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Toward histories of saving energy: Erich Walter Zimmermann and the struggle against "one-sided materialistic determinism"

Résumé

While energy use has appeared historically consequent for most of human history, it now seems energy non-use may determine our future. It is clear that the worst effects of climate change can only be averted if vast quantities of fossil fuels go unburnt. Accordingly, this paper argues historians of energy should pay attention to the rich histories of past attempts to conserve, save, constrain, and use energy with greater efficiency. To make this argument, the paper revisits the life and work of resource economist Erich Zimmermann, and extends his thinking beyond his lifetime to address more recent concerns. In historicising past energy saving initiatives, the hope is we may find new means to achieve reductions in harmful energy use.

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INTRODUCTION

1 When we flick off a switch, we may believe this action will save energy. But with a moment's reflection, we might struggle to explain precisely how our actions reduce overall energy consumption. We might imagine a series of events prompted by our action. Depending on how we derive our power, perhaps our action acts as an informational signal, entering the grid, marginally slowing the rotation of vast electromagnetic coils in a distant power plant, and reducing both the load and the corresponding combustion of fuel used to generate steam to drive the turbine. We might imagine, then, our actions save an infinitesimal amount of coal or natural gas. In which case, what stops this forestalled quantity being consumed elsewhere? How might we disentangle the concept of efficiency from that of conservation? Moreover, what was our intention? Did we intend to reduce the overall rate of fossil fuel use or to prolong the availability of such fuels? In doing so, were we motivated by household economy, altruism, a sense of equity, or growing evidence that the accumulated effects of burning fossil fuels are dramatically altering Earth's climate?

2 That last motivation raises the idea of a global carbon budget, an estimate of the quantity of hydrocarbons that can be burnt without creating catastrophic changes to the climate. This idea of a climatologically determined limit to energy use was first raised by analyst Florentin Krause, climatologist Wilfrid Bach, and energy economist Jonathan Koomey in 1989. As climate change became a concern, they argued that rather than just using fossil fuels efficiently "major restrictions on the use of global fossil resources" were necessary to avoid dangerous warming.[1] Initially the idea had little impact. But by 2010, the joint hottest year on climatological record at the time, the notion of "unburnable carbon" became a potent warning for the fossil fuel industry and those campaigning for divestment.[2] A recent estimate is that the latent emissions in known fossil fuel reserves are three-times higher than that which would exceed a widely agreed safe warming limit of two degrees centigrade. To avoid this limit, these authors warn, a third of oil reserves, half of natural gas, and over eighty percent of coal must go unburnt until 2050.[3]

3 Unburnable hydrocarbon reserves lie predominantly in Saudi Arabia, the United States, and Russia.[4] Given the objectives of the ruling classes of all three nations, the non-combustion of these resources seems unlikely. Whatever its feasibility, what the notion of unburnable carbon makes clear that fossil-fuelled climate change has superseded both economy and scarcity as the prime reason to reduce energy use. It also makes clear that, as in earlier decades of the 20th C., our problem is not energy scarcity but fossil energy abundance; a situation requiring fossil fuels to go unburnt, or for unproven geo-engineering technologies for atmospheric carbon dioxide removal to be deployed at an unprecedented scale.[5] Amid this stark situation, and despite the weight of expectation many place on energy saving as a planetary cure-all, the underlying mechanisms by which such savings are believed to occur remains curiously free from historical inquiry. To help address this deficit, this paper revisits the somewhat forgotten work of resource economist Erich Walter Zimmerman (1888-1961) as an entry point into a wider discussion about the need for histories of energy saving, whether ultimately successful or not.

1 Florentin Krause, Wilfrid Bach, Jon Koomey, Energy *Policy in the Greenhouse: From Warming Fate to Warming Limit* (London: Earthscan, 1990) cited in Ben Caldecott (ed.), *Stranded Assets, Developments in Finance and Investment* (London: Taylor and Francis, 2019), 4.

2 Jan Bebbington, Thomas Schneider, Lorna Stevenson, Alison Fox, "Fossil Fuel reserves and resources reporting and unburnable carbon: Investigating conflicting accounts", *Critical Perspectives on Accounting*, vol. 66, 2020, 1-22.

3 Christophe McGlade, Paul Ekins, "The Geographical Distribution of Fossil Fuels unused when limiting global warming to 2oC.", *Nature*, vol. 517, 2015, 187-190.

4 *Ibid*., table 1, 189.

5 Filip Johnsson, Jan Kjärstad, Johan Rootzén, "The threat to climate change mitigation pose by the abundance of fossil fuels", *Climate Policy*, vol. 19, n° 2, 2019, 258-274.

A NASCENT SUBFIELD

4 Humanities scholars concerned with energy have so far addressed a fairly circumscribed set of industries, resources, and the human and environmental consequences of their use.[6] The field of energy history has even been accused of "petromyopia", a focus on petroleum at the expense of other fuels. But even this call for an expanded research agenda fails to mention energy saving.[7] This absence is all the more perplexing given that one of the field's leading texts has described how intermittently throughout the 20th C., coal miners had withheld their extractive labour, restricting energy flow to demand political representation.[8] This paper therefore asks, what if, rather than "following the oil", as Mitchell advised, we follow the more prosaic practices of saving energy? By closely attending to the notion of energy as it is understood in physics and engineering, as geographer Andrew Barry has argued, we might gain a more comprehensive and holistic view of how energy, measured in increments of conservation and waste, contributes to historical change.[9]

5 In this vein, this paper joins those of a number of historians who have begun to address energy non-use. Environmental historians Christophe Bonneuil and Jean-Baptiste Fressoz have argued that energy historians must move from studying energy transitions toward the study of "situations in which societies were forced to reduce their energy consumption" such as the Great Depression or the fall of the Soviet Union.[10]Diplomatic historian Giuliano Garavini has recast the Organization of Petroleum Exporting Countries (OPEC) as anti-extractivists, whose embargo could be understood as an "ecological force" able to constrain overall oil consumption.[11] Economic historians Louis-Gaëtan Giraude and Antoine Missemer have contrasted notions of energy efficiency in engineering and economics to help better understand developments in energy policymaking.[12] While environmental historian Caleb Wellum has unearthed the nationalistic and ecological principles underlying North American energy conservation policy of the 1970s.[13]

6 Added to these works, this author's doctoral thesis documents the history of science upon which energy saving policy was based in Britain and the United States over the long 20th C. In this period, it was argued that a belief in the energy-saving capacities of increased energy efficiency shifted from a paradox to a widely accepted notion. Additionally, it was proposed that conserved energy should be understood as a "metrological resource" given the degree to which measurement and forecasting are central to the realisation of its resource-like capacities.[14] A wider observation was that the science of energy saving was both a reflection of and influential upon contemporaneous theories of political economy. Attending to this reciprocal influence bore witness to a significant transition in energy saving rationales. Early in the 20th C., intervention by the state was seen as a means of saving energy and a corrective to the wastefulness of a competitive market. But over time, such interventions came to be seen as impediments to the energy saving capacities of a freely operating market. Accordingly, by the 1980s, both British and North American political leaders, and those of other nations, scaled back direct energy saving interventions, attempting to instead ensure the dynamics of energy use approximated to that of an idealised efficient market.[15]

6 Andrew Barry, "Thermodynamics, Matter, Politics", *Distinktion: Journal of Social Theory*, vol. 16, no 1, 2015, 111.

7 Christopher Jones, "Petromyopia: Oil and the Energy Humanities", *Humanities*, vol. 5, no 36, 2016, 1-10.

8 Timothy Mitchell, *Carbon Democracy: Political Power in the Age of Oil* (London: Verso, 2011), 5.

9 Andrew Barry, "Thermodynamics", 113 (cf. note 6)

10 Christophe Bonneuil, Jean-Baptiste Fressoz, *The Shock of the Anthropocene* (London/New York: Verso, 2017), 181.

11 Giuliano Garavini, *The Rise and Fall of OPEC in the Twentieth Century* (Oxford: Oxford University Press, 2019), 9.

12 Louis-Gaëtan Giraudet, Antoine Missemer, "The Economics of Energy Efficiency: a Historical Perspective", *Centre International de Recherche sur l'Environnement et le Développement (CIRED) Working Paper*, no 74, 2019, 1-26.

13 Caleb Wellum, "'A Vibrant National Pre-occupation: Embracing an Energy Conservation Ethic in the 1970s'", *Environmental History*, vol. 25, no 1, 2020, 85-109.

