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Perspective

Opening up energy: toward more coherent research into transitions

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ABSTRACT

Is the phrase "a just transition to renewable energy" self-contradictory? That is, is the modern, abstract energy denoted in the phrase (and many others like it) inherently unjust and unrenewable? It might help social science energy research climb out of the rut in which it is currently stuck to take this perhaps surprising question seriously. It can open fruitful new avenues of inquiry to grasp abstract energy not as a universal, non-political resource shuttled here and there across an unchanging landscape – as is common today across the social sciences, state and international institutions and NGOs – but as an ongoing colonial process of reorganizing human and nonhuman territories into hierarchies favorable to capital accumulation. After all, it is only by repatterning entropy boundaries and flows that the abstract energy developed during the 19th century is able to serve the digital and other industrial machines that are used to bring more workers under the compulsions of capital, accelerate turnover, appropriate feedstocks and contain resistance. For grasping this process, the thermodynamics that theorized abstract energy is one indispensable, well-grounded idiom. But it is not neutral. In any democratic discussion about energy futures, it needs to be made vulnerable to translation into other energy languages in which plural energies of the commons are not subordinated to the singular energy hegemonic today in official circles. A regime of mutual, multi-directional translations, when combined with historical inquiry, exposure to alternative experience and democratic struggle, is a promising methodology for scholarship about livable energy futures.

1. An introduction in four metaphors

Much of today's academic research into energy futures is stuck in a loop and needs a thorough rethink. Repeatedly, researchers investigate ways in which energy might be made "renewable," often implying that doing so can satisfactorily address the ecological devastation associated particularly with fossil fuels. Yet evidence piles up year after year that a switch to energy alleged to be "renewable" – often held to include technologies such as solar, wind, biomass, wave, tide and geothermal, but sometimes also hydroelectric, hydrogen, nuclear or thermonuclear – is not sufficient to get at the roots of the ecological crises accumulating around energy. To treat it as if it were, moreover, may well only deepen those crises. For one thing, such "renewable" energies tend to reproduce patterns of territorial degradation similar to those identified with fossil fuels [1–14]. As Erik Post, Marisol Rosas Perez and colleagues [15] note, the "green" energy infrastructures espoused by most corporate and governmental actors simply "rearticulate the colonial, capitalist, and extractivist logics that fuel climate change and underpin hegemonic power relations." The result has been a cascade of land and water grabs and ecological violence and disruptions, as well as environmental resistance [16,17,18,19,20]. In addition, so-called renewables are neither replacing fossil energy nor, in global terms, in conflict with it. Rather, they supplement and feed on fossil sources in numerous ways [21–25]. In a recent book, historian Jean-Baptiste Fressoz [26: 9] sums up the story of supposed renewables as "not one of resistance, or even of additions, but of the entanglement and symbiotic expansion of all energies." The very language of a "transition to renewables," Fressoz argues, hides what amounts to an underlying continuity of environmentally-damaging extractivist regimes. Nor, furthermore, have the energy efficiency measures that are sometimes coupled to renewable energy programs shown any sign of relinquishing their well-documented historical role of accompanying rather than checking net global increases in energy use, together with the associated harms [27–29].

One aspect of the exaggeration of the potential of "renewable" energy development to address crisis is an often outsized confidence in the efficacy of tools from the social sciences and humanities to help "fix" whatever interconnected social, ecological and political issues arise. Scholars specially qualified to understand the politics, ethics and social "implications" of energy in its various forms are frequently expected to

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be capable of joining engineers and other technicians to remedy tendencies of renewable energy programs to reproduce or exacerbate existing injustices [30–34]. Among the social science-informed strategies deployed are measures ensuring the "inclusion" [35] or "free, prior and informed consent" [17,36,37] of affected peoples, their enhanced "participation" or "empowerment" [38], and a more "sustainable" or "rights-based" form of development sensitive to local communities' entitlements [39–42]. Part of making energy "green," according to another familiar narrative, is distributing it fairly in line with principles of justice long explored in the humanities [34]. Other proposals, meanwhile, advocate greater "recognition" [31,43] of the differing needs, understandings, identities and other practices of Indigenous or peasant peoples, slum dwellers, proletarians, and so forth as an effective counter to the colonialism or authoritarianism often associated with large-scale renewable energy development.

However, while these efforts often help reveal the internal tensions of the project for a just, renewable energy transition, they are typically insufficient to address them. For example, where people do not want modern energy, better and wider distribution of it may threaten justice rather than advance it [44,45]. Similarly, where "participation," "inclusion" or "consent," or "rights-based" mechanisms introduced by social scientists sidestep or undermine accepted practices on the ground, or merely cover over an authoritarian paradigm, the results are likely to be anti-democratic [35,46–49]. As Lina Alvarez and Brendan Coolsaet [43: 15] explain, parity of "participation," even when it involves the "consent of those who are likely to be the first victims of environmental injustice may contribute to the reproduction of environmental injustices when detached from a radical transformation of the institutions where participation takes place." In many cases, well-intentioned efforts to ensure environmental justice may simply founder when confronted by more powerful corporate or state imperatives to secure cheap industrial raw materials at the lowest cost and contain the resistance of affected peoples [4,50]. Nor is it clear how to make a start on the radical project of making energy into a shared commons [51,52,53,54,55,56] rather than a privately-owned commodity [57,58], given the extent to which the abstract energy whose structure will be explored later in this article has always been intertwined with commons-unfriendly institutions such as centralized states, profit-making corporations [59], legal infrastructures of private property rights [60] and what Bruno Latour [61] calls the "modern constitution" walling off the "natural" from the "social." (see Sections 3 and 4 below).

In sum, proponents of a "just transition to renewable energy" often find themselves in the position of the proverbial fly in the fly-bottle. The fly-bottle is built so that once inside, a fly has a certain limited freedom to go in this or that direction for a short distance but, time after time, finds itself butting its head against a transparent glass wall preventing its exit because it is unable to locate the opening through which it flew in the first place. What this article will suggest is that the hegemony of abstract energy itself forms a fly-bottle for many dedicated advocates of energy alternatives, but that with some effort they can find a pathway to a larger realm where they can go forward with their work with fewer impediments. It will argue that energy *itself* – as manifested in a particular, structured, often authoritarian pattern of energy conversions in the contemporary global landscape and whose theory, first articulated in aspects of 19th-century thermodynamics, is now propagated by energy corporations, ministries, international agencies and most non-governmental organizations – tends to be anti-ecological, anti-democratic, disempowering, colonialist and unjust. From this perspective, research into making energy production, use and distribution "renewable" or "just" that proceeds without asking first what this energy *is*, and whether it *can* be made renewable or just, is question-begging and runs the risk of unintentionally serving structures that may themselves be nonrenewable or unjust [62]. The way forward, the article will stress, is not to despair of all concepts of energy, but rather to expand the scope of research into "energy alternatives" to include (for example) more inquiry into ever-present countercurrents to and within modern or abstract energy itself.

This article could thus be said to take its cue – to shift the metaphor – from an enduring slogan of feminist activism, namely, that addressing patriarchy cannot be just a matter of adding more women to various institutions and then stirring. Those institutions must themselves be examined to see whether adding more women does not simply cover over – or, worse, reinforce – the mechanisms through which the institutions themselves continue to reproduce patriarchal hierarchies. Similarly, the article argues, promoting energy alternatives needs to be more than just a matter of rushing to add measures intended to promote "renewability" and "justice" to the form of energy that rules globally today, and then vigorously stirring the mixture. Such an approach, the article contends, is bound to have contradictory, confused results. More successful quests for renewable or just energy regimes will need to go deeper and ask questions about 19th-century energy itself as it is manifested in today's biophysical and political landscape. To deploy a final metaphor, this one from computer parlance, research into energy futures needs to understand that non-renewability and injustice are not pesky "bugs" awaiting elimination from a neutral, universal matrix of energy provision, but rather intrinsic "features" of modern energy itself in both its green and brown versions. Such an understanding can help avoid the pitfalls of a too-narrow pursuit of, say "low-carbon" energy. It can also help avoid a misplaced faith that measures such as "free, prior and informed consent" to energy projects will be capable of finessing the political conflict rooted in the territorial violence entailed by modern energy itself. In addition, it can open up new possibilities for exploring dialogues and alliances with thinkers at the grassroots, including Indigenous thinkers, whose long-standing disagreements with official orthodoxies about free energy, efficiency, productivity, waste, and the valences of resources and entropy have often been misconstrued as ignorance or misinformation. In this respect, this article is intended to supplement and enrich recent calls for a cooperative "insurrection in energy research" made by Carlos Tornel, Alexander Dunlap and others [20,63–65], as well as to contribute to numerous current conversations implicitly questioning 19th-century abstract energy among social movements in the global South [66,67].

The remainder of the article is divided up as follows. The second section seeks to situate the article's argument in the contemporary flow of discussion about energy futures by charting both the academic currents capable of carrying it along and the countercurrents against which it must make headway. This section encompasses not only a literature review and an indication of the gaps that the article seeks to fill, but also a frank sketch of what is hoped might be possible treatments of sociological and psychological blocks to acceptance of its thesis. A third section explores the roots, in thermodynamics and elsewhere, of the common view that energy is a neutral, noncolonialist substance, resource, object or "thing" independent of, but of universal benefit to, humanity. The fourth section will describe a countercurrent within thermodynamics itself that offers a more perspicuous understanding of the colonialisms intrinsic to energy. This is intended to underline the need for the active participation of physics "proper" in setting new directions in social science energy research. The fifth section cautions against any temptation to suppose that conventional entropy economics, as exemplified by the valuable work of Nicholas Georgescu-Roegen [68] and his followers, might by itself be sufficient to reboot energy futures research in the way proposed by this article. A concluding section recaps and extends the various suggestions that have been made throughout of what a revised research program into energy futures might look like while also drawing together other threads from the article.

