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Paradoxes of “Decarbonization”

David B. Spence†

Despite continuing skepticism among the ideological right about climate science,¹ scholars and policymakers continue to debate the shape of a post-carbon world, and how fast the United States can “decarbonize”² its energy sector. Decarbonization is creeping forward, pushed along by market forces and a suite of federal, state, and local policies favoring renewable energy. Federal tax credits for renewables—frequently on life support, but never dead—have long buoyed the industry,³ as has the spread of renewable portfolio standards (RPS) in the states.⁴ Together these two policy instruments have helped renewables compete against the traditional sources of electric generation (coal-fired, gas-fired, and nuclear power) for three decades, and deserve some credit for the improved efficiencies and cost reductions in wind and solar technologies over that time.

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² The terms “decarbonize” and “decarbonization” are awkward, in part because they are not the antonyms of “carbonize” and “carbonization,” which refer to the chemical process of deriving carbon from organic matter using pyrolysis. Instead, they are verbs invented to refer to the process of reducing or removing fossil fuels from the electric generation mix. As used by energy policy scholars, “deep” decarbonization usually refers to the complete elimination of fossil fuels from the generation mix.

³ For a summary of the history of tax credits, see Felix Mormann, Fading into the Sunset: Solar and Wind Energy Get Five More Years of Tax Credits with a Phase-Down, 47 TRENDS 9, 10 (2016).

⁴ Typically, a state RPS requires retailers of electric power within the state to meet their supply obligations using a specified percentage (or, in some cases, amount) of electricity from renewable sources. State Renewable Portfolio Standards and Goals, NAT’L CONFERENCE OF STATE LEGISLATORS (Dec. 28, 2016), http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx [https://perma.cc/YS3Q-J32Z]. State RPSs vary widely: each defines “renewable energy” differently and establishes different targets. For up-to-date information about state RPSs, see Database of State Incentives for Renewables & Efficiency, DSIRE, http://www.dsireusa.org [https://perma.cc/NG56-2MGJ]. For fuller explanations of state RPSs and their operation, see generally Lincoln L. Davies, State Renewable Portfolio Standards: Is There a “Race” and Is It “To the Top”? 3 SAN DIEGO J. CLIMATE CHANGE & ENERGY L. 3 (2011–2012).
More recently, two additional trends have further strengthened the decarbonization movement. First, coal-fired power is facing unprecedented regulatory and market obstacles. The shale gas revolution has ushered in an era of inexpensive natural gas for the foreseeable future, cutting into coal’s market share and causing cognitive dissonance among climate activists. Further damaging coal-fired power’s prospects are a group of Obama administration EPA rules, the most important of which address mercury and greenhouse gas emissions. Those rules would force additional closures of coal-fired power plants, and add compliance costs to natural gas-fired generators as well. The Trump administration has pledged to repeal the greenhouse gas rule, though it would likely have to replace it, and several of the rules face legal challenges. Nevertheless,


10 See Adelman & Spence, supra note 7, at 383–91 (using EPA data to project the distribution of closures of coal-fired power plants in response to these rules).

11 See e.g., Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources, 81 Fed. Reg. 35824 (June 3, 2016) (to be codified at 40 C.F.R. pt. 60) (final rule requiring oil and gas producers to mitigate methane leakage from their equipment and operations).


13 The Supreme Court struck down the MATS rule in Michigan v. EPA, 135 S. Ct. 2699 (2015) (holding that EPA’s conclusion that it need not consider costs in determining whether regulating mercury emissions from coal-fired power plants was inconsistent with the statute). On December 1, 2015, EPA reiterated its conclusion that regulating mercury as a toxic pollutant is appropriate, this time after considering costs, and signaled its intent to promulgate the rule. See Supplemental Finding that It Is Appropriate and Necessary to Regulate Hazardous Air Pollutants from Coal- and Oil-
any additional regulation of coal-fired power plant emissions should make renewables at least marginally more competitive against fossil-fueled generators in electricity markets over the long term, all else equal. Second, a few states have begun to aim even more directly and aggressively at rapidly decarbonizing their energy sectors. Both California and Minnesota have enacted aggressive low-carbon standards for their electricity sectors,14 and New York’s Reforming the Energy Vision (REV) plan has ambitions to decarbonize the New York energy mix by emphasizing distributed energy resources (DER), such as rooftop solar.15 All three states have aggressive near-term targets for renewable energy growth.16 Furthermore, recent experience integrating large amounts of wind power into the grid17 has fed optimism about rapid and “deep” decarbonization. Many proponents of the larger decarbonization project, including prominent academics18 and environmental nongovernmental


14 See CAL. HEALTH & SAFETY CODE § 38562 (West 2007); MINN. STAT. ANN. § 216H.02 (West 2007).


17 See infra notes 54–55 and accompanying text.

organizations (NGOs), believe that within the next thirty-five years it will be possible to wean the electricity sector—entirely or mostly—off of fossil-fueled generators. Some American municipalities, such as Aspen, Colorado, and Burlington, Vermont, seem to be proving this point by transitioning to “100 percent renewable energy,” while others have set explicit goals to decarbonize by 2050.

Only a few of these trends are reversible by the new president. Coal-fired power seems likely to remain more expensive than the alternatives, and the new administration has relatively little leverage over most state energy policies. Even the repeal of EPA rules is subject to statutory standards that may be difficult to meet. The decarbonization task, then, seems straightforward. First, continue to strengthen policies that promote the development and use of renewable (or zero-carbon) sources of electricity, particularly wind and solar power, and so-called demand-response (DR).

This direct approach implies continuation or expansion of renewables’ tax credits, strengthening state RPSs, requiring operators of wholesale power markets to integrate wind, solar, and DR into electricity markets on favorable terms, supporting state and local policies favorable to renewable DERs, and spreading the aggressive decarbonization policies of California, Minnesota, and New York (and Aspen...
and Burlington) to other locations. The second way to advance the cause directly is to discourage the use of fossil fuels in electricity generation. In the absence of a federal carbon tax or cap-and-trade legislation, that means defending EPA rules that disadvantage coal and natural gas, encouraging the spread of state laws that limit carbon emissions, and opposing the production and transportation of fossil fuels whenever possible.25

Unfortunately, however, encouraging the perpetual substitution of renewables for fossil fuels creates unintended consequences—paradoxes26—that stem in part from two sometimes unavoidable and underappreciated truths. First, despite recent advances in the cost of renewable energy production and electricity storage,27 it remains true that the three attributes society values in the electricity system—cost, reliability, and environmental performance—remain in tension with one another. Advancing any one value comes at the expense of the others, and there are limits to the size of the cost increases or reliability decreases the public will accept in order to improve environmental performance. Second, most of the decisions about which types of electric generators will be built, and how and when existing generators will be used to serve demand, will not be made or dictated by policymakers; rather, they will be made by private sector actors guided by economic motives. Power generation technologies compete continuously with one another on price, and the market reacts to the injection of more renewables into that competition in ways that may not always strike the popular or intended balance between reliability, cost, and environmental performance.

This article explores three sets of paradoxical consequences of rapid, deep decarbonization that emanate from these two truths. Part I describes the unique characteristics of modern American electricity markets, which have become a strange polyglot reflecting different regional choices about reliance on market forces versus government regulation. Part


26 I use the term “paradox” loosely here to refer to the fact that many of these consequences are contrary to most people’s intuitions.

II details three paradoxes of deep decarbonization: (1) the reliability-cost paradox, in which higher levels of clean, inexpensive renewable energy generation beget steps necessary to ensure system reliability, which beget both unintended environmental consequences (in competitive markets) and a feedback loop that exacerbates reliability and cost problems; (2) the health paradox, which refers to the fact that policies that discourage all fossil-fueled generation can be environmentally counterproductive, because different fossil fuels have different health and environmental consequences; and (3) the fairness paradox which focuses on the relative costliness and potentially regressive consequences of plans to use distributed generation as a path to decarbonization. Part III concludes by recommending a more realistic approach to decarbonization, one that is both more transparent about—and sensitive to—cost and reliability constraints. Because the three paradoxes imply that the shortest (and surest) route to that destination may not be a straight line, experts and policymakers ought to be more intellectually honest about the difficult tradeoffs at the heart of this transition. Policymakers do a disservice to the public when they deemphasize the potential environmental, cost, and distributional effects of their choices. That transparency, in turn, will raise the profile of cost and reliability concerns in the decarbonization debate, and may already be leading some policymakers to try to avoid some of these effects by discouraging fossil-fueled and nuclear generators from exiting the grid as renewable penetration levels increase.