14 Thomas Turnbull, "From Paradox to Policy: The Problem of Energy Resource Conservation in Britain and America, 1865-1981" (PhD dissertation, University of Oxford, 2017), 433.

15 *Ibid.*, 327-332.

7 Drawing on this work, and seeking to contribute to a nascent subfield of energy historical inquiry, this paper will outline this transition in the overarching principles of energy saving. To do so, it revisits and extends the work of resource economist Erich Walter Zimmermann. The intention is to outline the possible scope of a subfield of energy history focused upon demand reduction rather than increased supply. Examples of attempts at energy non-use, from substitution, to electrification, the rationing of production, and the reallocation energy consumption over space and time, will be touched upon throughout. In concluding, some of the problems faced by historians of saving energy are addressed and a number of resolutions offered.

THE RATIONALISED ECONOMY OF ENERGY

8 Increasing energy efficiency has long been seen as historically consequential. Around 1890 physical chemist Wilhelm Ostwald began to argue that civilisation advanced in step with the "transformation coefficient", the ratio with which society transformed available energy into productive outcomes. Ostwald therefore considered the avoidance of wasted energy a civilizational imperative.[16] Around the same time, the North-American historian Henry Adams described the growing intensity of coal-use more pessimistically. Regularly crossing the Atlantic on coal-fired steamships, for Adams, their ever more efficient operation seemingly demonstrated the acceleration of historical time.[17] Far from implying progress, Adams took such acceleration as a sign of advancing civilizational disorder: a disorientating dynamic he blamed for societal ills ranging from drug abuse to insanity.[18] In effect, Adams argued that increased energy efficiency caused only societal entropy and led the "ash-heap" of history to grow ever larger.[19]

9 Between these two extremes, the view of German-American resource economist Erich Zimmermann can be situated. In 1933, Zimmermann grandly declared the "rationalised economy of energy" as "mans' greatest triumph and his biggest task".[20] Drawing upon the work of Ostwald, Serbian physicist Mihajlo Pupin, and British geographer James Fairgrieve, Zimmermann had authored an extensive survey of global resource use with energy at the fore. Written during the Great Depression, the book sought to caution against ignoring the specific "physical basis" upon which the at-the-time ailing "price economy rests".[21] But the book was far from a materialist rebuke to orthodox economics; in fact it articulated an aversion to any simple form of determinism.[22] Of central importance to historians of energy saving, he accused those who saw history advancing via the discovery of "new forms or additional amounts of energy" of a "one-sided materialistic determinism". Having surveyed the prosaic realities of resource use, he called attention to the "equal, if not greater, importance of making fuller utilization of old forms and of limited amounts of energy."[23] Zimmermann's emphasis on efficiency set his work apart from more recent scholarship which tends to focus on the materiality of energy use.[24]

16 Janet Stewart, "Sociology, Culture, and Energy: the case of Wilhelm Ostwald's 'Sociological Energetics' – A translation and exposition of a classic text", *Cultural Sociology*, vol. 8, no 3, 2014, 11-12.
17 Crosbie Smith, Ian Higginson, "Consuming Energies: Henry Adams and the Tyranny of Thermodynamics", *Interdisciplinary Science Reviews*, vol. 26, no 2, 2001, 103-111.
18 Henry Adams, *The Education of Henry Adams* (New York: Modern Library, 1931), 402; Keith Burich, "Henry Adams, the Second Law of Thermodynamics, and the course of History", *Journal of the History of Ideas*, vol. 48, no 3, 1987, 467-482.
19 Henry Adams, *The Tendency of History* (New York: Macmillan, 1919), 5.
20 Erich Zimmermann, *World Resources and Industries: A Functional Appraisal of the Availability of Agricultural and Industrial Resources* (New York and London: Harper & Brothers Publishing, 1933), 75.
21 *Ibid.*, foreword, vii.
22 William Meyer, Dylan Guss, *Neo-Environmental Determinism: Geographical Critiques* (Basingstoke: Palgrave Macmillan, 2018), 34.
23 Erich Zimmermann, *World Resources and Industries*, 53 (cf. note 20).
24 Matthew Huber, "Energizing Historical Materialism", *Geoforum*, vol. 40, no 1, 2009, 105-115.

ERICH ZIMMERMANN

10 Born in Mainz in 1888, Zimmermann remains amongst the foremost theorists of energy and resource conservation. After studying in Berlin, Birmingham, and Munich, in 1911 he received a doctorate from the University of Bonn for a thesis on the history of the British coal trade. Soon after, he travelled to the United States to study the economic geography of the Great Lakes. Following the outbreak of war in Europe, Zimmermann settled in North America, first in Illinois and then at the University of North Carolina. Drawing on his thesis, his first book concerns the economics of ocean shipping and documented "the transition from coal to oil" as means of propulsion in the British and American Naval fleets.[25] But it was *World Resources and Industries*, published in 1933, which brought widespread praise. In 1942, as war raged against Germany and with his loyalty to the United States sufficiently recognised, Zimmermann was nominated to a professorship at the University of Texas. Soon after, a revised version of *World Resources* was published to further acclaim. Zimmermann then devoted the rest of his career to studying the petroleum industry, which Texas dominated at the time. His final book, published in 1957, concerns a nationwide attempt to conserve petroleum by controlling its production rate. Four years after its publication Zimmermann died.[26]

11 Zimmermann's work offers much of importance for contemporary energy historians. His most influential maxim was that "resources are not, they become".[27] Within the confines of the laws of physics, this mean resource availability was as much a function of human want and ability as geophysical availability. In effect, Zimmermann sought to ground the economist's notion of a resource in physical reality while also articulating the degree to which resources were, to some degree, a relative concept. Resources, he evoked "evolve out of the triune interaction of nature, man, and culture, in which nature sets outer limits, but man and culture are largely responsible for the portion of physical totality that is made available for human use".[28] In outlining this "functional theory" of resource availability, he emphasised how "every advance in sciences and art compensates to some extent for the loss of physical reserves."[29] This assertion of reciprocity emphasises the central importance of the history of science and technology to the history of energy and resources, and in particular, the history of attempts to save energy.

Zimmermann was an avowed institutionalist, a 12
form of economic thought that stressed the specific role that institutions play in shaping economies in place of mathematical abstraction. This perspective encouraged his belief that "institutions have as much to do with the ultimate efficacy of energy use as have engines, machines, and logarithm tables."[30] He saw resources as inescapably anthropic, entities that could not exist outside the specific means of their exploitation and the society they served. But this did not lead to a naïve cornucopianism. The 1951 edition of *World Resources* clarifies that "not even omniscience can create matter or energy out of nothing. Nor can any science, no matter how skilful and advanced, ever restore to human use the energy once locked up in coal, oil, or gas, but spent."[31]

This has not prevented some from misinter- 13
preting Zimmermann's work as a form of idealism which justifies untrammelled resource exploitation.[32] In fact, having experienced the

25 Erich Zimmermann, *Zimmermann on Ocean Shipping* (New York: Prentice Hall, 1921), 178.
26 Stephen McDonald, "Erich W. Zimmermann, the Dynamics of Resourceship", in Ronnie Phillips (ed.), *Economic Mavericks: The Texas Institutionalists* (Bingley: Emerald Publishing, 1995), 182.
27 Erich Zimmermann, *World Resources and Industries*, 782 (cf. note 20).
28 Erich Zimmermann, *World Resources and Industries: A Functional Appraisal of the Availability of Agricultural and Industrial Materials* (New York: Harper, 1951), 15.
29 Erich Zimmermann, *World Resources and Industries*, 799 (cf. note 20).
30 *Ibid*., 44.
31 Erich Zimmermann, *World Resources and Industries*, 10 (cf. note 28).
32 Robert Bradley, "Resourceship: an Austrian theory of mineral resources", *Review of Austrian Economics*, vol. 20, no 1, 2007, 63-90.

economic disequilibria of the Great Depression, Zimmermann believed that government had an obligation to stabilise resource availability as it fluctuated in line with technological changes.[33] And far from an unconditional faith in scientific progress, Zimmermann believed the "technological unemployment" of the 1930s had been caused by the growing efficiencies and quantity of productive machinery.[34] Science alone was not enough to ensure the stable provision of energy and resources.

