shoeing horses etc. However, with the advent of industrial society there were what seemed to be an intrinsic impediment to any systematic forms of prosumption. Specifically:

- National states required children and young adults to be schooled outside of the home
- Industrial products required raw materials, skills and capital equipment beyond the means of any individual household.
- Industrial innovation required a level of technical expertise and collaboration that was beyond the means of any individual householder or even a community.

On all three counts, high tech presumption can now overcome these limitations. Homeschooling has expanded enormously since covid which accelerated the development of highly technical education and skills acquisition via the YouTube and dedicated social media which can be equal to or superior to a university degree. The dynamics of miniaturization and economies of scale (ironically) are now producing sophisticated desk-top, household and community scale manufacturing and fabrication machinery that makes domestic high-tech production a real possibility. And finally, the Internet 2.0 has made possible forms of online collaborative innovation that virtually eliminate spatial or topographical constraints [134,135]

8. The Post-Liberal Alternative: Energy Transition as a Function of Virtue and Post-Liberal Politics

Against the ecomodernist vision of green growth led by states and corporations operating within increasingly integrated global regulatory and governance frameworks, there has always been a subaltern vision of sustainability which is informed by some (Christian, Islamic, Hindu) version of Natural Law or the 'perennial vision'. Foregrounding biophysical 'limits to growth' the tradition of ecological economics associated with Herman Daly, E.F. Schumacher, Mahatma Gandhi, Ivan Illich or Tolstoy, starts not with the 'means' but with the 'ends' of economic activity. Some of these approaches have been explicitly tied to the project of sustainable development. In other cases, the green vision has been an accidental function of broader metaphysical commitments in relation to community, or the appropriate goals for individuals and families – and specifically a rejection of consumerism, individualism and materialism, usually on religious grounds.

The bottom-up, decentralized, open-source and community-based version of IR4.0 intimated above works with the grain of the technology. Information wants to be shared. But it also works with the grain of human nature which is inclined towards collaborative creative activity. The modern separation of work from the household has always been an anomaly – and the source of much societal dislocation (particularly in relation to the role of women). The new technology is at least making conceivable a high-tech version of the original communitarian and localist green vision. This centred on the re-embedding of economic activity into the weft of shared religious commitments, familial obligations in relation to children and elder care, the return of very contextual ethic and practice of stewardship to the immediate environment (as opposed to the global abstractions of climate)

Although we are only in the early stages of this technical revolution it is already clear that additive manufacturing, web-based computer aided design, workshop-scaled and modular robotic manufacturing systems, scaled down versions of extrusion and moulding technologies – combined with virtually all the necessary technical knowledge, information and skills-teaching available via online platforms – are making it possible to replicate entire industrial ecosystems at the scale of small towns and regions. Since the 2000s the pop culture version of this potential has been spreading under the moniker of the 'maker movement', supported by a variety of now institutionalized expos, websites and journals and numerous community-based maker-sheds and tool libraries. Providing much needed historical context, Kevin Carson [136] identified the distinctive feature of the new configuration in terms of the low overhead costs. Using 3d printing, Arduino and conventional fabrication techniques, pioneers of the Peer-2-Peer (P2P) revolution are unfolding a future in which there is no longer a necessary choice between high tech and local sufficiency.

Couched in terms of a libertarian ethic of self-sufficient families and communities, the P2P economy, combined with micro-fabrication and computer-aided design and married to a renaissance in traditional craft and fabrication skills, offers a new relationship between hand and brain. The technics of this new kind of political economy could give rise to a positive 'post-liberal' society [49,137–141]. Precisely because post-liberalism involves a dramatic reversal in the relationship between means and ends, because it involves a rejection of materialism, secularism and individualism and the recovery of pre-modern virtue ethics and Natural Law as the undergirding societal compass – it does bring with it the possibility of genuine transformation in the per capita metabolic footprint. However, to the extent that this plays out it will not be on the back of the kind of overt, external restrictions and incentives that are associated with 'global environmental governance'. Rather, the possibility turns on the reemergence of structures of meaning that are not strictly environmental at all. It is an open question as to why families might begin to embrace the localist political economy of prosumerism (El Mahmoudi et al., 2020). But almost environmentalism will not be the primary motivation. Rather, it will hinge on intuitive understandings of what is good in terms of family and community, an innate propensity for social and creative activity and a reaction to the excesses of modern individualism. If there is a school of political economy that best reflects this potential it would be social catholic distributism [143–145] and the strain of virtue-ethical moral and economic reasoning that emerged from the writings of late 19th century Pope Leo XIII – the namesake of the current Pope Leo XIV.