I. MODERN AMERICAN ELECTRICITY MARKETS

Modern electricity markets look different today than they looked for most of their existence. Since the 1990s, the Federal Energy Regulatory Commission (FERC) has actively promoted competition in wholesale power markets by requiring investor-owned utilities (IOU) to open their transmission systems to third-party users, and by urging IOUs to form regional markets governed by Independent System Operators (ISO)28 and

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28 FERC Order 888 encouraged utilities to join together to form ISOs to manage the grid and the geographically broader markets that accompanied the move to competition in wholesale electricity markets. See Order No. 888, Promoting Wholesale Competition Through Open Access Nondiscriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities, 75 FERC ¶ 61,080 (Apr. 24, 1996). Transmission owners retained ownership of their lines when they joined the ISO, but relinquished control over their use (including pricing and scheduling of transmission services) to the ISO. Id.
Regional Transmission Organizations (RTO).

Some IOUs did so, but others did not; those in the Mountain West and Southeast opted not to do so. At the same time, some states have restructured their retail markets along similar lines, offering consumers a choice of retail power suppliers.

All this restructuring has left three basic market forms: (1) hybrid markets, characterized by competition and market pricing at the wholesale level, but with traditional public utility commission (PUC) regulation of retail prices; (2) traditional markets, in which vertically integrated utilities continue to generate most of the power they sell to their retail customers (obviating the need for a robust wholesale power market) at a PUC-regulated rate; and (3) competitive markets, characterized by market pricing and competition in both the wholesale and retail markets. Despite the heterogeneity of U.S. electricity markets, they share two common characteristics. First, in all of these markets, private companies dominate the provision of electric service: most generating facilities are built with private capital by profit-seeking companies; and most power is sold at retail by private, profit-seeking companies. Second, in all of these electricity-pricing regimes, the law requires that rates be “just and reasonable” and nondiscriminatory.

Both of these truths have important
implications for ongoing efforts to decarbonize American electricity markets.

Most people prefer clean energy, but they also want reliable, inexpensive energy, and each of us places our own (varying) weights on those three central attributes of electric service. Public utility law, however, has traditionally emphasized cost and reliability in order to protect ratepayers from suffering power outages or paying more than is necessary for power. Consequently, one of the longstanding, bedrock principles of grid management is that power plants should be dispatched on a least-cost basis. As the next increment of power is needed to satisfy additional demand, the grid operator should dispatch power from the available generating facility that can provide the needed power at the lowest marginal cost. Grid operators deviate from this least-cost rule only to ensure the security of the power system—that is, to avoid severe congestion or other operational problems associated with dispatching the least-cost unit. Thus, the grid operates on a “security constrained economic dispatch” (SCED) rule that prioritizes reliability first, costs second, and environmental performance not at all.

This rule applies both in traditionally regulated systems controlled by a single, vertically integrated IOU, and in competitive, organized wholesale markets characterized by arms-length sales between generators or wholesalers and retailers. In most competitive spot markets (which tend to be those managed by an RTO or ISO), sellers submit day-ahead bids indicating the price at which they will be willing to sell power into the system at various time increments the following day. Buyers do the same, submitting bids representing the amount they are consistent with the Federal Power Act). See Morgan Stanley Capital Grp., Inc. v. Pub. Util. Dist. No. 1, 554 U.S. 527, 530 (2008) (declining to rule on the question posed in the Lockyer and La. Energy cases).


36 Because we cannot (yet) store electricity in commercial quantities at an acceptable cost, the amount of power dispatched to the grid must be kept in balance with the amount being consumed off of the grid at all times.


38 Id.

39 For a basic description of SCED, see id.

40 See id. at 5–6 (describing SCED’s general use in the industry).
willing to pay for power during those same time increments. For each time increment, the ISO or RTO matches buyers’ and sellers’ bids and determines the market-clearing price, which all sellers will receive for power dispatched to the system during that time period.\textsuperscript{41} Theoretically, in a competitive market, sellers should bid into the market at a price that reflects their marginal cost of supplying power. In this way, the SCED rule tends to push spot market prices toward the marginal cost of the market-clearing plant.

This decision rule omits any consideration of the environmental attributes of electric power, except in so far as environmental regulation imposes compliance costs on generators, thereby influencing bidding behavior.\textsuperscript{42} Alternatively, one could incorporate a system of environmental dispatch, including “adders” representing the external costs of generation,\textsuperscript{43} but grid operators do not because many consider it inconsistent with their statutory mandate that rates be just and reasonable.\textsuperscript{44} A few states have experimented with rules requiring IOUs to consider environmental attributes in decisions about which new generation plants to build, or how to otherwise acquire wholesale power.\textsuperscript{45} Management of the externalities of electricity generation, however, is mostly left to environmental laws like the Clean Air Act\textsuperscript{46} and the Clean Water Act.\textsuperscript{47} Because some believe that environmental laws mandate levels of pollution control that fall short of those necessary to maximize social net benefits,\textsuperscript{48} the suite of federal, state, and municipal policies

\textsuperscript{41} For a brief primer on the operation of electricity spot markets, see Electricity Primer—The Basics of Power and Competitive Markets, ELEC. POWER SUPPLY ASS’N, http://www.epsa.org/industry/primer/%3Ffa=prices [https://perma.cc/BHA5-FKAW].

\textsuperscript{42} Though most of the costs of compliance fall on the capital expense side of the ledger, pollution control equipment does entail some operating costs. WILLIAM M. VATAVUK, ESTIMATING COSTS OF AIR POLLUTION CONTROL 23–30 (1991).

\textsuperscript{43} For a discussion of the literature on environmental dispatch and adders, see Hammond & Spence, supra note 35, at 197–99, 214 (discussing adders and environmental or full social cost dispatch).

\textsuperscript{44} The D.C. Circuit addressed this question peripherally in Grand Council of the Crees v. Federal Energy Regulatory Commission, 198 F.3d 950, 957 (D.C. Cir. 2000), rejecting the claim that alleged environmental harm from a power project was in the zone of interests by the statutory requirement that rates be just and reasonable. The court described those interests as purely “economic,” noting that the Supreme Court has never suggested they could or should “encompass considerations of environmental impact,” and that the FERC has “affirmatively forsworn environmental considerations.” Id.

\textsuperscript{45} See Hammond & Spence, supra note 35, at 206–07.

\textsuperscript{46} 42 U.S.C. §§ 7401–7661 (2012).

\textsuperscript{47} 33 U.S.C. § 1251 (2012).

\textsuperscript{48} This is evident from the large, positive benefit-cost ratios associated with additional regulations. For a discussion of this phenomenon, see Michael A. Livermore & Richard L. Revesz, Rethinking Health-Based Environmental Standards, 89 N.Y.U. L. REV. 1184, 1236–47 (2014) (illustrating that the benefits of rules establishing National
designed to promote renewable energy may be understood as a second best, supplemental way to reach that goal.