14 But Zimmermann was also not an energy determinist. In fact, he was critical of the Technocrats, that short-lived political movement in the 1930s whose adherents saw the Great Depression as a result of collective failure to recognise the energetic basis of national wealth.[35] He accused them of failing to account for the "relative efficiency" with which energy was used. Alerting his readers to the comparatively greater efficiency of French automobiles versus those of North America, Zimmermann pointed out that the same quantity of energy consumed in one place could achieve a markedly different outcome elsewhere.[36]

15 Context was central to the effectiveness of energy consumption. In fact, he believed variation in the efficiency of energy and resource use would become ever more important, as a form of energetic "productivism" was becoming the new means by which nations engaged in geopolitical rivalry.[37] Zimmermann's sense that progress lay in increased efficiency rather than territorial expansion led him to argue that "the greatest progress may be expected not from the country which possesses the largest coal deposits, but from the country which uses its coal most efficiently and wisely". However, a fundamental problem remained, the very definition of efficiency, not to mention wisdom, remained "a difficult question", one that required the consideration of "a large number of intangible and seemingly unrelated elements."[38]

STELLAR ENERGY

16 One important element in understanding efficiency as it relates to energy is the underlying physics. In its functionalism, Zimmermann's thinking attempted to accommodate the physical principle of relativity within resource economics;[39] he speculated on the implications of Albert Einstein's work for economics.[40] At the same time, his view of nature was underwritten by a classical approach to thermodynamics. Deferring to Pupin and Ostwald, Zimmermann described the availability of terrestrial energy as a result of incoming "stellar energy". Energy radiating from the sun fuelled photosynthesis, powered carbon and nitrogen cycles, dictated Earth's climate, and ultimately provided the gravitational force which drove the hydrological cycle. As a subset of the universally constant quantity of energy, it was the sun that granted the terrestrial system its specific "capability to do work".[41] However, this was "no guarantee of undiminishing supply", as the quality of energy

33 Stephen McDonald, "Erich W. Zimmermann", 32 (cf. note 26).
34 Erich Zimmermann, "The Resource Hierarchy of the Modern World Economy", *Weltwirtschaftliches Archive*, vol. 33, 1931, 431-463.
35 Ernst Bernd, "From Technocracy to Net Energy Analysis: Engineers, Economists, and Recurring Energy Theories of Value", in Anthony Scott, John Heliewel, Tracy Lewis, Philip Neher (eds.), *Progress in Natural Resource Economics* (Oxford: Clarendon Press, 1985), 337-366.
36 Erich Zimmermann, "The Relationship between output of work and economic well-being", *The American Economic Review*, vol. 24, no 2, 1934, 245.
37 Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (Los Angeles CA: University of California Press, 1992), 70; see also Neil Smith, *American Empire: Roosevelt's Geographer and the Prelude to Globalisation* (London: University of California Press, 2004), 11.
38 Erich Zimmermann, *World Resources and Industries*, 53 (cf. note 20).
39 The influence of relativity beyond physics is evident in Forman's account of Oswald Spengler's work. Though a vulgarisation of the physics, writing in 1918, in Der Untergang des Abendlandes (The Decline of the West, trans. 1926) Spengler argued that "There simply are no conceptions other than anthropomorphic conceptions", on this see Paul Forman, "Weimar Culture, Causality, and Quantum Theory, 1918-1927", *Historical Studies in the Physical Sciences*, vol. 3, 1971, 30-31.
40 Erich Zimmermann, "Crossing the Frontiers of Science", *Social Forces*, vol. 14, no 1, 1935, 139.
41 Erich Zimmermann, *World Resources and Industries*, 39 (cf. note 20).

tended to deteriorate in accordance with the second law of thermodynamics. Over time, all energy became "diffuse" and no longer a feasible resource.[42] Somewhere between these two conditions, energy's universal constancy and its diffusion into less useful forms, the anthropically significant work of minimising the waste of "free" energy occurred.

17 Though not an energy determinist, Zimmermann believed the efficient use of energy was of singular importance. Its continued availability was "the key to resource availability" as it could expand the functional availability of other industrial inputs: "Coal hoists and moves; steel helps to make more steel".[43] Akin to the contemporary notions of Gaia or the Technosphere, like many geographers of the late 19th and early 20th C., Zimmermann saw the world as an aggregate organism, "a living growing complex of matter and energy" which assumed a significant degree of independent agency.[44]

18 Thus, the supplies of mineral fuels and machine materials must be viewed not as a dead mass of inert materials, but as parts belonging to a living organism which is possessed with dynamics powers of its own even though they are subject to human will and human control.[45]

19 This idea, that Earth and its industrial system were an organism in process has led at least two authors to relate Zimmermann's views to those of his contemporary, the philosopher Alfred North Whitehead, in semblance if not explicitly.[46] Developed over a lifetime, Whitehead's philosophy argued that no entity could exist in isolation and that reality was an outcome of processes of interrelation.[47] At his most philosophical, Zimmermann similarly theorised that his inquiries into the use and conservation of resources had revealed the "altogetherness of things", an 'inextricable mesh of forces and conditions' against which human intentionality struggled for realisation.[48]

20 These constraints could be discerned in the work of steam engineers and their efforts to make "conversion more efficient, to lessen the losses engendered".[49] Since the 1800s, engineers had demonstrated that the combustion of a certain quantity of coal produced a measurable amount of work. The power transferred was described as having been conserved, and came to be known as energy.[50] Somewhat confusingly, all kinds of engine could therefore be thought of as means of conservation, in so far as they realised a proportion of a fuel's potential to do work and—as they improved in efficiency—lessened energy waste.[51] This efficiency-driven conservation could, of course, only be achieved in relation to an act of consumption. This was only a problem in so far as the cosmic "storehouse" of energy, as Pupin had called it, was finite.[52] For humans, in the case of "animate" or renewable energies, such as falling water or human labour, efficiency of use was less a concern than the maintenance of conditions of continued renewal. But "inanimate" energies, those "spill-overs" of carbon formed hundreds of millions of years earlier, whose use involved irreversible destruction, this problematic distinction between efficiency and conservation was more complicated.[53]

42 *Ibid.*, 46.
43 *Ibid.*, 430.
44 David Livingstone, "Evolution, Science and Society: Historical Reflections on the Geographical Experiment", *Geoforum*, vol. 16, no 2, 1985, 119-130.
45 Erich Zimmermann, *World Resources and Industries*, 530 (cf. note 20).
46 Alfred Chalk, "Schumpeter's Views" (cf. note 30); Jamie Linton, *What is Water? The History of a Modern Abstraction* (Vancouver: University of British Columbia Press, 2010), 27-29.
47 As Phillip Rose notes Whitehead's philosophy lends itself to ecological thought. Philip Rose, *On Whitehead* (Belmont: Wadsworth, 2002), 92.
48 Erich Zimmermann, *World Resources and Industries*, 818 (cf. note 20).
49 *Ibid.*, 48.
50 Thomas Kuhn, "Energy Conservation as an example of simultaneous discovery", *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago, University of Chicago Press: 1977), 68.
51 Norton Wise, Crosbie Smith "Work and Waste 1: Political Economy and Natural Philosophy in Nineteenth Century Britain", *History of Science*, vol. 27, no 3, 1989, 263-301.
52 Erich Zimmermann, *World Resources and Industries*, 9 (cf. note 20).
53 *Ibid.*, 51.

EFFICIENCIES

21 Having ranged far from the conventional abstractions of economics, Zimmermann had still to define efficiency. He believed one's disciplinary perspective could obscure the altogetherness of the problem. The natural scientist, be they steam engineer or geologist, emphasised the biophysical, and chemical limits of Earth's resources and their interaction with technologies. For example, improvements in smelting processes might allow lower concentrations of copper ore to become a workable commodity, vastly expanding the availability of global copper. However, perhaps wrongly, Zimmermann believed natural scientists largely failed to consider "the implications of pecuniary economics".[54] Social scientists, Zimmermann argued, upheld a similarly plastic view of resource availability, but one based on increments of socio-economic change. Economists in particular associated increased productive efficiency with lower costs, a dynamic that would result in lower prices and stimulate demand, causing an acceleration in overall rates of resource use. In certain configurations therefore, far from conserving resources, increased efficiency could have the opposite effect.[55]

22 Here Zimmermann deferred to British economist William Stanley Jevons. Prompted by fears about Britain's continued industrial supremacy, in 1865 Jevons had addressed the longstanding question of the duration of Britain's coal.[56] Though abundant at the time, he forecast that by the year 2000, if use rates continued to increase at the rate at which they had in the 1800s, Britain's mines would be effectively exhausted. As quantitative indicators of utility, if prices fell as a result of an increase in efficiency, this would likely cause an increase, up to a certain point, in the rate and scale of resource consumption in a given market. This dynamic later became known as "Jevons' paradox" or the "rebound effect".[57] In his doctoral thesis, Zimmermann had used Jevons' work to argue that as steam engines had become more efficient over the 19th C., far from saving coal, coal use had expanded in rate and scale.[58] Clearly, the unanticipated outcomes of increased energy efficiency of energy use have long been known.