2. Situating the thesis: obstacles, pathways, literature review

This section will briefly describe how the article's argument fits into and supplements the existing literature and orature [69,70] on energy alternatives.

The first part of this task must be to acknowledge solidly-entrenched and sometimes unconscious academic prejudices that can on occasion discourage its topic from even being broached. In particular, the article's treatment of the complicated practice and theory of energy that has characterized world biophysical and political landscapes since the 19th century needs to confront head-on the still-common notion that the truths of the First and Second Law of Thermodynamics – which form part of the definition and elaboration of that specific energy – are unsituated, unproblematic "views from nowhere" [71], or observations from a *punto cero* ("zero point") that cannot itself be observed [72,18]. According to this notion, the energy that came to prominence in the 19th century lies outside world history, world politics and indeed scientific argument itself. While insisting that the First and Second Laws of Thermodynamics, together with the energy concept that they help define, are well backed-up, correct as far as we know, deep in their implications, uniquely inspiring, and useful in uncountable ways to various societies and the analysis thereof (including the analysis pursued in this article), this Perspective will also venture to argue that they are also partly constituted by historical practices that benefit some interests more than others and obscure some material realities more than others. In addition, the article will contend, these laws have always swum in a thick vapor of further claims about society and nature that have continually been contested inside as well as outside anything that might be called a scientific community.

The article thus constitutes one small effort toward what historians Christophe Bonneuil and Jean-Baptiste Fressoz call the "denaturalization" of the history of energy [73,64]. It questions the perceived status that thermodynamic energy still enjoys today in many academic circles of being an unmarked, universal backdrop to any possible social activity. The article implies that it is faulty methodology to assume that while energy can be "used" for a full range of political projects, good and bad, it itself nevertheless must have a neutral, privileged essence that was revealed once and for all in a protected zone of pure "scientific curiosity" about which little more should be allowed to be said. The article thus contains a challenge to a state of affairs in which energy scholars are expected to differ over, say, whether a particular technology is renewable or not, or whether a particular energy policy is just or not, but not over whether energy itself – whether manifested on physics classroom whiteboards or in electricity substations – contains biases that undermine the survival and flourishing of many social groups. It seeks to uncover the prejudices of a vocabulary commonly used in the social sciences according to which, say, the "economic implications of the Second Law of Thermodynamics" is a legitimate topic for inquiry, but not, for example, the "implications for energy theory of the modes of labor control that emerged in the 19th century." It suggests that whatever institutional, financial, temporal, and personal investments may have been made in keeping the historically-grounded biases of energy invisible is not in itself a good argument for continuing to make those investments. Finally, it insists on a form of intellectual discipline that makes more room for popular movements to argue that energy itself is a political problem (as they often do [35,44,67]).

These theses can sometimes provoke, among academics and others, extremely interruptive, combative and emotionally-defensive reactions whose fervor this article needs to acknowledge and engage up front, all the more so in an era of authoritarian-fostered "culture wars" [74] inside and outside academia. Indeed, such reactions are probably unavoidable in the course of the engagement with the literature that this article pursues, because they can sometimes imply changes in the very lives of energy researchers [75]. In that way, they are perhaps reminiscent of the prickly or repressive reactions among some groups that sometimes result when the concept of whiteness is turned into an object of inquiry and deprived of its status of being an unexamined background against which difference is measured [76]. Patiently or not, such reactions must somehow be navigated through in multiple ways in the conjoined causes of good science and liberation. What are the best ways of doing so in different circumstances? While not tiptoeing past controversial issues, this Perspective will adopt the strategy of trying to reassure sensitive energy investigators across all disciplines, including the social sciences, that in order to go on doing their work as well as to respect, defend, engage and apply the well-established truths of thermodynamics, there is simply no need to elevate any aspect of the practice and theory of 19th-century energy into a transcendental object which is somehow *not* constituted through and through by continuing strife, including class and racial conflict. The article retains the faith that irrationalist or obstructionist responses to this thesis can be met through a fusion of scholarly argument, exposure to alternative experience, and democratic struggle.

Hence the article, while treating the truths of thermodynamics with the greatest respect, is constantly buttressed with referenced reminders that they are not, in fact, "views from nowhere," but hail from a very particular somewhere [71,77,78]: certain elite circles in Northwest Europe in the 19th century. These reminders draw on the work of a variety of thinkers. Ivan Illich [79] was one of the first to sketch how the new energy abstraction formulated in Europe during the 1800s posited a cosmos defined by the eternal scarcity of a substance that only industrial society could provide to its generic humans. Around the same time, George Caffentzis [80], in his unique investigations of the links between the rise of energy physics and the growing role of industrial machines in extracting value from labor, located the flip side of this scarcity in the new impetus that capital's unending "search for new work forces" was given by the vista of an "infinite multiplicity of energetic forms" that the First Law of Thermodynamics helped open up. In sometimes conflicting ways, Hans-Dieter Bahr [81], J.-C. Debeir and colleagues [59], Andreas Malm [82], Bonneuil & Fressoz [73] Timothy Mitchell [83], Daniela Russ [84] and many others have spelled out in fuller detail the multiple ways in which various capitalist interests advanced their struggles with labor through the political flexibility they developed via machinery and, ultimately, the new ranges of energetic choices theorized by thermodynamics. Theodore Porter, meanwhile, has helped reveal how an "economic point of view formed the root of thermodynamics" [85: 141], while Crosbie Smith and M. Norton Wise have contributed extensive insights into how the mathematical physics of Lord Kelvin was "thoroughly permeated" by an industrial capitalist cosmovision [86: xx-xxi]. More recently, Marian Jacobs has noted of 19th-century Germany that "physical knowledges and institutional arrangements of the energy system were shaped in conjunction, establishing a certain path dependency to such developments" [87]. In their studies of the energy culture inherited from 19th-century Europe, Michel Serres [88], Barri Gold [89] and, again, Crosbie Smith [90] have also helped wean intellectuals away from the recurring presumption that thermodynamic thinking and its exponents are isolated from the rest of society. Larry Lohmann and Nicholas Hildyard [91,92], for their part, have traced the political structure of thermodynamic energy in part by reconceptualizing it as a post-1800 mode of reorganizing global landscapes and territories to the advantage of some groups over others. Cara New Daggett 's 2019 book *The Birth of Energy: Fossil Fuels, Thermodynamics, and the Politics of Work* has now helped a new generation locate energy in historical time and political space [93], underlining the point that energy's past will forever need to be contended with when confronting its present and anticipating its future.

From another angle, venerable figures in energy research such as Alf Hornborg [94,95] have raised profound objections to the historical and continuing fetishization of industrial machines. These objections also apply, this article urges, to the fetishization of an energy object. In their vitally-important research, Hornborg and colleagues have in turn relied on renegade economists who have been alert to the traditions surrounding the Second Law of Thermodynamics, including especially Nicholas Georgescu-Roegen [68], whose follower Kozo Mayumi [27,96] is another notable pioneer. The aspect of the denaturalization (or alternatively, decolonization) of energy that this Perspective hopes to advance connects also with the work of many scholars with an activist bent. Myles Lennon [62,97,98], for example, finds in anti-racist movements and in the persistence of "racial grief" challenges to "dominant understandings of what energy fundamentally is amid burgeoning efforts to 'democratize' energy." Joanna Allan [13], Alexander Dunlap [65], Hamza Hamouchene [5], Catalina de Onis [10], Chris Hesketh [17], Jaume Franquesa [11], Noura Alkhalili, Muna Dajani and Yahia Mahmoud [9], Franziska Müller [99] and Christos Zografos and Paul Robbins [100], among many others, help trace the continuous thread of colonialism and resistance to it that winds through the history of abstract energy from the steam to the wind and solar eras.

Crucial throughout this article are the insights of physicists, chemists and other scientists laboring at the coal face of energy thinking. In addition to the work of Ilya Prigogine [101] and other nonequilibrium thermodynamicists such as Axel Kleidon [102], this Perspective relies particularly on the quantum physicist Carlo Rovelli's [103] conceptualizations of entropy, Richard Feynman's [104] well-known rebuke to physics popularizers that energy is not a blob, and theorists of the thermodynamics of life from Erwin Schrodinger in the 1940s [105] through Jeremy England [106] and many others in the present. The stunning but insufficiently-known syntheses of the philosopher Maxine Sheets-Johnstone [107,108] regarding animate movement, meanwhile, provide an essential link that has hitherto been missing between the physics literature on entropy and the literature on just energy transitions (see Section 4). Further insights about entropy from the polymaths Alicia Juarrero [109] and Terrence Deacon [110] constitute additional challenges to the energy studies mainstream. In some senses, the approach of this Perspective also harks back to earlier 20th-century figures like Alexander Bogdanov [111], Alfred Sohn-Rethel [112], and Georg Lukacs [113]. Ultimately, as argued in Section 4 below, it leads back in time to 1824, when the French military engineer and first genius of thermodynamics Sadi Carnot [114] coined the evergreen metaphor of energy "falls."

No less important is what might be called, following the example of David Graeber and David Wengrow [115], an ongoing "Indigenous critique" or set of recontextualizations of the peculiar practices and theories of abstract energy that were articulated in writing in Northwestern Europe over the 19th century [13,15,19,35,116,117]. This critique is very seldom explicitly recognized in mainstream academic circles as a contribution to *technical* debates about thermodynamic energy and energy transitions. Instead, it is usually seen in one or both of two alternative ways. The first places it as an interesting or cute but scientifically-irrelevant "cultural," "poetic," or "rhetorical" side commentary on an energy that remains part of a single shared "natural" background that lies beneath and underpins the panoply of such supposedly "social" matters [118]. The second encourages appreciation of and research into the Otherness of Indigenous energy landscapes, but mainly as part of a strategy for, in the words of Antonella Mazzone and colleagues [35: 23], "including Indigenous people in largely pre-defined energy-development projects that are informed by a uniform, Western epistemology." This merely perpetuates the exclusions and oppressions that are inherent in the structure of 19th-century abstract energy.