Regardless, the growth of renewable energy in the last decade has been nothing short of astounding. Between 2001 and 2014, wind generation in the United States grew by a factor of 30, from about 6000 gigawatt-hours (gwh) to more than 181,600 gwh.\textsuperscript{49} Utility-scale solar generation grew steadily from 543 gwh, in 2001, to about 1800 gwh in 2011.\textsuperscript{50} Since 2011, solar generation has doubled annually.\textsuperscript{51} All of this growth has occurred during a period in which electricity demand has been relatively flat.\textsuperscript{52} As noted, rapid cost reductions have fed utility-scale renewables growth,\textsuperscript{53} as have incentives like state RPSs and federal tax credits.\textsuperscript{54} While nonhydro renewables still comprise less than 10% of total generation, they sometimes comprise much larger shares of the generation mix for discrete periods of time. On December 20, 2015, wind power provided 45% of the electricity on the Texas system, a record high,\textsuperscript{55} and it has supplied significant amounts of generation in other locations for longer periods.\textsuperscript{56} Sizeable cost reductions in electricity storage technology\textsuperscript{57} would further improve the prospects for relying on renewables by addressing the intermittency problem; those reductions may or may not be on the horizon.\textsuperscript{58}

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\textsuperscript{49} See Electricity Data Browser, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/electricity/data/browser/ (data reports on file with author).

\textsuperscript{50} Id.

\textsuperscript{51} Id.


\textsuperscript{53} According to the Solar Energy Industries Association, the average price of solar generation per watt decreased from about $7.50 in 2009 to less than $3.00 in 2014. Solar Industry Data, SOLAR ENERGY INDUS. ASS’N, http://www.seia.org/research-resources/solar-industry-data [https://perma.cc/VU5Z-THNS].

\textsuperscript{54} See supra notes 3–4 and accompanying text.


\textsuperscript{57} Right now, storage is expensive. For estimates of the costs of various storage technologies, see Siraj Sabihuddin et al., \textit{A Numerical and Graphical Review of Energy Storage Technologies}, 8 ENERGIES 172, 176, 184–85, 190, 197 (2015); Andreas Poullikkas, \textit{A Comparative Overview of Large-Scale Battery Systems for Electricity Storage}, 27 RENEWABLE & SUSTAINABLE ENERGY REVIEWS 778, 786, tbl.6 (2013).

\textsuperscript{58} Theoretical and desktop breakthroughs in battery technology and cost have proven stubbornly difficult to commercialize. See STEVE LEVINE, THE POWERHOUSE: INSIDE THE INVENTION OF A BATTERY TO SAVE THE WORLD (2015) (recounting multiple theoretical breakthroughs that could not be translated into commercial success).
“behind the meter” options that would help address the intermittency problem, like demand response and rooftop solar generation, are already experiencing rapid growth. Consequently, a few states now aim for much higher levels of wind and solar penetration; New York, for example, aspires to secure 50% of its electricity from renewables by 2030, and to phase out carbon emissions by 2050. A 2016 resolution before the U.S. House of Representatives supported a national policy aiming to reduce carbon emissions from the electricity sector to zero. Some prominent academics argue that it is possible for renewables (wind, solar, and hydro) to supply 80%–100% of global energy (or U.S. energy, or energy for individual states) by 2030. At first glance, the most direct route to this kind of rapid, deep decarbonization seems to be the continuation and extension of policies that encourage the construction of ever-more renewable power, and discourage use of fossil fuels. Indeed, proponents of this direct route to decarbonization scored victories during the Obama administration, though some of those victories seem to be in the crosshairs of the Trump administration. The Trump administration has pledged repeal of two key greenhouse gas regulation rules and to “cancel” the Paris Agreement on climate change. 


60 See Bade, supra note 21.


62 See generally Jacobson & Delucchi, Part I, supra note 18; Delucchi & Jacobson, Part II, supra note 18; see also ROTH, supra note 18, at 4 (envisioning an electric grid running on 90% renewables by 2040).


65 Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. at 64,510 (standards for new sources); Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. at 64,566. This rule
mercury rule,\textsuperscript{66} cooling water rule,\textsuperscript{67} and a suite of several other recent rules, aim to advance the cause of decarbonization. In 2015, Congress extended tax credits for solar energy until 2022, and for wind energy until 2019, as part of an omnibus spending bill.\textsuperscript{68} In the states, defenders of RPSs have been largely successful fending off attempts to repeal or weaken RPSs by the American Legislative Exchange Council.\textsuperscript{69} At the state and local levels, proponents of renewables have been engaged in battles over “net metering,” the practice of crediting rooftop solar owners at the full retail price for excess power they generate and dispatch to the grid, so long as the owners are not net sellers of power over a billing period.\textsuperscript{70} Despite criticism that this practice forces the remaining grid users to subsidize rooftop solar owners’ use of the grid,\textsuperscript{71} most states, however, have retained net metering.\textsuperscript{72} Some state and local governments have also sought to decarbonize by banning or restricting oil and gas development in the wake of the hydraulic fracturing boom, arguing that this combats climate change because methane is a potent greenhouse gas that is emitted from those operations.\textsuperscript{73}

\textsuperscript{66} National Pollutant Discharge Elimination System—Final Regulations to Establish Requirements for Cooling Water Intake Structures at Existing Facilities and Amend Requirements at Phase I Facilities, 79 Fed. Reg. 48,300 (Aug. 15, 2014) (codified at 40 C.F.R. pts. 122, 125). The mercury rule would require significant reductions in mercury and other toxic air emissions from coal-fired power plants, and is projected to lead to the retirement of some plants.

\textsuperscript{67} 42 U.S.C. § 7429 (2012). This rule would limit cooling water use by power plants, including fossil-fueled plants.


\textsuperscript{69} See, e.g., Samantha Page, The Tide Is Turning Against ALEC in the Renewable Energy Battle, THINK PROGRESS (June 5, 2015), http://thinkprogress.org/climate/2015/06/05/3661566/alecs-rps-battleground/ [https://perma.cc/V9ZC-MY2M].


\textsuperscript{71} In principle, demand response programs that reward customers for reducing demand at peak periods raise the same problem, at least in hybrid and traditional jurisdictions. This problem of covering the fixed costs of the grid as more customers consume less power is sometimes referred to as the “utility death spiral.” Id. The state of Nevada has adopted an additional demand charge to be paid by rooftop solar owners to cover the cost of reliance on the grid. See NEV. ADMIN. CODE § 701B.130 (2014).


\textsuperscript{73} New York and Vermont have banned fracking, and Maryland has placed a temporary moratorium on the practice. States Take Wait and See Approach on Fracking Regulation, CONGRESS.ORG (July 9, 2015), http://congress.org/2015/07/09/states-take-wait-
Thus, electricity markets are changing rapidly, and the push toward greener electricity is being driven by a combination of market forces and public policies. Often those policies seek simply to promote renewable generation and to discourage traditional (particularly fossil-fueled) generation. That simple, direct route to decarbonization, however, may not necessarily produce a cleaner generation mix, and it may yield other consequences that voters and policymakers would prefer to avoid. Those unintended consequences are explored in the next section.

II. PARADOXES OF DECARBONIZATION

This section explores three ways in which this direct and rapid route to deep decarbonization creates paradoxical outcomes tied respectively, to (1) the tradeoff between decarbonization, on the one hand, and reliability and cost, on the other; (2) the differential health and environmental impacts associated with using renewables to displace coal versus natural gas in the electric generation mix; and (3) the distributional inequities that can arise from the way policy incentives for distributed renewables are structured in most jurisdictions. Significantly, the path toward decarbonization may be smoothed by policies that grapple directly with these paradoxes, and that recognize the need to incentivize investment in generation and storage technologies that can support renewable power—a subject explored more fully in Part III.

A. The Reliability-Cost Paradox(es)

Because wind and solar power are intermittent resources, their penetration of the market at very high levels will eventually exacerbate the demand for backup capacity, posing reliability and cost challenges for the grid. As noted above, grid operators have integrated wind generation over increasing stretches of time without too much difficulty and without jeopardizing reliability.\footnote{See supra notes 55–56 and accompanying text.} It does not follow, however, that further progress toward one hundred percent renewables will not undermine cherished cost and reliability goals, or that such a linear progression will trigger a corresponding linear decrease in carbon or other pollution...
emissions. It should be evident, for example, that in the absence of clean storage technology, municipalities like Burlington, Vermont, and Aspen, Colorado, that claim to have “gone 100 percent renewable,” do not actually consume only wind and solar power.75 Undoubtedly, both cities consume some power from the grid at times when renewable generators are not generating power in amounts necessary to satisfy their demand. What those cities do to support the “100 percent” claim is to either (1) generate renewable power for the grid in amounts equal to their consumption levels, or (2) purchase renewable energy credits representing their consumptions levels—compensating renewable generators for power actually generated and dispatched to the grid somewhere at some time.76 As more cities emulate Aspen and Burlington, bringing very high levels of renewable energy into the system, the reliability imperative will trigger a number of unintended consequences.