Zimmermann lamented that, in his own time, the term conservation was used with imprecision. If "to conserve means nothing more than to economize, why burden our vocabulary with this synonym?"[59] The question was rhetorical. He set out the distinction. In general usage conservation meant reducing the rate of a given resource's consumption. By contrast, "economisation", or efficiency, could be defined as an increase in the ratio of the input and output of a given productive activity. As Jevons argued, economisation did not necessarily result in conservation. If coal hydrogenation became more efficient, for example, this would lower its price, which would likely raise demand and hasten depletion.[60] Just as efficiency did not always conserve, conservation did not mean imposing an immediate restriction on resource use, so much as forestalling its use to a certain point in the future. The goal of conservation could therefore come into conflict with that of efficiency. At the same time, if conservation was understood as waste minimisation, complete denudation could still count as a success. 23

Zimmermann also added a significant addendum to Jevons's argument. Unlike Jevons, he had witnessed the Russian Revolution, the establishment of the Soviet Union, and the "wonders" of its five-year plans: a demonstration that other forms of economic life were possible.[61] Theoretically, in a centrally controlled market, if overall production rates were reduced, economisation could result in conservation. Whereas in a capitalist system, in which price movements 24

54 *Ibid.*, 789.
55 *Ibid.*, 791.
56 Fredrik Albritton Jonsson, "The Coal Question Before Jevons", *Historical Journal*, vol. 62, no1, 2020, 108-109.
57 See "Conservation encounters climate" section below.
58 Erich Zimmerman, *Die britische Kohlenausfuhr, ihre Geschichte, Organisation unde Bedeutung* (Essen: Girardt, 1911), 4.
59 Erich Zimmermann, *World Resources and Industries*, 790 (cf. note 20).
60 *Ibid.*, 438.
61 *Ibid.*, 648.

largely dictated demand, unchecked economisation would likely increase overall resource consumption. As he put it, in market system in which "conservation is inseparably linked up with a reduced rate of output or of consumption, economies which stimulate output or consumption cannot be called conservation."[62] But far from advocating centralised control, Zimmermann merely conceded that, for the conservation of resources to be achieved in a holistic way, a degree of market intervention was necessary, be it via the police power of the state or via taxation.

25 To better clarify the many aspects of conservation, Zimmermann proposed a suite of definitions: *economisation* meant to improve the ratio between input to output, for reasons of increased productivity, competitiveness, and profit-making in the present; whereas *conservation* was distinguished by its orientation toward the future, immediate economic benefit would be sacrificed for prosperity's gain; *conservancy* meant a reduction in use rate as a by-product of economisation, an example might by a naval fleet's shift from coal to oil for reasons of economy which incidentally conserves a quantity of coal; *economancy*, by contrast, meant economisation as a by-product of conservation, as occurred with Jevons' paradox.[63] Though subject to later criticism, and somewhat confusing, Zimmermann's neologisms point to the ambiguities that hide behind the term conservation.[64]

THE FUTURE

26 If conservation meant "restraint in current use for possible future benefit" the future would unsurprisingly assume a central role in saving energy.[65] Throughout the 20th C., in various guises, the future would provide a horizon toward which the work of conservation could be deferred, and offer hypothetical forecasts against which the cumulative effects of present-day energy saving initiatives could be measured. Unsurprisingly, of all disciplines, economics was often the most confident in staking claims in the future. One example, described by Zimmermann, was the work of Harold Hotelling, a pioneering Minnesotan mathematical economist. In a period when such methods lacked credibility, Hotelling had used mathematics to argue that oil should be consumed freely within a market. As it became scarce, its price would rise alongside that of other goods and such rises would discourage consumption and mean that, in the case of oil, extraction would be deferred to some point in the future.[66]

By 1957, the economics of temporal deferment would be further enshrined by German-American Siegfried Ciriacy-Wantrup. Another Bonn graduate, Ciriacy-Wantrup combined principles of scientific agronomy with cutting-edge mathematical economics to develop an analytical approach to resource conservation.[67] Superseding Hotelling's formalisms, advances in econometrics and calculative technologies now allowed large sets of linear equations to be computed, from which the optimal means of allocating resources over time could be derived.[68] Each resource, energetic or 27

62 *Ibid*., 806.
63 The term economancy was added to the 1951 edition, Erich Zimmermann, *World Resources and Industries*, 27 (cf. note 28).
64 Stephen McDonald, "Erich W. Zimmermann" (cf. note 26).
65 Erich Zimmermann, *Conservation in the Production of Petroleum* (Connecticut: Yale University Press, 1957), 26.
66 Harold Hotelling, "The Economics of Exhaustible Resources", *Journal of Political Economy*, vol. 39, no 2, 1931. 137-175; see also, Timothy Mitchell, *Carbon Democracy*, 196 (cf. note 8); recent archival analysis demonstrates Hotelling had a greater appreciation of geological constraints than subsequent interpretations of this paper would suggest, see Roberto Ferreira da Cunha, Antoine Missemer, "The Hotelling rule in non-renewable resource economics: a reassessment", *Canadian Journal of Economics/Revue Canadienne d'Economique*, vol. 53, no 2, 2020, 1-21.
67 Influential German agronomists included Johann Heinrich von Thünen (1783-1850) Friedrich Aereboe (1865-1942) and Theodor Brinkmann (1877-1951). Ciriacy-Wantrup described his approach as 'analytically oriented institutional economics'. See Gerald Vaughn, "Siegfried von Ciriacy Wantrup and his Safe Minimum Standards of Conservation", *Choices: The Magazine of Food, Farm, and Resources Issues*, vol. 12, no 4, 1997, 1-4.
68 On relevant developments in mathematical economics see Thomas Turnbull, "A Transition in the Economics of North American Energy Resource Conservation", Stephen Gross and Andrew Needham (eds.), *Toward a New Energy*

otherwise, had a dynamically optimal use rate, depending on past, present, and future. Ciriacy-Wantrup therefore described conservation as the pursuit of the "time distribution of use rates (of resources) that maximizes the present value of the flow of (expected) net revenues".[69] As a resource became scarce, its untapped reserves would become more valuable, and as overall interest rates rose, increases to the exploitation cost would defer a degree of resource consumption to the future. In effect, this meant the work of conservation could be left to the market, an aggregate of constantly economising consumers.

28 An institutionalist, Zimmermann resisted the encroachment of econometrics. He saw the economist's faith in the free-market as "a far cry from the pleas for preservation" associated with the ideals of the first Roosevelt Presidency.[70] To his mind, Ciriacy-Wantrup had achieved "little more than a substitution of mathematical symbols for the solution of the real problems of policy making".[71] More generally, Zimmermann believed the onus to conserve exceeded the bounds of such narrow economic reasoning. To sacrifice the productivity of the present for the needs of prosperity was to invoke "a moral issue, giving rise to claims and counterclaims not subject to verification or proof."[72] Econometric abstractions ignored the complex constraints individual resources imposed. It was the properties of each resource that dictated the terms of their conservation. For example, petroleum was "fugacious"; it tended to dissipate once a reservoir was tapped, as a result of its chemical composition and the specific geology in which it was encased. Given such idiosyncrasies, as we shall see, petroleum conservation would initially go beyond the economising capacities of the market.[73]

Given his lack of faith in economic reasoning and his acknowledgement of the moral aspect of conservation, Zimmermann considered it an appropriate problem not just for the engineer and geologist but also for the social scientist. In an almost classical sociological formulation, he stated that "In the problem of conservation, the question of conflict between group and individual, between social and private interests, finds its most concrete expression."[74] So, far from endorsing a single position, Zimmermann would call for the study of the "*conservational* implication of efficiency". To do so, he admitted, would require not only an understanding of the future consequences of efficiency increases but also "the evaluation of all the effects" that followed from such an increase. Such evaluation could not be "limited to a mere segment". Amid the complex mesh of forces humanity found itself in, evidence that a conservation saving had been achieved would have to be "extremely complex and comprehensive".[75] 29

ELECTRIFICATION AS CONSERVATION

Over his lifetime Zimmermann had witnessed many metamorphoses in the semantics of conservation, fueling his observation that the term's "meaning changes with time and place".[76] Beyond physics, the term had first become prominent in North America as the mantra of a government-led wilderness and resource preservation movement. Following an agricultural depression, in 1908 Republican President Theodore Roosevelt spoke of foresight and restraint in land and resource use. His government requisitioned vast tracts of land to ensure "wise use", which invariably meant drawing on the principles of scientific management to rationally plan efficient resource use.[77] Alongside his dim view of the term conservation, Zimmermann considered the term wisdom vacuous in this context 30

History: Energy Transitions in Europe and America during the Twentieth Century (Pennsylvania: University of Pittsburgh Press, forthcoming).