This article takes a different view that is indebted in many ways to the approach taken by anthropologists such as Marisol de la Cadena [119], Elizabeth Povinelli [120] and Helen Verran [121,122]. It proposes that the Indigenous energies described by, for example, Ibanga [116], Tumwebaze and colleagues [35], Allan [13] and many others constitute and have always contained both real and potential challenges to thermodynamic energy itself, particularly as it continues to inhabit most programs for a just, renewable energy transition. Thermodynamic energy has always evolved in explicit or implicit friction with other energies. Where it commensurates, it constitutes itself against complementarities involving prohibitions on that commensuration. Where it imposes scarcity, it limits sufficiency. Where it elaborates a resource conception of nature, it opposes commons [55,56]. Where it erects centralized hierarchies by subsuming concrete energies entangled with specific land and water commons to abstract energy, it restricts the development of alternative patterns of entropy flows. Where it assumes a dualism between nature and a universal human species, it acts in aggression against the life of Indigenous *territorios* [44]. Where it becomes a component of subject formation, it resists commons norms. Reciprocally, 19th-century abstract energy has often been touched by other energies, at least indirectly, through the continuous resistance that flows through the "intra-actions" [123] and "bindings and unbindings" [124] to which it pertains and through which it is continually remade. In much the same way that the state has always evolved in tension with Indigeneity [125: 38], abstract 19th-century energy has always been shaped by its Indigenous critique, even if this fact has occasionally escaped the self-understanding of practitioners of the science of thermodynamics, and even if it cannot always be obvious where, when and even whether the critique is being voiced or developed [126]. While this article sees the Indigenous critique of energy as unignorable by any academic discipline relating to energy, whether physics or literature, it does not regard it as possessing any special *a priori* or metaphysical privilege over other energy critiques from, say, peasant communities from Latin America, hydroelectric dam resisters from Asia, slum dwellers from Africa, or physicists from Cornell. Nor, presumably, would the Indigenous critique itself want to seek any such privilege.

What the article does insist on, rather, is seeking more ways of bringing together on a more balanced footing the varied critiques it discusses, both with one another and with the mainstream "just energy transition" discourse, so that a more fruitful kind of discussion on energy futures can take place than is occurring at present. This is the particular "gap that needs filling" – to use the standard language of academic articles – that this Perspective identifies in the literature just reviewed. To take just three quick examples, the article sees its role as stimulating moves toward finding new ways of bringing together and encouraging speak to one another:

- The "distancings" of 19th-century thermodynamic energy undertaken by historicizing authors such as Porter [85], Daggett [93] and Fressoz [26,73] and congruent "distancings" undertaken by social movements and academics from the global South (see Section 3).
- Current work on far-from-equilibrium thermodynamics and engaged geography scholarship, academic work on the long-term evolution of cognition and cooperation, and ongoing explorations in "sustainable" ways of living by Indigenous, peasant, urban laboring, and other communities in a variety of ecosystems (see Sections 3 and 4).
- Anticolonial and Marxian "world ecology" [127] analyses of modern energy and a repoliticized, territorial version of entropy theory together with feminist energy activism at community and other levels.

The article's role, in other words, is to sketch a skeleton manifesto for "provincializing" [44] energy that will be difficult to act on until many conversations that are now considered inconceivable or illegitimate by many energy researchers can be first imagined, then accepted as permissible, and finally deliberately fostered by researchers themselves.

One ground rule for this enterprise will be that the translations that form these conversations are encouraged to be two-, three- and four-way. For example, in addition to thermodynamics being applied in the defense of Indigenous lifeways as well as the critique of traditional economic development, as this article itself does in company with many predecessors, Indigenous energy thinking must equally be acknowledged as opening up fresh critiques of the thermodynamic premises of the activities of states, corporations, consultancies and international agencies. The resulting translingual conversations will unavoidably be difficult, slow, open-ended, hard to arrange, and completely beyond the narrow scope of "interdisciplinarity." Some of them will have to be permanently imaginary: how else to contrive means by which Sadi Carnot might speak to a contemporary ecofeminist and vice versa? But there is now less excuse than ever for dismissing the possibility of such conversations by *a priori* excluding various interlocutors from a common world or by bestowing privileged status on Europe, or whiteness, or men in white coats.

The question is always what political conditions need to obtain in such free arenas of two- or three- or four-way translation, in which no pre-existing equivalents exist for exchange [128,129,132]. Accordingly, this literature review must also include a corpus of work on a research methodology that may be unfamiliar to many energy researchers – one loosely associated with what has been called the "new translation studies" [130]. These include investigations, conducted over the past few decades by Naoki Sakai [131], Lydia He Liu [132,133] and Richard White [134], that themselves constitute specific arenas in which the rule of one-way translation that prevails in most scholarship becomes usefully void. None of these authors happens to discuss the specific challenge of resituating thermodynamic energy in a way that could break open the currently-sclerotic discussion on energy futures. White discusses circumstances when it became possible, during a certain period in the history of the Great Lakes, to "provincialize" European common sense about prices, trade, debt, leadership, and so forth. Liu looks at the conditions in which it became possible (or not) to counter-translate certain reified European translations of Chinese experience. Sakai, meanwhile, draws on other experiences of imperialism to lay out the conditions for a "heterolingual" mode of interaction that produces new communities and alliances precisely by contesting the assumption that it is one-way translation that fosters them. Nevertheless, all three help limn the structure of possible "contact zones" [135] in ways that can be directly applied to building better discussions of energy futures.

3. Nineteenth-century energy: some roots of a resource view

Industrial capital and the state generally share the position that energy is a substance that must constantly be replenished because it is constantly running out. In the last half century or so, indeed, energy has come to be treated as "just another resource" like "hard rock minerals, forests, land, water, etc." and to be analyzed in the same way [136: 483-84]. Hence the incessant hunt for more oil fields or sites for dams or wind or solar farms to provide society with more of this "resource." Most economists, politicians, bureaucrats, environmentalists, democrats and energy academics repeat this narrative. Many critical academics, social movements and anti-capitalists repeat parts of it as well – for example, when when they write about "embodied energy" as if it were an object that could be fairly divided up [137–139] or otherwise frame energy justice as being at least in part the symmetrical sharing out of a measurable universal good [42].

Historically, this "substance" or "resource" view of energy coincides, though in complex and sometimes contradictory ways, with the stumbling 19th-century rise of the set of practices and theories emblematized by the First Law of Thermodynamics. As the historian Joel Mokyr [140: 20] memorably points out, the First Law summarized an emerging realignment of physical and social relations that had been foreign to the experience and understanding of almost everybody in the world before 1800, including Europeans: "that a horse pulling a treadmill and a coal fire heating a lime kiln were in some sense doing the same thing." The First Law helped bring into the political foreground a new fact: that heat and mechanical motion were systematically "convertible into each other, so that wood and fossil fuels could … be used to produce motion and watermills [to] produce heat." But it was not only treadmills, coal fires and lime kilns that were "made the same" [141] via various political processes, physical manipulations, calculations and equations, but also river flow, wind, lightning, chemical reactions, magnetic activity and more. The First Law's meaning was shaped through the 19th-century development – in economic practice, physical theory and the material landscape alike – of a whole series of further calculable "equivalents." These included equivalences between chemical energy and electricity developed in the history of batteries (c. 1800); between electricity and mechanical energy in the history of electric motors (c. 1830); between the sun's radiation and electricity (c. 1839); between magnetism and electricity in telegraph lines (c. 1844) and transatlantic cables (c. 1858); between mechanical energy and electricity in windmills, dynamos (c. 1867) and hydroelectric dam turbines (c. 1880); between electricity and heat and light in light bulbs (1802-1880); and so on. As the chemist-philosopher Isabelle Stengers observes, the energy concept emerged from nothing more than the "manipulation, control, and production of measurement" of such connections [142]. Yet creating these equivalences was never straightforward either on the land or in the laboratory or classroom. Recalcitrant experimental apparatuses like James Joules's had to be coaxed and cajoled before they yielded even approximately similar numbers. Hydroelectric stations had to get funding from agribusiness, factory or transport enterprises before uprooting humans and nonhumans in their environs. Steam engines needed a lot of physical infrastructure, social networking and political repression before they could become serious sites of physical inquiry and serious aids to profit. At the very root of early 19th-century thinking about energy, moreover, lay a complete fiction, the reversible heat engine, in terms of which the messy metrics of real-life irreversible industrial energy conversion were conceptualized [142].

To observers today, in short, it might seem a simple proposition that a certain quantity of coal has a particular heat content, or that a specified current of electricity can create a magnet of such-and-such power and vice versa. But here, as elsewhere, "simplification is complicated" [143]. It was the hard graft of commensuration among manifestly diverse things that created the new energy "object" that was quantified [141] – and, thanks to that quantification and objectivization, figuratively "transferred" conceptually and physically across the globe in the service of infinite economic growth. The industrial upheavals in the political and physical geography of the 19th-century were condensed into a law constituting an energy that was said to be "conserved" through all its transformations. Abstract energy was "discovered" not in the way a rainforest explorer runs across a new species of beetle that can immediately be slotted into an existing scheme of classification, and its position and movements in the forest logged, but more in the way engineers work together to build up intricate and spatially-extensive new systems of apparatuses by force or otherwise.

At no point was this energy physics independent of the growing mechanization of the factory sector in Northwestern Europe [86,90] and of the linked colonial plantation, extractive and slave economies of the rest of the world [144–146]. One example is the idea, dating from the lifetimes of James Joule and Julius Robert Mayer, that heat might have a quantifiable "mechanical equivalent" [80,90]. Such ideas cannot be disconnected from industrial strategies for specifying and arranging the quantities of wood or coal needed for machines to produce the uniform, coordinated, season-independent motions that helped capitalists profitably to insert more of their influence into the lives and living labour of factory workers [147]. The emergence of an omnibus, versatile energy from the commensuration of every breeze, stream, forest, mineral outcrop or burst of sunshine was always intimately linked with the growing use of machines to boost productivity, control and concentrate workers, fight labor resistance, spread the wage-labor relation around the world [148], accelerate turnover and appropriate new raw materials. Far from being an exception, digital capitalism, including artificial intelligence, is an apotheosis of this same 19th-century energetic process aimed largely at control and exploitation of human labor [149–154]. What is important not to miss in any discussion of energy alternatives is that the proliferation of metrics applicable to this pattern of ever-burgeoning industrial conversions is internal to the modern concept of energy itself, including "renewable" and "justly-distributed" energy [80,155].