1. The Reliability Imperative Limits Environmental Gains

The Federal Power Act, which establishes the regulatory standards FERC applies to manage transmission and wholesale power markets, requires that the grid accommodate increasing penetration of intermittent resources in ways that prioritize energy security and cost.77 As described above, market pricing and SCED dispatch make those decisions very sensitive to changes in each generator’s relative marginal costs, including relative fuel costs.78 For fossil fuels, the continuous race to reduce costs means that, for traditional technologies, relative marginal costs are changing all the time. According to the Energy Information Administration, the variable costs of coal-fired power remain close to those of natural gas-fired power, despite the unprecedentedly low price of American natural gas in the wake of the shale revolution.79 As Figure 1 demonstrates, our historical reliance on coal-fired generation is closely tied to the price of coal relative

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76 Id.
77 See supra note 35 for an explanation of the legal origins of this requirement.
78 See supra Part I.
The ratio of the price of coal to the price of gas (on a per-Btu basis) fell between 1981 and 1988, and coal’s market share grew; the relative price climbed from 2005 to its highest level in many decades in 2012, and coal’s share of the electric generation market fell to unprecedented levels in the modern era.\textsuperscript{80} The shale revolution did indeed drive down coal’s relative position in the generation mix, but it retains a major share of that mix for the time being. Wind and solar have no fuel costs; the marginal cost of dispatching a kilowatt-hour of renewable electricity is zero, or negative when that kilowatt-hour generates a revenue under the production tax credit.\textsuperscript{81} Thus, these technologies are dispatched whenever the wind is blowing or the sun is shining, displacing other types of electric generation in the dispatch order. At the same time, this dynamic increases the demand for ancillary services—backup generation ready to dispatch power on very short notice if the wind stops blowing or the sun stops shining.


\textsuperscript{81} Daniel Gross, The Night They Drove the Price of Electricity Down, \textit{Slate} (Sept. 18, 2015), http://www.slate.com/articles/business/the_juice/2015/09/texas_electricity_goes_negative_wind_power_was_so_plentiful_one_night_that.html [https://perma.cc/7YDB-9YU3].

The environmental impacts of increasing reliance on wind (and solar) power, then, are partly a function of the resources used to back up wind (and solar) power. If a coal-fired generator is called upon to provide “spinning reserves”\textsuperscript{83} in anticipation of a sudden decline in wind generation, that coal-fired facility is burning fuel (and generating pollution) even though it is not dispatching power to the grid. The generator may also be required to ramp up and down in response to fluctuations in wind or solar generation; because coal-fired plants were not designed to ramp efficiently, ramping generates more pollution per kilowatt-hour of electricity generated.\textsuperscript{84} This means that displacement of 20% of what would otherwise be coal-fired generation does not translate to a 20% reduction in emissions from coal-fired power plants. The National Renewable Energy Laboratory has estimated that 20% penetration of wind produces pollution reductions of only a few percentage points in the eastern grid,\textsuperscript{85} and slightly more in the western grid.\textsuperscript{86} As noted above, coal faces other regulatory pressures that are causing it to exit the system, but a great deal of coal-fired capacity remains.

The cleaner the source of backup power, then, the better. Theoretically, hydroelectric power operated in storage mode\textsuperscript{87} could provide a renewable storage solution, which is how

\textsuperscript{83} “Spinning reserves” are generation sources that are up and running (e.g., burning fuel) and ready to dispatch power to the grid on short notice but are not yet doing so. Spinning Reserve, ENERGY STORAGE ASS’N, http://energystorage.org/energy-storage/technology-applications/spinning-reserve [https://perma.cc/P4E8-KR34].


\textsuperscript{87} For conventional hydroelectric facilities—those in which a river is dammed to divert water through turbines—the term “storage mode” refers to the collection of water in the reservoir behind a dam for diversion through the hyrostation’s turbines later, when the power is needed. Alternatively, one could store hydroelectric energy using a pumped storage project, which requires pumping water from a lake or river to an elevated reservoir when electricity supply exceeds demand, and running the water back down to lower elevations through turbines to generate electricity when electricity is scarce. For information about the operation of pumped storage projects, see Sabihuddin et al., supra note 57, at 177–78.
hydropower is used in northern Europe. There are, however, a limited number of projects and project sites in the United States—but certainly not enough to provide enough system back-up for an all renewables grid. Moreover, using hydropower as storage would require a change in the way most existing U.S. hydroelectric facilities are operated, one that would attract significant environmental opposition. To support renewables, hydrostations would need to allow water to collect behind the dam when renewables are generating, and draw down the reservoir by running water through the turbines when renewables are not generating. The FERC, which licenses hydroelectric projects, requires most operators to maintain hydrodam reservoirs at a constant level so as to avoid the environmental damage to the reservoir ecosystem associated with allowing the reservoir level to rise and fall. Barring strong environmental opposition, the FERC could instead sanction the construction of new pumped storage hydroelectric projects, but the question remains whether the financial prospects for such facilities (generating power only when wind and solar cannot) are sufficiently bright to induce prospective investors to build them.

Nuclear power is a very reliable zero-carbon option, but one not well suited to support intermittent resources like wind and solar. Existing nuclear power plants do not ramp up and down quickly and efficiently, and newer systems that could be used to do so seem prohibitively expensive, at least in competitive electricity markets. Nor is DR likely to be able to
provide all or most of the necessary ancillary services in an all-renewables future. The RTO offering the most generous terms for DR participation in wholesale markets is PJM, and DR comprises only a relatively small percentage of the PJM capacity market. Dynamic retail pricing, in which retail rates vary moment-to-moment with wholesale spot market rates, might produce larger reductions in demand when power is scarce and might offer a cleaner solution to the problem of sudden losses of renewable generation; however, retailers have not been particularly eager to offer dynamic retail rates to their customers, perhaps because they believe customers do not want to face the price risk associated with dynamic rates.

Finally, the environmental impacts of renewables penetration vary by region. California and the Northeast rely very little on coal-fired power. In these regions, the ancillary services used to back up wind or solar power will likely come mostly from natural gas-fired plants. The rest of the country relies more heavily on coal; therefore, coal-fired plants may be required to back up wind and solar at times. If even weakened versions of the EPA’s Clean Power Plan and mercury rule survive judicial challenge and the Trump administration, we can expect reliance on coal-fired power to continue to decline further. As long as some coal-fired plants remain cost-competitive—or are deemed necessary by grid operators to ensure the reliability of the system—coal-fired power will remain a part of the energy mix.

2. Renewables, Price, and Long-Term Reliability

Higher levels of renewables penetration can create perverse long-run incentives as well, complicating planners’ efforts to ensure long-term system reliability. The increasing participation of zero-marginal-cost sources in wholesale spot

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94 PJM, which once stood for “Pennsylvania,” New “Jersey,” and “Maryland,” now covers most of the Middle Atlantic region and significant portions of the Midwest.
98 See supra note 13 for a description of litigation challenging these rules.
markets depresses spot prices, thereby reducing long-run returns to all sellers in the market. In traditional markets this is not much of a problem because integrated IOUs are assured of earning a fair return on their prudent investments in generation—even on a seldom-used natural gas-fired power plant, for example. In hybrid and competitive markets, however, generators must earn their returns by selling power to actual customers. As spot prices decline, the possibility of earning a reasonable return on investment decreases for increasing numbers of generators. Obviously, this phenomenon discourages investment in new generation, which can eventually jeopardize system reliability—a phenomenon known as the “missing money” problem.99 This problem of attracting private capital lies at the heart of public utility regulation,100 and hangs like a shadow over hybrid and competitive markets.