69 Siegfried Ciriacy-Wantrup, *Resource Conservation: Economics and Policies* (University of California: Berkeley, 1952), 44.

70 Erich Zimmermann, *Conservation*, 30 (cf. note 65).

71 *Ibid.*, 31.

72 Erich Zimmermann, *World Resources and Industries*, 781 (cf. note 20).

73 *Ibid.*, 67.

74 *Ibid.*, 805.

75 Erich Zimmermann, *Conservation*, 29 (cf. note 65).

76 Erich Zimmermann, *World Resources and Industries*, 788 (cf. note 20).

77 Samuel Hays, *Conservation and the Gospel of Efficiency. The Progressive Conservation Movement, 1890-1920* (Pittsburgh: Pittsburgh University Press, 1959), 3.

and its ambiguities partly responsible for the eventual failure of the movement.[78] Roosevelt's government had been unwilling to restrict competition or intervene in economic activity, hence, as Jevons had warned, increased efficiencies had stimulated demand and accelerated consumption. As Zimmermann saw it, it was as if the first conservation movement recognized the relation between competition, overproduction, and waste, but "there the line of thought seemed to stop".[79]

31 Electrification illustrated this conflict between conservation and competition. Industry boosters had long made great claims of the coal-saving capacities of electrical power. In 1909, at the height of the Progressive Era conservation movement, Lewis Stillwell, chief engineer at the electricity company Westinghouse, had argued that electrical power be generated in larger and more efficient plant than those powered by steam, thereby consuming less coal per unit of power.[80] Zimmermann also pointed to the impressive sixty-six percent decrease in the amount of coal needed to generate a kilowatt hour of electricity which had been achieved between 1900 and 1929. But he cautioned that coal savings were only credible if overall use rates remained static.[81] As historian of electricity Julie Cohn later noted, in fact such efficiency increases had allowed electrical utilities to attract "more customers who used electricity at every hour of the day […] to operate the plants at maximum efficiency and thus realize the per-unit savings of coal".[82] Jevons' familiar dynamic was in effect. In the long-run and at scale, electrification could seemingly contribute to an overall *increase* in coal consumption.[83] Not even hydro-electrical power could claim exemption from this dynamic. Zimmermann noted how the interconnection of remote sites where water fell with sufficient velocity acted to extend the transmission grid. In effect, water-derived electricity effectively subsidized and helped spread the means for fossil-derived electricity supply.[84]

PRODUCTION RATIONING

What of the specific conditions that petroleum imposed on its conservation? Zimmermann had asserted that the fugacity of petroleum meant its conservation required an approach that exceeded "economic imperatives".[85] A volatile mixture of oil, gas, and occasionally water, petroleum's molecular composition contributes to a buildup of pressure over geological timescales. When a drill strikes a reservoir, this ancient pressure acts as a propellant, forcing the petroleum to the surface.[86] Controlled expulsion of a well's "charge" remains critical to efficient petroleum extraction. If multiple operators raced to sink wells, reservoir pressure would be lost, and the average recovery rate could fall to just ten percent. The remaining petroleum would have to either be abandoned or pumped out at considerable cost.[87] By the time Zimmermann was living in Texas, the state's oil regulator had begun to impose policies that limited the rate of petroleum production, with the support of the Federal government. Zimmermann noted that these interventions were believed to raise the average reservoir recovery rate by as much as seventy percent.[88] 32

What were the origins of this compact? Contrary to its buccaneering image, the oil industry had in fact entered into a regulatory agreement with the U.S. government, sanctioning a degree of centralized control. At the Federal level, the need for such intervention had first emerged under President Warren Harding, who had formed a 33

78 Erich Zimmermann, *World Resources and Industries*, 790 (cf. note 20).
79 *Ibid.*, 785.
80 Lewis B. Stillwell, "Electricity and the Conservation of Energy", *Transactions of the American Institute of Electrical Engineers*, vol. 18, no 1, 1909, 165.
81 Erich Zimmermann, *World Resources and Industries*, 569 (cf. note 20).
82 Julie Cohn, *The Grid: Biography of an American Technology* (Massachusetts: MIT Press, 2017), 352.
83 Erich Zimmermann, *World Resources and Industries*, 569, 788 (cf. note 20).
84 *Ibid.*, 569-570.
85 *Ibid.*, 808.
86 Erich Zimmermann, *Conservation*, 58, 63-64 (cf. note 65).
87 *Ibid.*, 432.
88 *Id.*

Federal Fuel Administration in 1917 to oversee the maintenance of petroleum and coal during the war.[89] Afterward, still facing shortages, the organisation's moderate successes encouraged President Calvin Coolidge to create a peace-time commission in 1924. The resulting Federal Oil Conservation Board (FOCB) was tasked with trying to ensure petroleum's long-term availability by formulating means "to conserve oil in the ground".[90] But wartime shortages were soon superseded by the discovery of large new oil fields. So, by the late 1920s, concerns had switched from scarcity to overproduction. The FOCB were now worried about petroleum's "cheapness, which in turn leads to wastefulness and disregard".[91]

34 Faced with a glut of low-cost oil, the FOCB began to promote the idea of nationwide rationing of the overall rate of petroleum production, to ensure supply increased in line with future demand rather than exceeding it. Despite initial opposition from industry, in the early 1930s, facing ruinous prices after the discovery of a vast oilfield in East Texas, the recently formed American Petroleum Institute (API) gradually warmed to the idea, recognising that Federal interest in conserving their product might help resuscitate its price.[92] In East Texas, where the discovery had reduced the cost of a barrel of oil to just eight cents, prices had been increased by the industry's regulator at the state level, the Texas Railroad Commission, which imposed limits on the production rate of individual wells, by force when needed.[93]

35 In 1933, under the sweeping reforms of President Franklin Roosevelt's New Deal, specifically the National Industrial Recovery Act (NIRA), the FOCB was first given power to oversee petroleum production rationing (termed "pro-rationing") in all oil producing states. However, in 1935 the Supreme Court ruled that such Federal control conflicted with anti-trust legislation. New legislation was drafted calling on individual states to oversee their own rate of petroleum production rates to avoid wasteful gluts and price gouges. All oil producing states bar California joined the resulting Interstate Oil Compact Commission.[94] The Federal government's role was significantly limited. It now simply issued monthly forecasts of expected demand, which state regulators were to consider as guidelines for their respective rates of petroleum production.[95]

36 It fell to the Federal Bureau of Mines to delimit monthly levels of petroleum demand. To make this forecast, they began with the number of registered automobiles and their average gasoline consumption. Added to this, the amount of heating oil needed was estimated according to the season. These two variables could then be calculated in crude oil equivalencies by multiplying them by a number reflecting the average efficiency of American refineries.[96] Companies could then appeal to State conservation agencies for the right to produce a proportion of this forecast demand.[97] For industry majors, well placed to lobby state regulators, this arrangement meant their petroleum could be sold at a price approximating a hypothetical equilibrium between supply and demand, even when this deviated from the reality of the situation, thereby ensuring healthy profits for the industry under the aegis of conservation.[98]

89 John Clark, *Energy and the Federal Government: Fossil Fuel Policies, 1900-1946* (Urbana and Chicago: University of Illinois Press, 1987), 100-101.
90 Federal Oil Conservation Board, Complete Record of Public Hearings, 1926, USGPO, IX.
91 *Ibid.*, 11.
92 Erich Zimmermann, *Conservation*, 252 (cf. note 65).
93 Edward Constant, "Cause or Consequence: Science, Technology and Regulatory Change in the Oil Business in Texas, 1930-1975", *Technology and Culture*, vol. 30, no 2, 1989, 432.
94 *Ibid.*, 38-39.
95 FOCB, *Complete Record*, 158-159 (cf. note 90).
96 Alfred White, "The Bureau of Mines Forecasts of Demand for Motor Fuel and Crude Oil", in National Resources Committee, Energy Resources and National Policy. 76th Congress, House Document 160 (Washington: USGPO, 1939), 403.
97 The Yale Law Journal Inc., "Proration of Petroleum Production", *The Yale Law Journal*, vol. 51, no 4, 1942, 608-628.
98 Matthew Huber, "Enforcing Scarcity: Oil, Violence, and the Making of the Market", *Annals of the Association of American Geographers*, vol. 101, no 4, 2011, 816-826.