It is in this sense that the First Law of Thermodynamics is one of those "documents of civilization" to which Walter Benjamin once referred as being also a "document of barbarism" [156]. To make this point is not to deny that the First Law is an enduring contribution to the endowment of humanity. It is associated with achievements the breadth of which no one needs reminding. Albert Einstein was surely justified in feeling that the First Law, along with the rest of thermodynamics, was the "only physical theory of universal content" that he could not anticipate ever being "overthrown" [157]. Like any great cultural creation, moreover, the Law also contains seeds of unpredictable possibilities of critique, inspiration and liberation (see Section 4 below). The notion of energy conversions used in the analytic "distancing" of thermodynamics essayed in this Perspective is itself an instance of First Law thinking. The notion of entropy the article relies on to understand biological evolution and territorial border-making is, similarly, an example of Second Law thinking. Yet the conditions in which the First and Second Laws take shape are not only ones in which certain scientific results become satisfactorily repeatable in the eyes of certain core groups [158]. They are also conditions in which, simultaneously, unprecedented varieties, volumes and patterns of what later become known as energy conversions occur across a landscape permeated by barbaric colonial violence aimed at deepened exploitation of labor, silencing of Indigenous and peasant voices, and appropriation of new swathes of "cheap nature" [127]. These are conditions in which a new hierarchy takes hold in which it becomes both possible and permissible to subsume a congeries of human and nonhuman commoning activities to an energy abstraction. In this hierarchy, what might (anachronistically) be called the "little-e" energies [55] of the commons – cooking fuel collected from common woodlands, oil deliberately left underground, undammed streams, Saharan winds [13] – become demoted to the status of potential ingredients in an overarching, intrinsically scarce "Big-E" Energy [55] originally conceived in terms of an omnibus "fuel" for industrial capital [80,93]. This singular energy is defined as being ready for use in infinitely-expanding amounts by conversion engines. For example, river systems that are not exploited with hydroelectric dams that break their falls become conceptualizable as "wasted resources" [159], often much to the bemusement of communities that have depended on them for generations. Simultaneously, energy conversions and waste transfers that might hitherto have been blocked by relations of complementarity among incommensurables – for example, among the hills, forests, springs and local cultivations characterizing *chuchutsipi* practices in Totonac Mexico [117] – become, mediated by class struggle, at once more conceivable, more practicable and more in line with the ascendant "moral economies" [160] of capitalism. As scholars such as Witold Kula [161], Wendy Espeland [162], John O'Neill [163] and Stephen Gudeman [164] remind us in different ways, commensuration can never be a neutral act. More broadly, the First Law, together with much of the rest of the "makeshift patchwork" of post-18th-century energy discourse, is an indirect reflection of an elite understanding of far longer pedigree, running from Aristotle to Max Tegmark [165], that civilization requires slavery [76], whether of human beings or of nonhuman entities cleverly amalgamated into a reservoir of dumb quasi-labor power. Nevertheless, the specific politically-biased material reality commonly referred to today by educated classes as "energy" is quite new to the 19th century [140].

From a related perspective, 19th-century energy falls into place as something that developed as one more Cartesian "extended thing" whose inanimate antics could be placed under the centralized control of managerial "thinking things" [56]. Roughly speaking, the effect was to push for an idealized binary relation (society/nature) to take precedence over much more complicated local webs of multiple, many-sided relations that tended to accompany a sense that certain rivers, winds and fires, for instance, were not extended nonliving or nondead substances but rather living beings alongside others [119]. Here, thermodynamics was both a dependent and an independent variable in turn, depending on circumstances. To adapt and extend the terminology of Jason W. Moore, one of its functions lay in "channeling but also informing" the practices of "imperialism and its trinity of conquest, class formation and commodification." Energy science and colonial domination "crystallized together" for a reason: their "unity was crucial to imperial class projects – cultural, political and economic – aimed at securing the conditions of expanded accumulation" [166]. Helping bring this process into focus, the various Indigenous and other critiques of abstract 19th-century energy referred to above do not arise out of bordered essences or identities pre-fixed by isolated "traditions," into which capitalism and the discoveries it enables belatedly encroach. Rather, like Indigeneity itself [125], these critiques mature in concrete contemporary [156] situations, conditions, encounters and translations among diverse groups under threat that can, moreover, suddenly "explode out" [167] into revelatory senses that, for example, "we are all Indigenous." This is exactly what happened in, for example, a recent struggle documented by Japhy Wilson that involved a motley crew of protesters in an oil-affected zone in Ecuador [168]. The same kind of processes can issue in unanticipated understandings that "we are all proletarians" (when workers from separate rural backgrounds are thrown together), "we are all feminists" (when unexpected alliances emerge on the ground between women's movements and movements with contrasting genealogies), or "we are all the *territorio*" (when the European cliché that "we are all part of nature" unexpectedly dissolves in the crucible of uncomfortable real-life encounters between Cartesian and non-Cartesian traditions). Such processes are helpful in demonstrating that the energy of thermodynamics textbooks is not a neutral physical backdrop for all human action but rather has a strong political skew to which there have always been coeval alternatives. Some of these alternatives operate without the "neutral physical backdrop" formulation itself, as famously noted by Eduardo Viveiros de Castro [118,169]. Periodically-exploding critiques of the type cited above constitute one of the most important cautions against the common academic dogma that nonrenewability and injustice could not possibly be features of thermodynamic energy itself.

As suggested above, such forms of bias are manifested in countless concrete, sometimes brutal ways. Table 1 indicates a few of them, in its first row in particular. The everyday material nature of these biases might also be illustrated by a simple summary parallel. On the "seven hills" of San Francisco, California, as residents and visitors know well, the street grid itself tells pedestrians where and how to move: north, south, east and west along paved sidewalks, no matter how steep. There's no need to be explicit about not following contour lines through backyards, fences or parked cars. Similarly, in the Amazon, the layout of forests often encourages walkers to think where they are relative to winding local rivers instead of thinking in terms of Cartesian grids [170]. By the same token, many world landscapes that have evolved over the past 200 years implicitly instruct or compel their inhabitants to orient their lives and subsistence around lumping together forests, streams, winds, oil, sunlight, tar sands and radioactive ores as life-giving "energy sources," without any particular need for anyone to memorize texts on the First Law of Thermodynamics. This is one way in which what Ulli Brandt and Markus Wissen term an "imperial mode of living" [171] becomes hardened into territories themselves [172,173]. Nineteenth-century abstract energy is better conceived as a re-engineering of territories than as something that flows around "in" or "on" them [124]. Such re-engineered territories contain channels that could hardly be more physical for organizing subsidies, valuations, devaluations and impoverishments of the most diverse kinds. The First Law can't be "cleansed" of these characteristics either by wishing away its origins and entailments or by postulating out of nowhere an imaginary abstract energy pre-defined as something that someday might be made renewable or just. Resisting such expressions of naivete is precisely the opposite of dismissing or disrespecting the First Law of Thermodynamics or the energy that it helps theorize. On the contrary, it amounts to a necessary honesty about the complexities of both, and of their origins, so that these complexities can be collectively taken on board and engaged and contended with more effectively.

The political bias inherent in First Law energy was complicated and augmented early on by a process of reification of a kind that is familiar from other strands of world history. Almost no time elapsed between 19th-century inquirers' groping efforts to work out various equivalences and the fetishization of energy as an independent quasi-substance. As might be expected given what Caffentzis [80: 13] describes as the "essential function" of physics in providing "models of capitalist work," physicists themselves often didn't hesitate to involve themselves directly

Table 1
Some tensions and instabilities internal to post-18th-century energy conceptions

	ENERGY	SPACE	MOTION	CAPITAL	JUSTICE	WASTE	ADHERENTS, PRECURSORS	SOME CRITICS
DOMINANT FOREGROUND	Scarce, transportable resource for machines and bodies quantifiable in fuel equivalents (watts, joules, calories). Potential for abstract quasi-"work". Depletable and replenishable from a variety of sources. A universal need of generic "humans" capable of unlimited additive augmentation. Not historicizable.	Invariant Cartesian landscape across which substances are transferred. Inanimate matrix from which quantities of abstract quasi-"work" can be extracted. Monist geography in which places can be compared in terms of commensurable energy units extractable.	Quantifiable, centrally-directed, monolithic process enabled in bodies and machines by abstract energy.	Industrial machines as aids to accumulation in virtue of being located in a flat Cartesian space to which energy, a substance which feeds the machines, can be brought, converted from one form to another and "used up."	Equitable distribution of resource among groups and regions. Replacement of unequal exchange with equal exchange. Replacement of asymmetric with symmetric global resource flows. Right of humans to abstract wage work. Right to energy. Fair distribution among groups and regions of damaging effects of energy extraction from a universe structured as "dead" and "other" to society [43].	Energy that has not yet been converted in line with the needs of industrial machines. Energy that through conversion has become unusable by the same machines. Inefficiency.	First Law pioneers, physics popularizers in 19th- and 20th-century Europe, ministries of energy, International Energy Agency, most energy policy specialists.	Illich, Caffentzis, Rovelli, Deacon, Daggett, Indigenous thinkers about territory.
OCCLUDED BACKGROUND	A "relation of difference that eliminates itself over time." A "construct to designate the state of a field." A mathematical expression of symmetry. Not depletable. Historicizable.	Changing "Carnot landscapes" [58] featuring different patterns and rates of entropy increase and whose determination is political/physical/biolog-ical. Complementarity among incommensurables.	Qualitatively-described motions of bodies and machines that have evolved over billions of years in a world in which life is internally linked to entropy.	Industrial machines as aids to accumulation in virtue of their location relative to nested entropy slopes whose structure, location, number, incline and rate of flattening they influence. No need for energy.	Democratic decision-making about constitution and dynamics of diverse Carnot landscapes [58] for support of life. Freedom to defend territories. Questioning of abstract work and the "resource" picture of energy. Questioning of right to energy.	Energy conversion patterns unfriendly to entropy patterns associated with life processes.	Carnot and other pioneers of Second Law. Prigogine and nonequilibrium thermodynami-cists of life.	Implicitly, main-stream energy agencies; main-stream energy studies; the UN.

in such dubious reinterpretations of what the First Law reflected. In their role as popularizers of science for the middle classes, for example, physicists like Hermann von Helmholtz could be heard extrapolating from thermodynamic commensuration of heat, kinetic energy and electricity to a view of energy as a substance occupying a shelf in a general "storehouse of nature" that "we" could "draw upon for our purposes" and that yielded value to its "owners" (including mill-owners) [174: 393]. This kind of imagery persists today in, for example, institutional tables of statistics about "consumption," "production" and "supply" of an undifferentiated, abstract energy.