Marcin Jakubowski's Open-Source-Ecology (OSE) project is perhaps the most ambitious attempt to realize the potential of P2P production in a community context [146]. An anarchist version of the Manhattan project OSE aims to develop:

'open source industrial machines that can be made for a fraction of commercial costs, and sharing our designs online for free. The goal of Open Source Ecology is to create an open source economy – an efficient economy which increases innovation by open collaboration'

The scale of ambition is evident in the 'Global Vision Construction Set' – a checklist of mass collaborative, open-source R&D projects which aim to produce blueprints and detailed fabrication instructions for 50 plus pieces of industrial machinery. These range from an earth brick press and power cube to an electric motor vehicle and a generic tractor. Although less explicit than Carson about the implied social technics, OSE implicitly turns on the idea of low over-head and family-based

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production. In this sense it is most certainly a political project that stands squarely against the top-down, regulated and highly taxed version of the IR4.0 represented by the World Economic Forum. Low overhead production requires the cost and size of capital equipment to come down, but also the regulatory and fiscal costs of doing business. The principle is straight forward. Smaller and more place-bound enterprises serving more local markets should be subject to much lower taxes with less regulatory oversight (and perhaps none at all for farm gate enterprises).

Clearly the social democratic state will react badly to any such project of deregulation. But as libertarian and ecological farmer Joel Salatin has said many times vis-à-vis the domain of food regulation – the restrictions that were necessary at the dawn if industrial food manufacture have been made obsolete by the ubiquitous availability of fridges, stainless steel, disinfectant, and now, social media reputational systems which ensure crowd-sourced punishments and sanctions for any businesses that do not take reasonable precautions.

But the bottom-up version of (IR4.0) intimated by Marcin Jakubowski and the P2P community, is not just a challenge to conventional technologies and regulations. Necessitating a long-term decline in the size of the welfare state (because of declining tax revenues from the formal economy – see [147], the prospect really would require the re-emergence of a shared ontological and metaphysical understanding of society and normative conceptions of family.

The liberal society of individuals will always align itself with the top-down, corporatist and globalist model of ecological modernization. 'Appropriate technology' to revive an old-fashioned concept, might finally have the potential to be just as high tech and scientifically progressive. But can't work unless oriented to different ends embodying a reaffirmation of the intrinsic value of humanity (and our innate potential for creative work). Secular humanism in contrast is in fact threatening to make human beings redundant. The top-down model of IR4.0 is very much a driver of transhumanism.

9. Conclusions

The high-tech trajectory of the 4th industrial revolution (IR4.0) as conceived by dominant institutions such as the World Economic Forum, is a significant driver of the new paradigm of global net zero and a highly integrated agenda of eco-modernism. But global net zero cannot hope to achieve its own metabolic goals in respect of either energy flows or the circular economy. A competing, bottom-up and distributed model of the IR4.0 could potentially achieve these targets without falling prey to the Jevons paradox. This potential turns on the greater capacity of low-overhead, prosumer models of manufacturing to nurture completely different and less materialist cultural priorities that are less individualistic, more communitarian, more family oriented and more attuned to the human propensity for collaborative, creative activity. A smart energy system that emerges in the context of distributed, domestic and informal production is much more likely to mirror the complex, infinitely gradated and granular pattern of oscillating energy transfers that are characteristic of biological systems. From an ecological economic perspective, such a bottom-up approach to the IR4.0 is much more likely to see the orders of magnitude reduction in the unit energetic cost of social complexity envisaged, in principle, by Net Zero.

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Abbreviations

IR4.0 4th Industrial Revolution

Note

1. The politics are complex but even Nigel Farage, an instinctive Thatcherite, now renders the ideological a priori commitment to free trade in terms of 'fair trade' and acknowledges a mercantilist real politic that foregrounds the economic interests of nation states.

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