37 In Zimmermann's view, pro-rationing meant "the petroleum industry had become ardent believers in what they chose to call conservation".[99] Writing in 1957, he acidly remarked that as a result. Conservation had become a "business proposition" rather than a government crusade. In the same stroke. The term no longer meant government intervention to avert wasteful competition, but light-touch regulation of the rate of petroleum production:

38 The meaning of conservation thus merges imperceptibly into that of the interdependent concepts of efficiency and economy, and in doing so, changes from a concept alien, if not hostile, to capitalistic thinking to one that fits painlessly into the ideology of capitalism.

39 But what were the conservational implications of this metamorphosis? Zimmermann left this question unanswered. But two decades later an oil industry lawyer gleefully asserted that, given the increased rate of extraction pro-rationing afforded in the long term, this policy had meant fifty percent *more* oil had been recovered than would have otherwise been achieved in an unregulated market.[100]

THE VEXED PROBLEM OF DEMAND

40 Writing in the 1950s, a period of historically unprecedented increases in the rate and scale of energy consumption,[101] Zimmermann lamented the care that had been taken to conserve oil at the production end when the energy consumer could still behave with careless profligacy. Nothing better demonstrated North America's commitment to thoughtless energy consumption than the heavy, under-occupied "gasoline guzzler" automobiles which increasingly populated the nation's highways. Was such freedom to waste energy "the crowning glory of all this conservation effort"?[102] In the U.S., where material and spiritual prosperity were seemingly intractably linked, he feared any attempt to constructively reduce energy consumption would provoke accusations that the government were interfering in the rights of the sovereign consumer. With heavy irony, and the wry perspective of a European émigré, he remarked that to do so "would be the end of the American way of life, the end of the American dream!"[103]

In fact, the impetus to address energy demand rather than supply would come from outside the U.S. rather than within. To understand how, it is necessary to look again at the work of the FOCB. In 1929 they had surveyed the global availability of oil and had concluded that "the development of foreign fields, through technical assistance and the further investment of American capital, would seem to be a logical conservation measure".[104] Concession agreements agreed between Anglo-American oil companies and oil-rich nations from Venezuela to Saudi Arabia in the decades after World War One had ensured that a growing stream of cheap foreign oil was being channeled into the U.S. and other developed nations. As a result, the FOCB believed a corresponding proportion of domestic reserves would be left in the ground. However, quite the opposite occurred. Between 1938 and 1955, the import of foreign oil grew from 54 to 454 million additional barrels of oil a year. While at the same time, the production of domestic crude doubled in the same seventeen-year timeframe, growing from 1.2 to 2.4 billion barrels per year.[105] An expansionist dynamic, enabled by the development of a planet-spanning infrastructure of tankers, canals, and pipelines, helped mitigate distance and drew in vast quantities of oil at a low cost.[106] 41

99 Erich Zimmermann, *World Resources and Industries*, 801 (cf. note 20).
100 Robert Hardwicke, "Adequacy of Our Mineral Fuels", *Annals of the American Academy of Political and Social Science*, vol. 281, no 1, 1952, 63.
101 Will Steffen, Wendy Broadgate, Lisa Deutsch, Owen Gaffney, Cornelia Ludwig, "The trajectory of the Anthropocene: The Great Acceleration", *The Anthropocene Review*, vol. 2, no 1, 2015, 81-98.
102 Erich Zimmermann, *Conservation*, 47 (cf. note 65).
103 *Ibid*., 48.
104 US Senate, Regulating Importation of Petroleum and Related Products. Hearing before Committee on Commerce, 71st Congress. USGPO, 1931, 278.
105 Erich Zimmermann, *Conservation*, 351, 368 (cf. note 65).
106 Donald Worster, *Shrinking the Earth: The Rise and Decline of American Abundance* (Oxford: Oxford University Press, 2016), 142-143.

42 Demonstrating the retrenchment of national thinking, Zimmermann considered the importation of foreign oil a perfectly acceptable form of conservation.[107] He would pass away in 1961, meaning the subsequent and dramatic shift in the logics of energy resource conservation would not be subject to his analysis.[108] Accordingly, our story can continue only by extending his critical approach to the notion of energy resource conservation as it developed beyond his lifetime. In doing so, we will see how the fallacious use of oil importation to conserve domestic petroleum created the conditions from which a new, demand centered approach to energy saving would emerge.

MIDDLE EASTERN PRORATIONING

43 Of course, what looked like conservation to the Global North looked like wasteful expropriation to the oil-rich Global South. In 1960 the Organization of Petroleum Exporting Countries (OPEC) was formed by five major oil producing states, who recognized that their oil was a lever to fight back against exploitative concessionary agreements.[109] Agreed earlier in the century, these agreements had robbed developing nations of their right to impose taxes on oil, effectively allowing oil companies to act as sovereign states within their own borders.[110] Recognizing the iniquity of this arrangement, a counter-movement had formed which could be broadly termed "petronationalist" in so far as its objective was to channel the wealth afforded by oil to furthering the petrostates of the Global South rather than to the benefit of Northern, developed nations.[111]

107 Erich Zimmermann, *Conservation*, 354 (cf. note 65).
108 Stephen McDonald, "Erich W. Zimmermann", 157 (cf. note 26).
109 Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela. Later joined by Qatar (1961), Indonesia (1962), Libya (1962), UAE (1967), Algeria (1969), Nigeria (1971), Ecuador (1973), Gabon (1975). On membership see Euclid A. Rose, "OPEC's dominance of the Global Oil Market: The Rise of the World's Dependency on Oil", *Middle East Journal*, vol. 58, no 3, 2004, 424-443.
110 Giuliano Garavini, *Rise*, 31 (cf. note 11).
111 *Ibid.*, 39, 65.

In 1968 OPEC outlined its aims. It wanted its member states to participate in foreign oil companies' decision-making regarding taxation and to ensure they had a role in influencing the agreed "posted" oil price. Often forgotten is that OPEC's third aim was to ensure the "efficient development and conservation of petroleum."[112] Attendees at the Sixth Arab Petroleum Congress in 1967 had been told that the "conservation of natural resources and pro-rationing of its production are an American invention".[113] Its members were well aware that they could restrict their rate oil production, in order to raise prices, just as had been done in Texas and later across the U.S.[114] OPEC's adoption of the logics of production rationing was no coincidence. Sheikh Tariki, the Saudi Petroleum Minister, had studied geology at the University of Texas.[115] While Venezuela's government had hired Texas Railroad Commission Chief Engineer Jack Baumel to help implement pro-rationing in the 1950s.[116] But these conservation initiatives went beyond mere imitation. At a meeting between OPEC members in Tehran in 1971, the president of Iran's National Oil Company Reza Fallah had suggested oil "should not be burnt up to generate energy, but conserved only for advanced technologies, as in the petrochemical industry".[117] 44

As is well known, a more radical group of Arab member states formed a more radical Organization of Arab Petroleum Exporting Countries (OAPEC), who in October 1973 imposed an embargo on the export of oil to countries seen as sympathetic to Israel.[118] This did not stop Ali 45

112 John Vafai, "Production Control in the Petroleum Industry: A Critical Analysis", *Santa Clara Lawyer*, vol. 189, 1971, 189-228.
113 *Ibid.*, 200.
114 David Prindle, *Petroleum Politics and the Texas Railroad Commission* (Texas: University of Texas Press, 1981); Giuliano Garavini, Rise (cf. note 11).
115 Fiona Venn, *Oil Crisis* (London, Longman, 2006) 36.
116 David Prindle, *Petroleum Politics*, 60 (cf. note 114); Ramón Rivas Aguilar, *Venezuela, apertura petrolera y geopolítica, 1948-1958* (Bogotá: Universidad de los Andes. 1999), 73.
117 Giuliano Garavini, *Rise*, 224 (cf. note 11); Fadhil Chalabi, *Oil Policies, Oil Myths: Observations of an OPEC Insider* (London: I.B. Taurus and co. ltd., 2010), 111-112.
118 Giuliano Garavini, *Rise*, 176 (cf. note 11).