To be sure, there was, and continues to be, something that appears weirdly incoherent about such popularizations. As every physicist knew by the later 19th century, it wasn't energy that industrial capital needed or sought on any storehouse shelf. Energy didn't have to be produced or looked for anywhere. It was everywhere – in every quiet lake, in every plume of smoke, in every rock pile. Moreover, machines never consumed energy. They merely converted one form of it into another. Thus when coal was burned, producing ash and carbon dioxide, its energy wasn't used up. Some of it was transformed into heat. And that heat could be further transformed into mechanical energy or electricity – the deployment of which would leave a residue of yet more heat. Similarly, when the sun's hot photons arrived on earth, their energy didn't disappear. To a large extent, it was radiated back into space in the form of the heat of cooler photons – although increasing amounts soon started sticking around in the form of global warming. In short, if energy was what industrial capital was looking for in coal mines, waterfalls and plantations, it could have saved itself the trouble. Energy wasn't the kind of scarce commodity that mill owners would need to bother making into their private property. It had to be something else that they wanted.

What *that* might be emerged only gradually during the development of thermodynamics' Second Law. The sobering message of the Second Law was that as a result of any of the First Law's newly-quantifiable energy conversions in and around the machines that were increasing capital's take from labor, less energy would be available to the machines for the next round. As Caffentzis [80: 14] puts it, while the First Law's "infinite multiplicity of energetic forms inspired a tremendous optimism in capital's search for new workforces," the Second Law "laced this high with arsenic." Intellectuals had to resign themselves to the lesson that a "perpetual motion machine completely transforming the energy of the surroundings into work without loss was an impossibility." More recently, they have had to face more prosaic lessons about declining "energy return on investment" [175] and growing difficulties in getting hold of the earth's remaining endowment of low-entropy resources cheaply enough [127]. In 1865, Rudolf Clausius gave this First Law/ Second Law tension a cosmic spin: "The energy of the universe is constant; the entropy of the universe increases to a maximum" (entropy now being defined, revealingly, as a measure of uncertainty, "disorder" or "mixedupness").

A new generation of popularizers attracted to resource metaphors accordingly switched their attention from "energy" to "available energy." They were careful to specify that it wasn't energy as such, but energy-that-could-be-used-for-"work" that machines (and living bodies) needed. That was what was scarce, and that was what industrialists had to grab hold of. Over time, this "available" or "usable" energy was theorized in different ways for different contexts. "Free energy" [176,196] and, later, "exergy" [177] emerged as important concepts, among others. Not all these terms were equivalent, but they did share with "energy" itself a susceptibility to being interpreted as denoting scarce resources. "Don't waste energy, use it," urged chemistry Nobelist Wilhelm Ostwald [178: 544] in summarizing the lessons of his own career in energetics; obviously, neither Ostwald nor his fellow prophets of scientism [179] would have had much incentive to try to grasp the ways that this sentiment might or might not be at odds with the complex understandings of energies prevailing among the majorities in the colonies under domination by the Europe where he was born [44,178]. A bit later, Etienne-Jules Marey, Frederick Winslow Taylor and others [181] looked for stop-gap responses to the Second Law in more efficient ways of husbanding what was evidently the limited and declining available energy of the workplace. Taylor was succeeded by Amory Lovins decades later with his "negawatts," or units of energy conserved or saved [182]. Even Werner Heisenberg in the 1950s continued to present energy in its various forms to the public as what Illich [79] calls a "kind of alchemical find … the only real substance." In Illich's telling, this represented a persistent form of unofficial, folk religiosity that continued to flourish in the shadow of official "sacred" sites of energy research in labs and university departments. Some physicists themselves turned out to be only too willing to be drafted into the roles of "gurus and mystics preaching the dogma that [energy] was nature's ultimate Kapital," a universal, reified goodie craved always even by those who had hardly been aware of the craving. This religiosity is still omnipresent in technical energy talk today, both in the academic and the "gray" literature. It is found in energy consultancies, in energy history books [183] and in educational comics about climate change [55].

The view of energy as a substance eternally under acquisitive pressure has been taken down brilliantly by Andreas Malm [82: 20-26, 255-272]. Malm points out the absurdities in the view, still dominant today, that "there is a hunger to consume more energy in all human societies, and in the eighteenth and nineteenth centuries, Britain finally managed to satisfy it" [82: 257-58], at least for the time being. The image has been one of society needing to overcome a "bottleneck which sets limits to growth" by learning to treat energy more on the model of an (underground) stock than on the model of a flow defined by the parameters of an older "organic" economy. Critiques like Malm's can be usefully set alongside an older, persistent current of dissatisfaction among physicists themselves with the modelling of energy as a substance shorn of the relations that structure it. These include Ernst Mach in the 19th century as well as Emmy Noether, Einstein [184] and P. W. Bridgman [185] in the 20th. In recent times, the Nobel physicist Richard Feynman's [104] caution (which anticipates that of Stengers [142]) stands out. "In physics today," Feynman lectured, "we have no knowledge of what energy *is*. We do not have a picture that energy comes in little blobs of a definite amount." Instead, all there are are "formulas for calculating some numerical quantity, and when we add it all together it gives … always the same number. It is an abstract thing in that it does not tell us the mechanism or the *reasons* for the various formulas."

It would be a mistake, however, to assume that the strange inconsistencies and contradictions that have always characterized the broader 19th-century energy concept are nothing more than the result of scientific errors, hypotheses that are not quite right, inadequate experimentation, overzealous popularizations, conceptual shortcuts, confusions, or lapses into superstition that can all be overcome in time in a way that finally purifies the notion and makes it politically "neutral." In their analyses of whiteness and race, theorists such as Cedric Robinson [186], Charles W. Mills [187] Toni Morrison [188], Alberto Toscano [74] and Yarden Katz [76] have pointed out that it is the very incoherence and variability in such concepts – the difficulty of ever pinning down what might lie at their core – that gives them the flexibility or malleability they need to adapt to ever-changing political challenges. Such concepts and their claims to universality and neutrality, these writers urge, get their overall shape less from the rational backing that they claim – much of which fails to hold up for long – than from something more lasting: the need of elites to use them to connect different groups in the course of maintaining certain relations of power. It is part of the way these concepts work that they are both "unreal" and "real": unreal in that they feature inconsistencies and nebulosities, and real in that they have a "massive effect on people's psychology, culture, socioeconomic opportunities, life chances, civil rights" [187]. Energy studies have a great deal to learn from this analysis, even if the parallels with the new energy of the 19th century are not exact. The point of invoking the history of thermodynamic energy, including the full range of its cults and popularizations, is not merely to dismiss its "universality" or resist efforts to cleanse it of purported "extraneous" elements of politics. As Morrison might have put it, there is a more interesting question: What are the concrete ways that this energy works to *disguise* itself as a universal background equally friendly in principle to all human beings? What enables it to acquire the bogus "neutrality" that is so useful for the defense of the supremacy of what Jason W. Moore [127] would call capitalist natures – for instance, the subordination of those "little-e" energies to the Big-E resource abstraction? What are the means by which energy science's claims to universality allow it so often to dodge direct encounters with coexisting knowledge that self-reflectively "sits in places" [78]? And where do the various ripped seams in the "makeshift patchwork" [186] of this energy reveal its situated nature and ultimate vulnerability to interrogation by various democracy struggles?

Current scholarly research that circles around issues of energy's geography and materiality [189–191] might also benefit from more comparative study of processes of universalization and reification in other fields. One important area of inquiry is into what many Marxists call "real abstractions," including abstract labor, exchange value, Man, Nature, Civilization, and many others [166,192]. Alfred Sohn-Rethel [112] famously argued that some of these types of abstraction can be traced to repeated, down-to-earth experiences of commodity exchange in markets. Similarly, it can be argued that the force of today's energy abstraction, which has become so influential in global environmental management, derives less from the divine insight of specially-licensed scientific shamans than from the millions of banal acts of learning to take oil and mechanical force (for example) and "make them the same" [141] that have become widespread under the rule of capital since the beginning of the 19th century. Another, more neglected example might also repay study by energy alternatives specialists. This is the way that linguistic word-meaning gets reified in common sense into something fixed and abstracted from translation and translation's relational, often imperial, world politics [129,132]. Just as complex industrial processes employing violence to pick up the pace of energy conversions across the landscape often get reduced in technical and popular imaginations to benign efforts to tap into a gigantic, timeless reservoir of neutral abstract energy, so, too, do politics-drenched social processes of translation often get reified in common sense into detached efforts to tap into pre-existing meanings locked in the minds of translatees. What the logician W. v. O. Quine [128] called the "idea idea" – roughly, the false cliché that says that meaning is prior to translation rather than the other way around – is formally parallel to the equally-cliched, equally-dubious notion that an abstract resource called energy is what explains industrial history since the 19th century rather than the other way around. In recent decades, three exceptionally-distinguished scholars with an anti-imperialist bent (already mentioned in Section 2) have demonstrated at length what a difference it has made to world history when provisional equivalences that sublimate out of particular fraught translational encounters become hardened into "supersigns" that are treated as having an independent existence that is falsely supposed to underpin the possibility of translation itself. Naoki Sakai [131] and Lydia He Liu [132,133] have both studied connections between imperialism in Asia and the reification of languages and meanings, while Richard White [134] has explored an extended moment in North American history when the political impossibility of that reification kept open opportunities for species of democratic interchange that were later closed off. Such research becomes relevant to inquiry into energy alternatives when it helps reaccustom the scholarly imagination to the possibility that even what seems like foundational common sense in any field – such as that energy is a thing-like, universally-applicable, monolithic resource "out there" that merely has to be managed and divided up better in accord with imperatives of renewability and justice – can be conceived of as having interesting and important alternatives.