Table 1 summarizes the two prominent annual estimates of the “levelized costs of energy” (LCOE) for new plants by generation technology. The LCOE represents the per-megawatt-hour (mwh) price for power that each plant must earn over its lifetime to remain profitable and so can be seen as an estimate of the plant’s long-run average costs. It is evident from the table that new utility-scale renewables enjoy cost advantages over most other new generation technologies, advantages that are enhanced by subsidies like tax credits and feed-in tariffs.101 Those advantages are multiplied by state RPSs that ensure a market for renewable power (though not for any particular wind or solar generator). Even with these advantages, however, most utility-scale renewables are built only after the execution of a power purchase agreement guaranteeing a stream of revenue to the plant over the long term.102


101 Very few U.S. states have enacted feed-in tariffs, which act as a subsidy by guaranteeing a minimum rate for the sale of power from renewable generators. For an example of a feed-in tariff statute, see CAL. PUB. UTIL. CODE § 399.32 (West 2016).

102 See Stephen L. Teichler & Ilia Levitine, Long-Term Power Purchase Agreements in a Restructured Electricity Industry, 40 WAKE FOREST L. REV. 677, 706 (2005) (describing long-term PPAs as “an integral element of competitive power markets and restructured power industries” and arguing that they should account for future changes that may occur).
Traditional generators not covered by state RPSs or other direct subsidies must find their own customers in hybrid and competitive markets. Absent some sort of market intervention to provide generators with additional returns, the missing money problem can cause underinvestment in generating capacity, jeopardizing future reliability. States and RTOs/ISOs have

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105 There are many explanations for potential underinvestment in generation. Investors may be risk averse or may be averse to uncertainty, thereby causing them to decline to make an investment with a positive expected value because of the error bars around the expected value point estimate. Investors may believe that the option value of delaying investment exceeds the value of investing. Market prices may not reflect the option value of having standby generation. As more zero-marginal-cost renewables enter the market, investors may project that the long-run spot prices (based upon marginal costs) may fall below the LCOE of any plant. All of these considerations could be at work deterring investment. See PETER CRAMTON & STEVE STOFT, THE CONVERGENCE OF MARKET DESIGNS FOR ADEQUATE GENERATING CAPACITY: A WHITE PAPER FOR THE CALIFORNIA ELECTRICITY OVERSIGHT BOARD 8–11 (2006), http://www.cramton.umd.edu/papers2005-2009/cramton-stoft-market-design-for-resource-adequacy.pdf [https://perma.cc/75B7-E3NT] (describing the missing money problem); William W. Hogan, On an “Energy Only” Electricity Market Design for Resource Adequacy 6–8 (John F. Kennedy Sch. of Gov’t, Harvard Univ., Sept. 23, 2005) (explaining the idealized energy-only model); Paul L. Joskow, Capacity Payments in Imperfect Electricity Markets: Need and Design, 16
sought to reduce that risk by intervening in hybrid and competitive markets to ensure a fair return on investment for plant owners in a variety of ways. For example, several large RTOs/ISOs run “capacity markets,” auctions through which generators agree to make capacity available to meet reserve targets in the future, for a price. By contrast, the ERCOT region in Texas is experimenting with changes to its ancillary services markets that would operate much like a very short-term capacity market. Some grid operators use less systematic methods of achieving the same result, executing so-called “reliability must run” (RMR) contracts with individual generators under which the grid operator pays the generator to be available to provide power to the system when called upon to do so. In 2016, Ohio tried to contract with owners of coal-fired power plants to ensure their continued availability in the future, but backed away from those arrangements after the FERC objected that they would distort prices on wholesale power markets. Nonetheless, Illinois and New York have considered similar arrangements to extend the useful life of nuclear power plants in those states.

These policies represent reactions to the inability of real-world competitive markets to induce sufficient investment to ensure reliability, or to ensure it to the degree that policymakers desire. As more renewables penetrate the market, they drive down spot market prices and exacerbate this problem, triggering the need for more administrative intervention into the market for new supply.

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108 Several RTOs use these sorts of contracts to ensure the availability of resources in reserve and to address potential market power problems by other generators. For an example of a model RMR contract, see ERCOT Nodal Protocols Section 22 Attachment B: Standard Form Reliability Must-Run Agreement (2015), http://www.ercot.com/content/wcm/current_guides/53528/22B_040115_Nodal.doc [https://perma.cc/2WGB-7NHD].


3. The Reliability Imperative Requires Overbuilding

The most aggressive plans for rapid, deep decarbonization seem to minimize the importance of the reliability and cost tradeoffs they will trigger. One of the more prominent plans is that advocated by Stanford University’s Mark Jacobson, who argues that the obstacles to an all-renewables grid “are social and political, [but] not . . . economic.”111 But if electricity storage remains prohibitively expensive,112 then the amount of wind, solar, and hydro necessary to satisfy baseload electricity demand will be enormous, for several reasons. First, because the capacity factors of wind and solar are much lower than those associated with dispatchable resources, it is necessary to build much more renewable (rather than traditional) capacity in order to serve any given amount of instantaneous demand.113 For simplicity, assume a system consisting entirely of wind farms operating in four zones, and intermittency limits the capacity factors of individual wind generators to 25%. That means that at any single point in time, on average, the wind is not blowing in three of the four zones. Therefore, generating capacity in any one zone must be sufficient to serve demand in all four zones. By contrast, fossil-fueled and nuclear generators have capacity factors that can exceed 90%, and so would require much less capacity to serve that same instantaneous level of demand. Second, capacity factors are averages, and there is variation around those averages. This means that even with four-times capacity in our wind-only system, there will be times when the wind is not blowing in any of the four wind production zones. This implies that an all-renewables system must be geographically broader, with even more redundant

111 Mark Jacobson: Barriers to 100% Clean Energy Are Social and Political, Not Technical or Economic, ECOWATCH (Nov. 20, 2015), http://www.ecowatch.com/mark-jacobson-barriers-to-100-clean-energy-are-social-and-political-no-1882122292.html [https://perma.cc/4Q2A-36MR]. The writer of this article explains that the dollar value of the benefits of reducing pollution from fossil fuel combustion will exceed the out-of-pocket costs of an all-renewables grid. Id. However, this argument sidesteps the question of how to induce holders of investment capital to invest in the all-renewables grid.


113 See Ted Trainer, A Critique of Jacobson and Delucchi’s Proposals for a World Renewable Energy Supply, 44 ENERGY POLY 476 (2012) (discussing the need for “large scale redundancy” in an majority renewables systems); Nathaniel Gilbraith et al., Comments on Jacobson et al.’s Proposal for a Wind, Water and Solar Energy Future for New York State, 60 ENERGY POLY 68 (2013) (alleging that rapid, deep decarbonization scenarios fail to address whether an all-renewables system “could reliably meet instantaneous electrical demand . . . throughout the year”).
systems (supported by expensive new transmission networks), to continue to meet existing high standards of reliability.\footnote{Trainer calls this the “general variability problem.” Trainer, supra note 113, at 476–77; see also Ted Trainer, 100% Renewable Supply? Comments on the Reply by Jacobson and Delucchi to the Critique by Trainer, 57 ENERGY POLY 634, 636 (2013) (“[T]he capital cost of building enough turbines at all the places where the wind might be strong when it is not blowing anywhere else would be unaffordable.”).}