Attiga, Libyan Secretary General of OAPEC, from appropriating the language of American conservationism to justify their actions. He later recast the embargo as a "wise decision" which had not only saved vast quantities of oil but also given "rise to an intensive worldwide search for appropriate energy policies".[119] Attiga's promotion of a vision of altruistic resource independence for both oil producer and consumer was timely. The globally influential and well-orchestrated *Limits to Growth* study, from the Club of Rome, had warned of societal collapse as a result of scarce resources.[120] As the global south effectively adopted something akin to U.S.-style pro-rationing, the growth-dependent logics of oil consuming states was shaken both by the embargo and the specter of long-term geophysical scarcity. In response to these shocks, the U.S. would begin to conserve energy from *within*, by addressing the vexed problem of energy demand.

CLOSING THE SYSTEM

46 In 1957 Zimmermann had hoped the "problem of inter-fuel relations and the still tougher problem of end uses" would eventually be addressed.[121] Not without irony, it took an external threat for North America's policy makers to begin to address energy consumption. From 1971 onward, the National Science Foundation's Research Applied to National Needs (RANN) program channeled funds into America's universities, national, and industrial laboratories in an attempt to alleviate various developmental problems, not least the seemingly inexorable increase in demand for energy that characterized the postwar period.[122] In early 1973, before the embargo, the largest tranche of RANN funding was earmarked for research into alternative forms of energy supply and determining the causes of demand.[123] As a more general energy crisis emerged, the years 1975 to 1985 were marked by unprecedented Federal investment in energy research.[124] The full story of this reorientation cannot be entered into here, but it will suffice to say that a wide range of disciplines, from physics to sociology, would take part in an indirect struggle to secure adequate energy supplies.[125] Science, as Zimmermann would no doubt have predicted, seemingly held the answer to the energy crisis.

New approaches to fuel efficiency, non-use, substitution, and even reforms to the structure of the energy economy would find legitimacy under a set of science-derived policies that were concerned with saving energy at its point of use rather than at the site of its production. Central to this achievement was an idea. North America could become, in some sense, an energy autarky: a closed-system in which domestic energy supplies were consumed with ever increased efficiency. Under President Richard Nixon's *Project Independence*, economist Eric Zausner developed an econometric model which demonstrated how small increases in the efficiency of energy use, in aggregate, could allow North America's economic growth rate to decouple from growing energy consumption, eventually allowing the nation to become entirely energy independent by 1980.[126] Such thinking was reinforced by computer simulations which recast the energy economy as a closed system, in which energy demand could be manipulated as easily as lines of a computer program.[127] In such closed models, the conservational implications of efficiency increases could be clearly quantified. 47

119 Ali Attiga, "The Impact of Energy Transition on the Oil-Exporting Countries", *Journal of Energy and Development*, vol. 4, no 1, 1978, 41-48.

120 Giuliano Garavini, *The Rise*, 214-215 (cf. note 11).

121 Erich Zimmermann, *Conservation*, 388 (cf. note 65).

122 Richard Green, Wil Lepkowski, "A Forgotten Model for Purposeful Science", *Issues in Science and Technology*, vol. 22, no 2, 2006, 69-73.

123 'J.W', "NSF gets a record $768 million", *Science*, vol. 185, no 4156, 1030.

124 Daniel Kammen, Gregory Nemet, "Reversing the Incredible Shrinking Energy R&D Budget", *Issues in Science and Technology*, vol. 22, no 1, 2005, 84-88.

125 See Thomas Turnbull, *Paradox to Policy*, Ch. 4-6 (cf. note 14).

126 Andrew McKillop, "The Myth of Decoupling", in Andrew McKillop and Sheila Newman (eds.), *The Final Energy Crisis* (London: Pluto Press, 2005), 209.

127 Paul Edwards, *Closed World: Computers and the Politics of Discourse in Cold War America* (Massachusetts: MIT Press, 1994), 341.

48 Such idealised conceptions of energy demand were popularized by physicist-turned-environmentalist Amory Lovins who, toward the end of the decade, admitted having "shamelessly recycled" vast amounts of Federally funded research to demonstrate that U.S. energy demand could be reduced by thirty to forty percent by century's end.[128] RANN funded research had helped recast the energy consumer as the ultimate conservation actor, a move unimaginable to Zimmermann in 1957. To do so, as figures from Hotelling to Ciriacy-Wantrup had long suggested, it was argued that the energy economy would have to more closely cohere to an idealized conception of a free market. In his influential book, *Soft Energy Paths,* Lovins argued that energy could best be saved by harnessing the calculative capacities of the consumer, a decisionmaker whose manipulation of "a myriad of small devices and refinements" allowed for fine-grained informational feedback on energy demand. For this to work, he claimed, "institutional barriers", the very policies which in Zimmermann's time had been considered vital means of conservation, had to be removed.[129]

49 In the 1970s, the configuration of U.S. energy policy was somewhat contradictory. Nixon's government had introduced emergency oil and gas price controls in 1971, in a bid to diffuse forecast oil price rises. While in 1972, as part of *Project Independence*, the pro-rationing system had been hastily scrapped in an attempt to increase domestic petroleum production.[130] Looking to institute a more coherent program of market liberalization, in 1981 incoming President Ronald Reagan famously argued that the energy problem was not "a shortage of oil: so much as a "surplus of government".[131] His government scrapped emergency price controls in a move, it was claimed, that would save between 50 to 100 thousand barrels of oil per day thanks to consumption deterring price rises.[132] Far from mere symbolic changes, as some claim[133], the science and politics of energy saving had undergone a dramatic transition. The systemic approach to saving energy was clearly of consequence to the organizational principles of U.S. energy economy. The liberalization of the energy markets which would take place across the global North was in part justified in accordance with a belief in the conservative capacities of the market.

CONSERVATION ENCOUNTERS CLIMATE

The problem with this closed system conception 50
was that the consequences of fossil energy consumption exceeded such abstraction. As early as 1896, physical chemist Svante Arrhenius had surmised that the carbon emitted by fossil fuels could bind with atmospheric oxygen, creating a blanket of carbon dioxide that would retain a proportion of the sun's heat. Climatologists largely ignored the idea, believing that oceans could sequester vast quantities of carbon dioxide and that atmospheric water vapour made a greater contribution to heat retention.[134] It fell to steam power engineer Guy Stewart Callendar to resuscitate the idea. In 1938, he presented a paper to Britain's sceptical Royal Meteorological Society in which he empirically demonstrated the warming effect that the 150,000 million tonnes of carbon dioxide emitted in the past fifty years had engendered. Unexpectedly, from our perspective, Callendar hoped to accelerate this warming to delay the return of "deadly glaciers".[135]

128 Amory Lovins, *Soft Energy Paths: Toward A Durable Peace* (London: Friends of the Earth International, 1977), 147.
129 *Ibid*., 19.
130 Neil De Marchi, "Energy Policy under Nixon: Mainly Putting Out Fires", in Craufurd D. Goodwin (ed.), *Energy Policy in Perspective: today's problems, yesterday's solutions* (Washington DC: Brookings Institution, 1981), 497.
131 Michael Schaller, *Right Turn: American Life in the Reagan-Bush Era, 1980-1992* (New York/Oxford: Oxford, 2007), 28.
132 Erich Zimmermann, *World Resources and Industries*, 48 (cf. note 20).
133 Rüdiger Graf, *Oil and Sovereignty: Petro-Knowledge and Energy Policy in the United States and Western Europe in the 1970s* (Berlin: Berghahn Books, 2014), 186.
134 The following largely derives from Spencer Weart's *The Discovery of Global Warming* (Cambridge Mass: Harvard University Press, 2008).
135 Guy Stewart Callendar, "The Artificial Production of Carbon Dioxide and its Influence on Temperature" (1938), in Libby Robin, Sverker Sörlin, Paul Warde (eds.), *The Future of Nature. Documents of Global Change* (Connecticut: Yale University Press, 2013), 334.