It would be wildly surprising if there were no countercurrents within thermodynamics itself supporting such alternatives. As sociologist of science Harry Collins [193] has remarked, science tends to present itself to the public as if it were a model ship in a bottle that has somehow always been fully assembled. Related points have been expressed by the polymath psychoanalyst Jacques Lacan and his student Slavoj Žižek, who has noted how science tends to be constitutively "blind to the way it is integrated into the circulation of capital" [194,57], as well as by anthropologist Elizabeth Povinelli [120] and others. In the case of thermodynamics, the ship in the bottle presents the illusion that the job of figuring out what energy is was long ago done and dusted by a committee of concurring white men in white coats. What social scientists need to do, the story continues, is simply to accept this bottled ship for what it is presented as – a scarce substance eternally craved by generic human beings – and organize their analyses in a way that obediently treats it as a given social universal. In reality, however, it has taken too much suspiciously-inventive struggle against the world majority to get that energy ship into its bottle in the first place for that struggle to be dismissed as outside the scope of scholarly inquiry. The struggle and its protagonists may have become largely invisible to intellectual classes over the years – in some small part because the hard graft of the men in white coats has often been run together with, roughly speaking, divine revelation, by thinkers who largely work outside the physics profession itself. But that hard graft can be revealed again and again when needed, in part through the work of academics, to help reopen forgotten pathways toward alternative energy futures. The following section contributes to the historicization and problematization of energy as a category by returning to one of the great founding geniuses of thermodynamics itself: the young 19th-century French military engineer Sadi Carnot.

4. A countercurrent within 19th-century energy

Carnot's story [114,142,195] reveals the possibility of a more geographical view of energy that greatly clarifies the colonialism of its 19th-century emergence and continual re-emergence in the 21st. Carnot was no less representative a figure in European imperialism, nascent industrialism and racial capitalism than any other early exponent of thermodynamics. His concerns centered impeccably on capitalist efficiency. But the way he went about his inquiries 200 years ago might help expose some sides of energy practice and theory that are more useful to insurrectionary research approaches than today's dominant "scarce substance," "fuel" or "resource" threads.

In one of the great generative metaphors of modern science, Carnot called what we today term energy conversions "falls" (*chutes*) [114], on the model of waterfalls. Once a sluice gate is opened to let water run downhill to drive a waterwheel, the water can't be forced back uphill to restart the process without expending more energy than has been released. Similarly, once coal is burned, the resulting heat, ash and carbon dioxide can't be reassembled back into coal without using more energy than the coal provided. Later on, this picture was elaborated by Ludwig Boltzmann, who theorized that what happened in each energy conversion was that energy got dispersed across a greater number of microscopic states [197,198]. This is the increase in entropy Clausius referred to [198].

In the very beginnings of thermodynamics, then, lurked the seeds of a suggestion articulated two centuries later by Terrence Deacon that the "key to understanding what energy is is to stop focusing on the stuff that embodies it, and instead consider the form that is embodied" [110: 219]. Rather than being pictured as a substance, Deacon writes, energy might be more perspicuously described as a "relationship of difference that tends to eliminate itself." Distributed in a substrate that "can be anything from a heated solid object to a perturbed electromagnetic field," this relationship of unstable asymmetry "will spontaneously tend to even out if unimpeded." As "falls," energy conversions can thus be conceptualized in terms of a flattening of "slopes" between low and high entropy [199]. Instead of "using up" a resource, what energy conversions do, to switch to the terminology employed by the physicist Carlo Rovelli, is pull open various "doors" [103] in a process that enables whole territories to slip down these figurative slopes, eroding the gradients themselves in the process. Such gradients include, in addition to those between hot and cold in heat engines, those between the binding energy of electrons in molecular bonds and the heat generated in chemical reactions, between short-wave solar radiation at around 5760 Kelvin and longer-wave radiation emitted by the earth at 255 K into an outer space standing at a temperature of 2.7 K, and many others.

As these examples suggest, Rovelli's entropy doors are constantly being opened everywhere in the universe. In fact, the door-opening process is nothing less than, in his words, "what makes the world go round." It is "what causes events to happen in the world, what writes its history" [103]. But these doors have never been opened in the same ways at the same rate in every part of the universe in every epoch. Entropy increases unevenly, at different paces in different places. Often the pace is very slow [200,201]. Hydrogen and oxygen molecules can float around peacefully in a bottle for centuries, despite the fact that their combined internal bond energies are greater than that of the water that they could produce. Only when a spark is introduced will they react explosively to dissipate some of that internal energy into heat, forming the higher-entropy H_2O. Similarly, low-entropy oil that is left underground won't react with air to form heat and carbon dioxide for millennia if it is not deliberately unearthed and burned. Or consider those earthly territories of flowing water that are so often the focus of communal care across the world [202]. These territories are in a state of higher entropy than the solar particles that, combined with gravity and other factors, indirectly give rise to them. Indeed, they owe their continuing life to entropic processes that drive closed systems (perhaps even the universe itself) toward stasis. All the same, they constitute basins whose local rate of entropy increase can remain relatively low for thousands of years.

Complicating the picture is the fact that entropy increases tend to be structured in chains [203]. For example, what makes possible the sudden huge increases in entropy when hydrogen starts to be converted to helium in newborn stars is prior, very gradual increases in the entropy of hydrogen clouds contracting under gravity [103]. By the same token, today's Arctic warming is down not only to fossil fuel combustion but also to the reduced albedo of seas freed of ice by entropic melting processes. Conversely, any slowing of the rates of burning coal, oil, gas or forests will induce changes in entropy rates across broad fronts far from the sites of combustion themselves.

Living bodies, for their part, depend absolutely not only on entropy rates but also on such chains of entropy door-opening (for example, the oxidization of glucose, which outside the body would be more stable). But they combine these door-openings with door-blockings (such as prevention of decomposition). Animate bodies subsist in their environments by passing surplus entropy that they generate in one sphere on to bigger spheres inside or outside their skins [105,106] through movement either of themselves or of elements in themselves or their surroundings [107]. Like all life, they need the entropy slopes that they surf on to be constantly flattening out. What some 19th-century physicists dramatically interpreted as the universe's prolonged one-way trip toward *Wärmetod*, or "heat death," is, paradoxically, also what gives it life. But living bodies can't enjoy the entropy slopes they surf on forever if they are trapped in closed-off territories inexorably headed for universal flatness. The physics that describes how life goes on must be a far-from-equilibrium thermodynamics of open systems in which the breakers just keep on coming. And so for any science that explains the living planet [96,101,102,106]. In a fascinating twist of intellectual history, then, a science that began largely with the question of how to use industrial mechanization to winkle more surplus out of labor has now contributed fundamentally to the understanding of the life processes menaced by that same form of mechanization.

Industrial societies, of course, are characterized by patterns of entropy increase distinct from those associated with the *longue durée* of biological evolution. The speed, sequence and structure of much of their entropy door-opening has to be tailored specially to suit the operation of various post-18th-century conversion devices, including conversion devices that happen to be owned by private capital. It's no good having a sluice gate that can't be opened and closed at the right times; no use having a load of coal if heat and oxygen can't be applied and carbon dioxide vented in rhythms and places that fit the functioning of the machines that use that coal. In addition, the more intensively that energy is converted from one form to another in the closed systems that were of special interest to early thermodynamicists (that is, systems that can exchange heat and thermodynamic "work" with their surroundings, but not matter), the higher the entropy of the system as a whole and the closer that entropy changes come to halting altogether [80], silencing the machines. Any landscapes that privilege the sweeping proliferation of energy conversion engines whose activities came to be theorized by the First Law of Thermodynamics are also landscapes of increasing Second Law "waste" and, within the borders of those landscapes themselves, reduced potential for industrial activity. One example of such a progressively "flattening" territory might be a hydroelectric dam and its paired reservoir that slowly fills up with silt. Another might be a hermetically-sealed laboratory in which an internal combustion engine is tested until its fuel is expended, the room's air fills with carbon dioxide, water vapor and poisonous exhaust, and the engine stops. Still another might be a much bigger territory like those mapped by Hornborg [94], bounded at one end by what Maristella Svampa calls "sacrifice zones" [204], often in the global South, where low-entropy fossil fuels, lithium, nickel or biofuels are cheaply extracted, and at the other by energy beneficiary zones, often in the global North, where such materials are degraded in energy terms in the process of creating economic value. The territory might even be the earth system itself, whose overall entropy slope has flattened faster during the "Great Acceleration" in industrial energy conversions since 1945, hastening an overall crisis. To quote the words of physicist Axel Kleidon, it's this shifting "entropy balance" that "sets the limit to the power of the engine" [102]. (For convenience, I have elsewhere used the term "Carnot landscape" when referring to the evolving entropy profiles of these or any other territories [58].) Like living bodies, capital's energy conversion devices can be sustained only in environments in which their moves toward eliminating the gradients that allow them to work can be countered.