Thus, while LCOE estimates capture the relative cost of providing power from more generators representing a larger total capacity, such estimates may not fully capture the transmission costs of a disbursed system, the need for redundant generation to provide energy storage, or the political obstacles to building a bigger system. Such a system requires many more transmission lines, and additional generation devoted entirely to charging batteries or other storage devices to ensure a reliable electricity supply.\footnote{See Trainer, supra note 113 for a discussion of system redundancy.} Will ratepayers be willing to fund the construction of a system with that much additional capacity? One scholar estimates that the costs of redundancy would be ten times the cost of the existing system.\footnote{Trainer, supra note 114, at 638. Based on data from California and Germany, J.P. Morgan estimates the costs at less than two times the cost of the existing system, excluding transmission investment. J.P. MORGAN, A BRAVE NEW WORLD: DEEP DECARBONIZATION OF ELECTRICITY GRIDS 1–2 (2015), https://www.jpmorgan.com/jpmpdf/1320687247153.pdf [https://perma.cc/X35W-BBFW].} One rejoinder to the cost problem is that the costs of the current system exclude the externalities associated with fossil fuel generation.\footnote{See Mark Z. Jacobson & Mark A. Delucchi, Response to Trainer’s Second Commentary on a Plan to Power the World with Wind, Water, and Solar Power, 57 ENERGY POLY 641, 641 (2013), http://web.stanford.edu/group/efmh/jacobson/Articles/I/13-2ndRespEnergyPolicy.pdf [https://perma.cc/84Q8-MBZ4] (“[T]he annualized social cost of a system that reliably delivers electricity is the relevant metric for comparing energy systems rather than the capital cost alone.”). For estimates of the social costs of fossil generation, see infra Section II.B.} In assessing the \textit{welfare} effects of different energy systems, this rejoinder is correct, though most estimates of the cost of pollution externalities associated with electricity generation fall well short of the magnitudes associated with building an all-renewables system.\footnote{See infra Section II.B for an estimate of the cost impacts of fossil fuel generation.} Welfare effects aside, however, the more practical question is whether private capital will be willing to invest in such a system. Unless—and until—an omniscient planner or an optimal pollution tax internalizes the externalities of fossil-fueled generation in the price of electricity, the prospects for attracting sufficient capital to support an all-renewables grid seem dim at best.

What if the market were to experience a technological great leap forward, such that the price of renewables plus
storage drops sharply enough that each is comparable to traditional generation alternatives? That would still not completely solve the cost-redundancy problem. That is, even with economical storage options, wind and solar facilities would still need to produce enough power to satisfy current demand (while the wind is blowing and the sun is shining) and to charge batteries or other storage devices that would be used to satisfy demand later, when renewable power is unavailable. An all-renewables system will be more expensive than traditional generation because it will require more backup power (from storage), and because the LCOE of storage exceeds the LCOE of traditional, more reliable generation technologies.\footnote{Lazard, supra note 112.} It seems unlikely that either the market or mandates will produce enough storage to achieve the requisite reliability standards in an all-renewables grid, suggesting the need for backup power from dispatchable resources.

That is why even with geographic breadth and system redundancy, most deep decarbonization proposals recognize a continuing need for dispatchable resources on the system to kick in during those rare periods when renewables cannot serve demand.\footnote{In its 2015 analysis of deep decarbonization of the electric grid, J.P. Morgan’s first major conclusion was:}

> A critical part of any analysis of high-renewable systems is the cost of backup thermal power and/or storage needed to meet demand during periods of low renewable generation. . . . [A]s a result, levelized costs of wind and solar are not the right tools to use in assessing the total cost of a high-renewable system.

J.P. Morgan, supra note 116, at 1.

One leading proposal contemplates the continued existence of large amounts of natural gas-fired generation on the all-renewables grid that would almost never be used.\footnote{See, e.g., Elaine K. Hart & Mark Z. Jacobson, A Monte Carlo Approach to Generator Portfolio Planning and Carbon Emissions Assessments of Systems with Large Penetrations of Variable Renewables, 36 Renewable Energy 2778, 2788 (2011) (“The low carbon systems described in this study require very large capacities of dispatchable generation with very low capacity factors.”).} That acknowledgment begs the question: who will own and build natural gas-fired power plants that will almost never be used? In a system that depends upon private capital to fund energy infrastructure, it is naïve to expect investors to pay for the pipelines that supply natural gas to those rarely used plants, or to build the hydrostations that are to be operated only as backups for wind and solar. Nor can we expect private investment in other dispatchable resources, like nuclear power stations.\footnote{The J.P. Morgan analysis concluded that despite the relative costliness of nuclear power today, grids that retain 35% nuclear power to complement renewables} Will the government provide this service if the market
will not? If not, we might anticipate that the existing coal-fired power plants that remain on the system may be dispatched to backup wind and solar under the SCED rule, rather than more expensive DR or hydro.

In sum, rapid, deep decarbonization plans seem to overlook or downplay their reliability and cost consequences, and those consequences, in turn, can reduce the environmental benefits of the plans (depending on which technologies are used to support intermittent renewable resources). Rapid, deep decarbonization requires the political will to intervene in electricity markets in ways that preempt the SCED rule, and that impose significant costs on ratepayers to ensure the reliability of the electric system. The political will to do so could develop, but it does not seem imminent.

B. The Health Paradox

A second paradox of decarbonization stems from its proponents’ focus on reducing greenhouse gas (GHG) emissions, climate change, and the corresponding failure to distinguish between GHGs and the other byproducts of fossil fuel combustion. As Table 2 indicates, all fossil fuel combustion is not alike. Rather, there is an important distinction to be made between decarbonization, on the one hand, and protecting health and the environment, on the other.

TABLE 2. Pollution Rates, Coal- and Gas-Fired Power Plants (lbs/billion Btu)\textsuperscript{123}

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen Oxides</th>
<th>Sulfur Dioxide</th>
<th>Fine Particles</th>
<th>Mercury</th>
<th>Carbon Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>457</td>
<td>2,591</td>
<td>2,744</td>
<td>0.016</td>
<td>208,000</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>92</td>
<td>0.6</td>
<td>7</td>
<td>0</td>
<td>117,000</td>
</tr>
</tbody>
</table>

If one’s focus is exclusively on climate change, then there is at least an argument that natural gas-fired power plants and coal-fired power plants ought to be treated equally, and that reduced use of either is an unequivocal environmental good. Despite the fact that coal combustion emits about twice

as much carbon dioxide as natural gas combustion, there is a legitimate dispute over whether substituting natural gas-fired power for coal-fired power represents a climate change benefit, since methane, another potent greenhouse gas, leaks into the atmosphere as part of the natural gas production industry. The Environmental Defense Fund is currently undertaking a portfolio of studies aimed at measuring methane leakage from natural gas production activities. These and other studies are beginning to fill in our understanding of methane leakage rates in natural gas production systems. Preliminary results from those studies show a wide variety of leakage rates in different parts of the country and different parts of the industry. The bulk of the evidence, however, points toward average leakage rates below the rate at which the climate change harm done by reliance on natural gas equals that associated with reliance on coal for electric generation. However, the jury is still out on this question. Importantly, recently enacted and proposed EPA rules addressing methane leakage in the natural gas production system ought to eventually reduce these leakage rates considerably, if those rules survive the presidential transition.

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127 *See Andrew Burnham et al., Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum*, 46 ENVTL. SCI. & TECH. 619 (2012) (concluding that the life-cycle GHG emissions from natural gas combustion are about a third lower than those associated with coal combustion); Nathan Hultman et al., *The Greenhouse Impact of Unconventional Gas for Electricity Generation*, 6 ENVTL. RES. LETTERS 1 (2011) (concluding that the life-cycle GHG emissions from natural gas combustion are about 56% of those associated with coal combustion); Francis O’Sullivan & Sergey Paltsev, *Shale Gas Production: Potential Versus Actual Greenhouse Gas Emissions*, 7 ENVTL. RES. LETTERS 1 (2012) (concluding that emissions of GHGs from hydraulic fracturing have not significantly altered the GHG profile of the natural gas industry); David T. Allen et al., *Measurements of Methane Emissions at Natural Gas Production Sites in the United States*, 110 PNAS 17768 (2013) (concluding that emissions from natural gas production sites using reduced emission completions were well below EPA estimates); Christopher L. Weber & Christopher Clavin, *Life Cycle Carbon Footprint of Shale Gas: Review of Evidence and Implications*, 46 ENVTL. SCI. & TECH. 5688 (2012) (concluding that emissions of GHGs from hydraulic fracturing have not significantly altered the GHG profile of the natural gas industry).