51 Callendar's thesis was received with scepticism. It was only in 1950 that Canadian physicist Gilbert Plass made use of infrared spectroscopy to reveal a far dryer stratosphere than previously thought. The role of carbon dioxide in intercepting solar radiation became more tenable. Worse still, in 1958 oceanographer Roger Revelle discovered that oceans sequestered ninety percent less carbon dioxide than assumed. The final key came thanks to Revelle's employee, geochemist Charles Keeling, who accurately measured atmospheric carbon dioxide for the first time using infrared. Within two years, he had found clear increases in global mean temperature. Keeling saw no benefit in a warming world and joined forces with the nascent environmental movement of the 1960s, warning of the risks of glacier melt and sea level rise. His advocacy gradually filtered into public consciousness and an awareness that neither sea nor sky could absorb industrialism's excesses spread. [136]

52 By the 1980s, in contrast to the 1970s, it was clear that the greater risk was not so much a lack of fossil fuels so much as the climate's limited capability to accommodate the effects of their consumption. Given that this constraint was planetary, there was no longer an elsewhere to which the consequences of fossil fuel use could be outsourced, nor a future within which the sacrifice of conservation could be deferred. But for believers in the resource-conserving capacities of increased energy efficiency, this simply meant the closed system approach to saving energy should become a global endeavour.[137] Writing in 1981, energy analyst Amory Lovins was amongst the first to promote the optimistic idea that, simultaneously, scarce fuels could be conserved, industrial productivity increased, and climate change fought against.[138] Within the closed system of Earth's atmosphere, it was argued, energy efficiency would not only reduce the rate of fossil fuel consumption, it could also reduce carbon dioxide emissions.[139]

Critics saw no such benefit. In 1980, Iraqi-American economist Daniel Khazzoom criticised efficiency-based energy conservation, and its advocates who believed such a dynamic could be "mechanically" translated "from the laboratory to society".[140] In Jevons's formulation, he argued that such reasoning failed to account for the role of price as a demand accelerant. A second scholar, Leonard Brookes, former chief economist at the United Kingdom's Atomic Energy Authority, directed the same argument at those who believed climate change could be mitigated by increased energy efficiency. Citing Jevons, Brookes claimed increased energy efficiency would cause "a reduction in its implicit price with all that that implies for demand". If action were needed to fight climate change, a threat that Brookes was sceptical about, then he argued that this should involve "specific limitations on CO_2 emissions" or "worldwide agreement to place heavy taxes on the offending fuels."[141] 53

As policies to mitigate climate change became more widespread, in 1992 economist Harry Saunders termed the renewed doubt in the conservational implications of energy efficiency that were provoked, the "Khazzoom-Brookes postulate". As he noted, the widespread acceptance of an efficiency-based approach to conservation, which had taken hold in the 1970s, meant that once orthodox principles of neoclassical economics, namely the idea that efficiency increases induce demand, now looked like a "disturbing assault" on conventional wisdom.[142] 54

136 Spencer Weart, "The Discovery of the Risk of Global Warming", *Physics Today*, vol. 50, no 134, 1997, 39.
137 Bill Keepin, Gregory Katz, "Greenhouse warming: comparative analysis of nuclear and efficiency abatement strategies", *Energy Policy*, vol. 16, no 6, 1988, 538-561.
138 Amory Lovins, Florentin Krause, Wilfrid Bach, Hunter Lovins, *Least-Cost Energy: Solving the CO2 problem* (Baltimore: Brick House Publishing Company, 1981).
139 David Rose, Marvin Miller, Carson Agnew, "Reducing the problem of global warming", *Technology Review*, vol. 87, no 4, 1984, 48-57.
140 Daniel Khazzoom, "Economic Implications of Mandated Efficiency in Standards for Household Appliances", *Energy Journal*, vol. 1, no 4, 1980, ft. 5., 22.
141 Leonard Brookes, "The greenhouse effect: the fallacies in the energy efficiency solution", *Energy Policy*, vol. 18, no 2, 1990, 199–201.
142 Harry Saunders, "The Khazzoom-Brookes Postulate and Neoclassical Growth", *Energy Journal*, vol. 13, no 4, 1992, 131-132.

A science of energy resource conservation had developed which seemingly challenged the precepts of orthodox economics while also integrating aspects of economistic thinking. Amid this epistemological confusion, the conservational implications of increased energy efficiency have yet to be conclusively determined. A recent study explains the effects of energy efficiency increases as "an emergent property of a complex system".[143] Another study asserts that "the extent of rebound effects is, in practice, always an empirical issue".[144] The more data, the more evidence of rebound which can be found. In a sentiment Zimmermann would have applauded, another still argues that "the many impacts rippling through an economy" as a result of an increase in energy efficiency exceed the confines of economic reasoning and would do better to engage with psychology and sociology, amongst other disciplines.[145]

55 As it stands, the pursuit of energy efficiency remains based upon initiatives at the national or supranational scale, such as that of the European Union or signatories to the Paris Treaty. While commendable efforts have been made, such initiatives fail to fully account for the planetary implications of energy efficiency savings, in terms of the inducement of rebound effects and the degree to which supposed decoupling of energy and economic growth discounts the energy expended in producing imported goods.[146] Perhaps the growing ubiquity of digitalization can offer a suitable metrological infrastructure to better correlate data on energy consumption and atmospheric change at this scale, but the political will to act on such evidence remains absent.[147] At root, it seems a fundamental incommensurability remains between those who favor an interventionist approach to conservation and those who place their faith in the energy-conserving capacities of a free market. As Zimmermann would likely have guessed, a century of effort has failed to resolve this fundamental question. The dynamics of saving energy remain contested, and in this state of incommensurability they require sustained historical and humanistic inquiry.

CONCLUSION

56 By revisiting and extending the insights of resource economist Erich Zimmermann, this paper has sought to formalize a subfield of energy historical inquiry focused upon the contested notion of energy saving. Like conventional "material" transitions, attempts made to save and or use energy with greater efficiency have resulted in changes in the composition, pattern, or structure of societal energy use. Which is to say, past energy saving efforts, successful or otherwise, have created new constellations of energy use and their attendant material bases and infrastructures. One need only think of the growth of electrification in pursuit of coal conservation. Alongside which, the clear shift from an interventionist approach to energy saving to one predicated upon consumers acting efficiently in an unimpeded market clearly constitutes an important if largely unacknowledged transition. As the meaning of conservation has changed, its expected means of implementation has shifted from the state and industry to the consumer acting in a market. As a result, we are currently using policies to extend the supply of (artificially) scarce energy resources, developed in the 1970s in an attempt to reduce fossil fuel emissions. This presents a mismatch between

143 Frank Geels, Benjamin Sovacool, Steve Sorrell, "Of emergence, diffusion and impact: a sociotechnical perspective on researching energy demand", in Kirsten Jenkins, Debbie Hopkins (eds.), *Transitions in Energy Efficiency and Demand* (Abingdon: Routledge, 2019), 27.

144 Alan Grant, Michelle Gilmartin, Peter G. McGregor, J. Kim Swales, Karen Turner, "Modelling the Economy-Wide Rebound Effect", in Horace Herring, Steve Sorrell (eds.), *Energy Efficiency and Sustainable Consumption: The Rebound Effect* (London: Palgrave Macmillan, 2009), 72.

145 Reinhard Madlener, Karen Turner, "After 35 years of rebound research in economics", in Tilman Santarius, Hans Jakob Walnum, Carlo Aall (eds.), *Rethinking Climate and Energy Policies: New Perspectives on the Rebound Phenomenon* (Switzerland: Springer, 2016), 32.

146 Andreas Malm, "China as Chimney of the World: The Fossil Capital Hypothesis", *Organization & Environment*, vol. 25, no 2, 2012, 146-177.

147 Paul Edwards, "Knowledge Structures for the Anthropocene", *The Anthropocene Review*, vol. 4, no 1, 2016, 34-43.

policy and objective. As the notion of unburnable carbon demonstrates, hydrocarbons are overly abundant. As such, climate change mitigation requires a new approach toward energy saving which focuses upon dramatically reducing fossil fuel emissions in line with agreed limits to atmospheric concentrations of carbon dioxide. Such a goal will likely require large scale intervention in energy markets, a requirement that history suggests is not unthinkable.

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