To keep this balance right for the accumulation of surplus, special efforts must constantly be made to maintain gradients between low and high entropy inside and near industrial machines themselves, with high entropy being constantly "exported" into surrounding zones and low entropy "imported." This is, of course, similar to what happens with living beings, but is associated with a wholly different set of spatial patterns, as entropy borders and slopes are continually rejiggered across sprawling landscapes. To keep its machines running, business must either continually relocate its engines along new "falls" or constantly bring new "falls" to them in an ongoing, expanding geographic process of border-crossing, border reinforcement and border dissolution. More and bigger conversion engines mean changing kinds, locations and patterns of entropy slopes outside as well as inside the zones in which industrial machines themselves are sited. That is, if the entropy slopes on which industrial capital relies are, broadly speaking, about territory, they are also about one territory's physical and political relations with another. When, in one territory, different kinds of energy are disentangled from local entailments and thrown into a single industrial pool under the sign of the First Law of Thermodynamics in the interest of accelerated energy conversions, the Second Law will soon intensify the imperative to import low entropy from, and export high entropy to, places featuring less disentanglement.

Unsurprisingly, the *chains* of entropy increase that characterize centralized industrial structures organized under the rule of abstract energy tend to be as distinctive as the speed and distribution of any isolated increase. Before hydroelectric dams and turbines can go about their entropy-increasing business, entropy-increasing concrete and steel manufacture has to take place. Entropy-increasing wind farms can't be built without previous entropy-increasing balsa extraction in Ecuador and other countries [205]. Rising rates of entropy increase associated with the movement of electrons in millions of electric cars in the global North stem not only from the prior construction of dams, wind farms and other energy-conversion devices, but also from new waves of entropic lithium and copper extraction in the Atacama or in Ukraine and elsewhere. Such chains tend to multiply overall entropy increases, as well as the nature and geographic extent of entropy slope rearrangements. In coal-fired generating plants, 60 per cent or more of the fuel's chemical energy is lost as waste heat. An additional percentage of the electrical energy generated is then dissipated into heat in transit to – for example – high-frequency trading server farms or cryptocurrency "mines" stuffed with computer processors that need built-in cooling systems to dispel their own waste heat. Even the most up-to-date efficient light fixtures lose at least 20 per cent of the electrical energy feeding them. Their light is then partly downgraded again into heat on contact with, say, billboards on empty streets at night [206,26]. The Rocky Mountain Institute estimates that 400 exajoules, comprising 40 per cent of global expenditure on energy, are lost every year in extraction, transport, construction and other geographically far-flung activities before being applied to the creation of use value or exchange value [207].

Such dynamics tend to be both disruptive and colonialist. They are colonialist, moreover, not just in the sense implying robbery of fixed quantities of, say, silver, land or labor-time. One reason that Carnot's venerable image of "falls" is worth retrieving and revisiting is that it can show in so many more ways than "resource" conceptions alone why the 19th-century energy of thermodynamics is intrinsically an imperialist process of reorganizing living human and more-than-human territories into hierarchies favorable to capital accumulation. When basins of relatively low entropy are abruptly drained into a larger expanse of residual heat and other "wastes" that capital is hard put to recycle while still remaining capital, the effects are multi-dimensional. For example, seizing control of and converting the kinetic energy of free-running waters into electricity via hydroelectric dams tends to leave behind an upended landscape of waste tied to changes whose full description exceeds established quantitative traditions of analysis or planning. That landscape is qualitatively altered further when dredging of silted-up reservoirs must be powered via exploitation of further "falls" elsewhere, in what might be a comprehensive symbol for unlimited expansion of frontiers of degradation. Practices of burning oil or running radiation from the sun through solar panels or industrial biomass plantations similarly advance processes of door-opening and entropy-landscape flattening whose characterization requires a qualitative vocabulary of territorial violence as much as a quantitative one of unequal exchange.

In short, the counter-tradition of thermodynamics fertilized by Sadi Carnot's metaphor of "falls" is just as useful to study in any effort to understand the colonialism of 19th-century energy as thermodynamics' energy-conservation or commensuration traditions. Indeed, the two traditions complement each other. First, a hierarchy symbolized by the First Law is established in the landscape in terms of which relations involving sunlight, soil processes, flowing water, water vapor and aspects of the carbon cycle including the oil termed by some Indigenous peoples as the "blood of the earth" are run together and subsumed into a centralized, omnibus, quantifiable, abstract "fuel" or "work power" for industrial capital. Second, numerous consequences play themselves out in the evolving qualitative metamorphoses in that landscape entailed by the Second Law. These consequences are indistinguishably physical, biological, social and ideological. Any territory reorganized around a program of indefinite increase in global energy conversions and rechanneled, burgeoning entropy flows will form matrices that shape future ecologies, knowledge and value along certain lines and not others.

Indeed, forcible territorial and interterritorial political reorganization in the service of the governance of capitalist labor – the indefinite re-engineering of landscapes from above – is in a sense what thermodynamic energy is all about. What are called Ministers of Energy are in reality Ministers of Entropy Flow. Their brief is not to ensure energy supplies, tap them efficiently, nor sell them at the highest possible profit. There are no such supplies. Rather, their job is to help wrench open various entropy doors in their territories and, if possible, keep those territories in such a state that there will exist doors in it that can continue to be wrenched open in certain tailored patterns and rhythms conditioned by the needs of industrial capital and international politics.

These considerations are a useful supplement to existing criticisms of naive notions of renewable energy that confuse the elimination of carbon dioxide emissions (which may be theoretically possible) with the institution of reversible energy conversions (which is not). They highlight the geographical reality that the wholesale transformations in entropy rates and entropy border management that characterize abstract energy are likely to come to pass whether the energy in question is fossil, solar, wind or geothermal. Here, as elsewhere, academic energy researchers' analyses often lag behind those of popular ecological movements who understand that in their energetic as well as their more obviously political fundamentals, there may be little difference to speak of between, say, nickel mining for electric car batteries [208], fracking for industry, heating or transport [209], and the conversion of desert landscapes for solar monoculture [5].

One further lesson that it may be important to take from the variegated heritage of Carnot is that the relational, nonequilibrium thermodynamics that owes so much to his old trope of "falls" turns out, perhaps surprisingly, to be a good potential dialogue partner of feminist and other politically-radical voices on energy and ecology that take "life" as an irreducible term of analysis [43,180,210]. Some of the reasons why can be found in the work of philosopher Maxine Sheets-Johnstone [107,108] mentioned in Section 2. Sheets-Johnstone lays out the ways in which living beings' necessary capacity for specifically "animate" movement in a world of entropy that follows on from the Second Law underpinnings of biological evolution is central to all aspects of human and nonhuman flourishing, including cognition. Her insights suggest that a key research program of the future into energy transitions will consist of detailed analytical comparisons of the ways Carnot landscapes have come to be organized during the last 500 years of capitalism with the overlapping and often conflicting ways that they have been organized during nearly four billion years of biological evolution. Such a program has the potential to add extra meaning to feminist and Indigenous uses of the concepts of life and body-territory [211] as political terms of analysis in the technical debate over energy transitions. This is not to say that an imaginary discussion involving Sheets-Johnstone, nonequilibrium thermodynamicsts and local body-territory activists in the Andes would ever result in any of the dialogue partners "saying the same thing" or converging on anything like a "shared set of values." Rather, it is because if each is allowed to contribute to a discussion at sufficient length in a "contact zone" [135] where they are enabled to engage in two- and three-way translations and mutual commentaries while developing novel workarounds taking account of various irreconcilabilities [134], fruitful paths forward may suddenly become visible at unexpected points. This underlines the importance of regarding 19th-century abstract energy not as the seamless, monolithic object that it is sometimes pictured as, but rather as a contradictory, multidimensional process like many other products of historical conflict in a human and more-than-human world. As Gustav Cederlof [191] observes, thermodynamics can on occasion be a "conceptual framework" that is of use in exposing "highly unequal power relations."

5. The limitations of mainstream entropy economics as a way of restarting energy alternatives research

Economics is one social science whose overall intellectual quality can be said to have suffered greatly from a chronic inattention to energy as a process and set of relations – in particular, to the implications of how entropy borders are reorganized under industrial capitalism. Going some way toward correcting this neglect, Nicholas Georgescu-Roegen [68] undertook a heroic study of the Second Law of Thermodynamics from an economist's perspective around a half-century ago. Georgescu-Roegen might accordingly seem to have already started the energy social science reboot that this article advocates.

Unfortunately, this is not the case. Georgescu-Roegen's work does not problematize energy itself politically, but rather perpetuates the custom of treating it as if it were outside the pale of democratic discussion. It tends to hide the ever-changing maps of entropy flows mentioned above. Instead, it focuses on aggregate global *rates* of entropy increase under industrial capitalism – conceived as a singular, generic, universal "economic process," to quote the title of Georgescu-Roegen's famous book [68]. It fails to recognize the plural nature of the historical, underlying nonequilibrium *patterns* in which capital's authoritarian politics tries to reorganize the opening of entropy doors across differentiated landscapes. To put it another way, it tends to exempt the Second Law idea that the amount of energy "beyond our use" tends to increase in a closed system from queries such as that raised by Barri Gold [89]: "What use? And who's *we*?" The generic "we" that Georgescu-Roegen himself employs [68: 351] would be unlikely to include Indigenous peoples for whom what physicists would call the "unavailable" energy in a calm lake is far from it, or peasants who deny that the energy in a fast-flowing river is "wasted" unless converted into hydroelectricity.