Climate effects aside, quantitative risk assessments of the harm done by non-GHG pollutants emitted by fossil fuel combustion indicate that those other pollutants are at least as harmful as GHG emissions. EPA’s cost-benefit analysis of its Clean Power Plan (CPP) values the emissions reductions triggered by the CPP at between $19 and $51 billion, depending on the discount rate and the compliance methods used.\(^{129}\) At a 5% rate, the benefits of GHG reductions by 2025 total $6.4 billion; at a 3% rate those benefits equal $20 billion.\(^{130}\) In any case, the benefits associated with non-GHG emissions dominate EPA’s estimates of harms averted by the rule, and are significant and almost entirely associated with coal-fired power, not gas-fired power. Indeed, perhaps the best-kept secret in the popular energy policy debate is just how much more deadly coal-fired power is than natural gas-fired power. By most estimates, coal combustion kills more than 10,000 Americans (and millions of non-Americans) prematurely each year.\(^{131}\) A succession of studies in recent years from the National Academy of Sciences,\(^{132}\) health experts,\(^{133}\) and economists\(^{134}\) have quantified the uniquely devastating impacts of coal combustion. If we were to include the harm to health and the environment from coal-fired power in the price of coal-fired electricity, it would increase that price by

\(^{129}\) EPA, REGULATORY IMPACT ANALYSIS FOR THE CLEAN POWER PLAN FINAL RULE ES-20–ES-21 (2015). Because the harm attributed to climate change is further in the future than the harm attributable to other pollutants, estimates of the dollar value of GHG-related harm are larger when the discount rate (the rate at which future dollars are discounted against current dollars) is smaller.

\(^{130}\) Id. at ES-20.

\(^{131}\) See, e.g., Paul R. Epstein et al., Full Cost Accounting for the Life Cycle of Coal, 1219 ANNALS N.Y. ACAD. SCI. 73, 91 (2011) (citing a 2010 Clean Air Task Force Report putting the number of American fatalities at 13,000 “due to air pollution from all electricity generation in 2010”). Researchers at NASA and Columbia University estimate that nuclear power has averted 1.84 million air pollution-related deaths worldwide that would have resulted from fossil fuel combustion but for reliance on nuclear energy. See Pushker A. Kharecha & James E. Hansen, Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power, 47 ENVTL. SCI. & TECH. 4889, 4891 (2013).


\(^{133}\) See Epstein et al., supra note 131, at 93 (estimating the cost of national reliance on coal for energy at hundreds of billions of dollars annually over its full life cycle).

\(^{134}\) See Nicholas Z. Muller et al., Environmental Accounting for Pollution in the United States Economy, 101 AM. ECON. REV. 1649 (2011).
approximately 35% (more than 3.5 cents/kwh); the comparable number for natural gas combustion is 5% (0.5 cents/kwh).\textsuperscript{135}

This matters because, as Figure 1 indicates,\textsuperscript{136} natural gas and coal compete within the electric generation mix. In much of the country, coal’s losses are natural gas’s gains and vice versa. Indeed, Germany’s clean energy policy, the \textit{Energiewende}, has demonstrated clearly that the aggressive promotion of renewables does not necessarily imply reduced carbon emissions.\textsuperscript{137} German policies that disadvantage nuclear power\textsuperscript{138} and gas-fired power\textsuperscript{139} have forced Germany to continue to burn large amounts of coal for electricity in order to maintain system reliability, even as the country aggressively incentivized renewables. Like Germany, the United States has a large stock of existing coal-fired generating capacity ready to be dispatched each day when the price is right;\textsuperscript{140} the fate of that coal capacity is much more closely tied to its relative competitiveness with existing natural gas-fired plants than to its relationship to renewables. Therefore, proponents of decarbonization ought to shed the assumption that all policies that discourage the use of natural gas will produce environmental gains. Sometimes they will, and sometimes they will not.

C. \textit{The Fairness Paradox}

Some commentators\textsuperscript{141} and policymakers\textsuperscript{142} see distributed energy resources, particularly rooftop solar and DR, as central

\begin{itemize}
  \item \textsuperscript{135} \textit{Id.} at 1670, tbl.5.
  \item \textsuperscript{136} \textit{See supra} Figure 1.
  \item \textsuperscript{140} The average American coal-fired power plant is more than forty years old, meaning that the original capital investments in many of those plants have long since been paid off. \textit{See} Steven Mufson, \textit{Vintage U.S. Coal-Fired Power Plants Now an ‘Aging Fleet of Clunkers’}, \textit{WASH. POST} (June 13, 2014), https://www.washingtonpost.com/business/economy/a-dilemma-with-aging-coal-plants-retire-them-or-restore-them/2014/06/13/8914780a-f00a-11e3-914c-1fbd0614e2d4_story.html?utm_term=.eca5dfdb85a9 [https://perma.cc/8FHA-WNHV]. They can therefore offer relatively inexpensive power to the market. \textit{See} Adelman & Spence, \textit{supra} note 7, 153 tbl.3.
  \item \textsuperscript{141} For a recent discussion of this literature, \textit{see} Shelley Welton, \textit{Clean Electrification}, \textit{88 U. COLO. L. REV.} 571 (2017).
  \item \textsuperscript{142} New York’s “Reforming Energy Vision” initiative is the most prominent of the state policies. \textit{See} Order Adopting Regulatory Policy Framework and Implementation Plan.
elements of a decarbonized grid. As “behind-the-meter” options become more affordable, they can break the stronghold IOUs have on electricity generation in hybrid and traditional markets. Traditional ratemaking provides IOUs with little incentive to invest in renewables, and many traditional markets lack RPSs and the market for renewable power they create. Furthermore, state law in some hybrid and traditional markets inhibits non-IOU, third-party ownership of rooftop solar power. In all these ways, the IOU retail monopoly can prevent or slow decarbonization. In competitive states, by contrast, advocates of decarbonization see DER (and DR) as a way to promote their goal more affordably, by avoiding the costs of building expensive transmission lines to bring utility-scale renewables to the grid.

Decarbonization through DER, however, poses a fairness problem in most traditional and hybrid states. In competitive states, unbundling implies that customers pay separately for
power and delivery of power, and those payments go to different companies. But in hybrid and traditional states, monopoly IOUs impose a single charge on their customers reflecting both the payment for power consumed and payment for the service of delivering the power (which includes the customer’s share of the fixed costs of operating the grid). The customer pays a single, bundled rate based on the amount of power consumed. Under such a system, however, the portion of the grid investment dedicated to serving a particular customer does not necessarily track the amount of power that customer consumes, especially when customers begin to generate their own power.

The problem arises when rooftop solar owners who pay bundled rates are compensated at the full retail price for power they no longer consume. This is what happens in a so-called “net-metering” regime: customers pay the retail rate only for their net consumption. Under net metering, customers with rooftop solar arrays consume much less power, and contribute much less to the cost of maintaining the grid, even though they remain connected to the grid and can consume power from the grid whenever they need it. When their solar panels fail, or the sun does not shine, customers continue to consume power from the grid (using grid capacity) at the prior levels, but they will be paying for that capacity at a reduced level—one reflecting their (now lower) monthly volumetric consumption of power.147 The vast majority of states compensate rooftop solar owners for power using this sort of net-metering regime.148

Critics of net metering argue that this is a subsidy paid to rooftop solar owners by other customers, and that rooftop solar owners ought to pay a demand charge reflecting the portion of the grid dedicated to their use.149 A few traditional and hybrid states have adopted these so-called “demand charges,” but calculating demand charges is not always straightforward. For example, assume that I install a solar panel on my roof, and my average instantaneous peak demand on summer afternoons decreases from $N$ kW to $N/4$ kW, because my solar panels provide power


148 Welton, supra note 141, at 574 (more than forty states employ net metering in this way).


formerly purchased from the grid. That average instantaneous peak, \( N/4 \) kW, represents an instantaneous demand of 0 kW on 75% of summer afternoons, and instantaneous demand of \( N \) kW on 25% of afternoons (when the sun is not shining). What should my demand charge be? Should it reflect \( N \) kW or \( N/4 \) kW of capacity usage?