The work of the unfortunately still-limited number of economists who have followed in Georgescu-Roegen's brave footsteps is also not as helpful here as it could be. For example, when proposing ways forward, Georgescu-Roegen's student Herman Daly [212] tends to fall back on classic, already-failed strategies emphasizing globally-centralized, simplified capitalist environmental management: productivity increases, depletion quotas, population control, ecosystem service prices and so forth. Making such strategies still more unrealistic is the fact that, to be effective, they would all have to be administered by imaginary future global managers the mode of whose prospective rise to hegemonic power remains unquestioned, unexplored and unexplained. Essentially, this is to fall back on the tradition of envisaging energy as a universal resource for quantitative, top-down management rather than for continuing democratic negotiations that require recognition of the qualitative nature of strife involving mobile entropy borders and territories.

Kozo Mayumi [27,96], one of the entropy economists mentioned in the introduction to this article, has made incomparably more important contributions to the political understanding of energy. Nonetheless, Mayumi, too, assumes that the conceptual baseline for approaching energy politics must be to imagine unspecified leaders selecting a universal *rate* of entropy increase within a singular, ahistorical, thermodynamic "system," the evolving determination of whose internal and external borders remains unexamined. He makes few moves toward understanding the historical politics through which diverse *patterns* of entropy flow and system boundary-setting are established via racial and patriarchal as well as class domination. The "true question facing bioeconomic beings," he writes, "consists in the choice of *the* suitable rate of increase in entropy in the long term" [96] (emphasis added) – as if there could ever exist an undifferentiated, genderless, raceless class of "bioeconomic beings" waiting to implement the judgments of benevolent, omnipotent experts whom unknown parties have empowered to choose "the" single entropy rate increase "suitable" for the planet.

Unfortunately, this is no way either to conceptualize or to bring about environmental change of the type typically envisaged by proponents of a just energy transition. As Charles W. Mills has pointed out, this style of thinking is a mode of colonialist mystification. Unable to map contested territorial mosaics of entropy relationships, these proposals necessarily ignore what creates and recreates them. Erasing the actual history of what is today called energy, steeped in slavery, genocide, aboriginal expropriation and colonial rule over people of color, they replace it with a "sanitized and idealized White time" [213], during which European intellectuals' disinterested discovery of the possibilities of harnessing jacked-up energy conversion to industrial machines is assumed to be intrinsically a potential source of liberation for all humanity. Brushing aside energy history, such proposals are conceptually unequipped to find realistic ways forward through it [214,215]. To seek the roots of the current predicament in incorrect economics – or lack of a proper one-way information flow between thermodynamicists and orthodox economists – is to fail to confront the real-world issues of machinic imperialism.

Well-intentioned movements for a global energy transition, Green New Deal or "net zero" emissions regime tend to exacerbate the futility of this exercise. Insofar as they recycle the idea that energy is colorless, genderless and all-inclusive, such movements cannot formulate energy justice as anything much more than equitable production and fair distribution of a cleaned-up, essentially white substance [216] plus a notional just sharing of any entropic consequences. As Alvarez and Coolsaet [43: 6] suggest, such an approach is bound to (mis)interpret many struggles and movements over energy in the global South in particular as fights for the fair distribution of the energy good and of the risks and impacts of energy projects. It will not see them as fundamentally anti-colonialist and anti-capitalist battles for the right to live "in relation to one another and the natural world in non-dominating and non-exploitative terms" [180: 13] – a right that is at odds with the impetus behind 19th-century abstract energy itself in both its practice and its theory. These battles often involve an understanding that there can never be a "just sharing" of the entropic consequences of indefinitely-increasing global industrial energy conversions if those consequences involve a comprehensive, unending attack on life-giving territories worldwide.

The typical "just energy transtion" approach also tends to leave reparational justice – insofar as it requires a sense of nonwhite time and anticapitalist territories – by the wayside [217]. The fight against colonialist processes of reorganizing landscapes around capital-friendly entropy flows – represented by, to take just one example, the struggle over the Dakota Access pipeline [218] – is treated as if it could be brought to closure by, say, value-added lithium processing in Bolivia or expansion of geothermal or wind energy in some other landscape. To see racism as independent of historical territories in this way will only ensure that the natures of the future will be still more racist. A constructive reconsideration of energy alternatives research requires different premises.

6. Conclusion: what might it be like outside the fly-bottle?

Scholarly research into a prospective just transition to renewable energy has benefited greatly from investigations of what renewability consists in and what dimensions of justice need to be considered. The argument of this Perspective, however, has been that it has neglected a third question: should the focus of attention be only on an energy transition rather than on action that also admits the possibility of transitions *from* (abstract) energy?

In many ways, this neglect is not surprising, since energy is not usually considered to be something anybody could effect a transition from. Rather than being considered as an aspect of hegemony, it is commonly assumed to be a universal background to all social action. However, examination of the way dominant post-18th-century energy practices and theories have reorganized human and more-than-human landscapes reveals the political biases inherent in the unquestioned pursuit of energy, as well as the regressive political aspects of the assumption that energy is a neutral, scarce substance to which everybody is equally entitled. The non-renewability of energy projects [25] is not an accident correctible by ecomodernist patches. As Illich [79] saw more than 40 years ago, such patches only perpetuate a vicious cycle that deepens the "modernization of poverty" while providing new ways for capital to interpose itself between workers and their subsistence [147]. Rather, that inherent non-renewability is present at a prior stage, when the practices and theories of thermodynamic energy itself emerge for the first time in the 19th century, together with their implicit or explicit hierarchies and structures of permissions, prohibitions and imperatives for transforming expansive landscapes.

Nor can energy justice be achieved by restoring energy objects to their rightful owners or dividing them up equally together with the harms they occasion. No matter how they are carried out, such approaches are effectively complicit with forcible reworkings of landscapes of entropy flow that pit themselves against those "relational modes of life" [43] in which land and place are conceived, experienced and recreated as "a system of reciprocal relations and obligations" [180] involving nonhuman as well as human beings. There is no possible type of creation or redistribution of "energy resources" or of the benefits and harms from their exploitation that could overthrow the underlying unjust *processes* that constitute the rule of abstract, internally-commensurated energy. The treatment of, say, coal, gas or uranium as privately-ownable objects separate from living territories has already long been widely resisted as a so-called "ontological" injustice in many Indigenous contexts [119,120,219], but the treatment of the quasi-object of energy in similar terms carries the phenomenon into another dimension entirely.

The need to spell out and pursue different conceptions of energy and justice is one reason why it is important to the future of energy studies to bring a greater variety of critical voices from different communities and different academic disciplines into actual or imaginary dialogue with one another, as proposed in the Introduction and Section 4. Consider, for example, this sentence from Kleidon, a physicist: "The extent to which the boundary is flexible in exporting entropy is a critical factor in calculating how far the system can evolve away from thermal equilibrium" [220: 1306]. Then this sentence from Hornborg, a sociologist: "Unequal exchange in the world system is what reproduces machines, and machines are what reproduce unequal exchange" [94: 44]. Bringing just these two sentences into contact with each other already generates a veritable fizz of possibilities for novel energy research programs. These include, among many others, potential investigations into:

- How to draw and redraw detailed entropy maps that might help reveal different possible futures for, as well as away from, industrial capitalism.
- How and in what circumstances to translate, or not to translate [77,126], Indigenous and other critiques and "distancings" of 19th-century energy practice and theory into different terms for new audiences.
- How to contrast the entropy borders and changes involved in the care of life [105–107] and those required by various forms of industrial capital (see Section 4).
- How to supplement and modify the quantitative surveys of inequalities in the exchange of "embodied energy" highlighted by, for instance, Hornborg [95,139] and Jason Hickel and colleagues [138] so that they incorporate qualitative conceptions of the destructive

territorial forms of injustice thermodynamically entailed by the widespread use of industrial machines to control and discipline human labor and circulate commodities.

Each of these prospective research programs could help discussions of energy injustice move away from an overemphasis on metaphors of theft and maldistribution of harms [43] and toward a more rigorous recognition of the role of 19th-century energy itself in the forcible breakup and rejiggering of living entropy landscapes. Each carries fruitful challenges to the picture of useful energy as a scarce resource that is shipped here and there across an unchanging Cartesian grid. Each suggests that deep qualifications have to be made to the conventional wisdom that fossil energy is not as "land-intensive" as biomass energy. Each adds depth to Dunlap's justified criticism that "industrial-scale renewable energy is fossil fuel+" [221]. Each helps throw into doubt the presumption that colonialism might be eliminated from energy by more equitable distribution. Each, in short, has potential in helping researchers go beyond tired templates for energy transition that limit themselves to "adding renewability and justice to energy and stirring" [44].

In short, this Perspective looks forward to a future in which scientific studies of energy in industrial capitalism will base themselves on a great deal more than just the humdrum fact that capital, animate bodies and planets all change one kind of energy into another, and all organize and repeatedly reorganize the resulting entropy flows. They will show the *differences* in the evolving structures through which they do so, and the conflicts that erupt as a result. They will map and continually remap how these flows become structured in the overlapping, mutually-interacting territories of capitalists, commoners and more-than-human communities – by whom, for what, why, and with what effects on whom where. Such maps will be recognized also to be maps of never-ending political conflicts over extractivism, pollution and labor rights – as well as of the evolving political strategies of the divergent actors involved. They will reveal a good deal more of the cut and thrust of global energy politics than conventional charts showing the locations and flows of imaginary energy objects. In doing so, they may create fresh opportunities for social movements and other inquirers into energy to look in new places for fruitful approaches to injustice and ecological crisis. It is with such a vision in mind that this article has urged researchers on energy alternatives to restart efforts to understand exactly what it is that they are working on. Solidly entrenched in the physical and social world since the 19th century, the "theory-constitutive metaphor" [222] of energy as fuel object needs more of the kind of interrogation that can flourish only in independent "contact zones" [135] – transformative spaces where different communities with profoundly plural interests and heritages have enough time, opportunity and respites from coercion and hierarchy from within and without to engage in multidirectional and relatively freewheeling translations, mutual commentaries and fruitful cooperative expansions of energy science. Social scientists can choose to play either constructive or destructive roles in such zones, whose maintenance is arguably crucial in opening pathways to a livable future.

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Larry Lohmann: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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