Defenders of net metering argue that critics—utilities, in particular—are merely trying to discourage investment in renewables, particularly distributed renewables.\(^{151}\) They argue, further, that rooftop solar adopters confer benefits on the system in the form of (1) cleaner power, which inures to the benefit of everyone as it displaces dirtier fossil fuel energy, and (2) improved system reliability, by reducing (afternoon) peak demand and, thereby, the probability of an outage.\(^{152}\) Therefore, they say, net metering is a fair method of compensating these providers for their services. A small minority of jurisdictions have adopted a middle ground approach, namely, “value of solar tariffs” (VOST), which compensates rooftop solar owners for the power they dispatch to the grid at a rate less than the full retail rate, but typically greater than the wholesale power rate. The VOST typically reflects some credit for the environmental and reliability benefits of rooftop solar.\(^{153}\) The environmental benefits conferred by rooftop solar panels, however, are spread far beyond the utility’s service area, raising questions about whether other grid customers actually capture the benefits the rooftop solar owner is conferring. Similarly, one can challenge the argument that rooftop solar enhances the reliability of the distribution system, since in many places rooftop solar generation is unavailable during the latter portions of the afternoon peak, creating balancing challenges for grid operators.\(^{154}\)

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152 For a discussion of the fairness issue, and common rejoinders to the claim that net metering poses fairness concerns, see Welton, supra note 141. See Rule, supra note 151 (arguing that other cross-subsidies are common, and accepted, within electric rates).


Furthermore, even if the total benefits of distributed solar generation exceed the total costs, under either net metering or VOSTs, the remaining ratepayers on the utility’s portion of the grid are left to pay larger shares of the fixed costs of maintaining the grid, strengthening the incentive of others to install distributed energy resources, or DERs.155 Because rooftop solar adopters tend to have higher incomes than other customers, net metering (and, to a lesser extent, VOSTs) are regressive policies.156 As net metering and other incentives continue to promote rooftop solar generation, more relatively wealthy customers pay a declining share of the fixed costs of maintaining the grid, leaving those costs to a shrinking set of customers unable or unwilling to invest in rooftop solar. This is decarbonization’s fairness paradox, and it is part of what has become known in the electricity industry as “the utility death spiral.”157

III. TOWARD A MORE SOPHISTICATED PATH TO DECARBONIZATION

The direct route to rapid, deep decarbonization—policies that simply subsidize or promote unending renewable generation—produces unintended consequences. On the one hand, the environmental benefits of ever-more renewables will be few in parts of the country where coal-fired power backs up

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156 See Order Adopting Regulatory Policy Framework, supra note 142, at 2 (“[T]he trend toward affordability of self-generation threatens to create an unacceptable gap between those who can choose to leave the grid and those who cannot, with implications for the obligation to ensure reasonably priced and reliable service.”). But cf. Welton, supra note 141 (arguing that DER also serves other participatory values and that policymakers can incentivize opportunities for less wealthy customers to participate in DERs).

157 See BRONSKI ET AL., supra note 155, at 11. The death spiral encompasses at least two potential dynamics triggered by high levels of renewables penetration. The first is the fairness paradox associated with renewable DERs described here. If a large number of customers generate most of their own power and do not pay a charge to maintain the grid, net metering leaves a dwindling number of customers relying on the grid for electricity, paying increasing shares of the cost of maintaining the grid. The second focuses on the way utility-scale renewables decrease spot power prices in spot markets, described supra Section II.A.1. Theoretically, if zero-marginal-cost resources come to dominate the grid, long-run average spot prices could be pushed to levels lower than the long-run average cost incurred by every generator, making investment in power generation a losing proposition absent additional payments to ensure the availability of capacity. This scenario is analogous to the “death spiral” problem faced by the precursor to the California Public Utilities Commission in the mid-twentieth century, when streetcars (whose rates the CPUC then regulated) faced increasing competition from other forms of transportation. The streetcar company sought a rate increase necessary to recover their costs from a dwindling customer base. The courts ultimately declined to use public utility law to insulate the streetcars from competitive pressures See Market St. Ry. Co. v. R.R. Comm’n, 324 U.S. 548 (1945).
renewables. On the other hand, as renewables penetration hits very high levels, there will be a reckoning—in the form of either reduced service reliability, or higher costs, or both. Most of these paradoxes can be avoided by a clean energy strategy that retains focus on utility-scale renewables growth supported by generation technologies that some may find environmentally objectionable: new gas-fired, nuclear, or storage-mode hydropower.

Some of the proponents of a route to decarbonization that discourages both gas-fired and nuclear power seem insufficiently sensitive to these paradoxes. They may instead be betting on rapid technological and cost advantages in storage technology that would obviate the need for backup generation.\textsuperscript{158} Grid-scale storage could include batteries, compressed air storage,\textsuperscript{159} flywheels,\textsuperscript{160} and the aforementioned pumped storage hydroelectric power. Consumer-scale storage would include mostly batteries or some forms of thermal storage.\textsuperscript{161} Can we rely on technological optimism, that if we mandate storage or otherwise create the extreme need for storage by phasing out reliable generating plants, the market will provide clean, affordable storage?

Certainly, environmental law has a long history of establishing aggressive goals so as to force technological change and increase cost efficiencies. The Clean Air Act, for example, is based on this logic, and experience with that statute suggests room for optimism about the industry’s ability to comply with aggressive targets in affordable ways. Historically, ex ante industry estimates of compliance costs have sometimes been orders of magnitude higher than actual costs.\textsuperscript{162} Environmental NGOs and other proponents of a renewables-only strategy may have this experience in mind when advocating for a system without natural

\textsuperscript{158} Storage could be used in conjunction with DR, as well. But DR represents a small resource in percentage terms. One estimate puts DR potential at about 29 GW, representing less than 3% of the generating capacity of the grid. Robert Walton, \textit{U.S. Demand Response Potential Grows to 29 GW}, UTIL DIVE (Jan. 5, 2015), http://www.utilitydive.com/news/us-demand-response-potential-grows-to-29-gw/348409/ [https://perma.cc/C5GM-XZQA]. Moreover, most existing DR comes from nonresidential customers, many of whom employ alternate generation sources (some fossil-fueled) in lieu of purchases from the grid.

\textsuperscript{159} For a description of how compressed air energy storage works, see \textit{Compressed Air Energy Storage (CAES)}, ENERGY STORAGE ASS’N, http://energystorage.org/compressed-air-energy-storage-caes [https://perma.cc/KA3N-4JQM].


\textsuperscript{161} For a description of how distributed thermal storage might work, see \textit{Thermal}, ENERGY STORAGE ASS’N, http://energystorage.org/energy-storage/storage-technology-comparisons/thermal [https://perma.cc/H9DL-DNHE].

gas or nuclear power. As renewables command a larger share of
generation, a few states (California, for example) will force more
grid-scale storage on the system, others (New York, for example)
seem likely to encourage much more DER growth. Both states
rely extensively on natural gas-fired power to back up renewables
now. For states hoping to wean themselves off of nuclear or gas-
fired power, Germany offers a cautionary tale. The unavailability
of nuclear and gas-fired power to back up renewables has slowed
Germany’s efforts to reduce reliance on coal-fired power, and its
electricity costs are about three-times the U.S. average when
subsidies are included in the price.

Thus, the tradeoffs between cost, reliability, and
environmental performance seem unavoidable. Even if one
assumes great leaps forward in electricity storage technology
to solve the reliability problem, deep decarbonization will still be
expensive. It will entail huge investments in transmission and
redundant generation to compensate for the lower capacity
factors of renewable generators and to charge batteries.
Distributed generation seems unlikely to offer enough capacity
to fully (or at least significantly) mitigate that problem. For
that reason, in most places, during the transition toward ever-
more renewables, grid operators will find ways to ensure that
there is central station generation ready and available when
renewables go offline. That may mean compensating existing
generators on the system to remain on the system beyond the
time they would otherwise shut down. In some parts of the
country, the available existing facilities will be coal-fired; in
others, they may be gas-fired or nuclear facilities. Worries
about future reliability may be driving New York’s decision to
offer incentives to extend the life of nuclear plants in the
state, and discussions of “reregulation” in Ohio and Michigan.

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163 See discussion of state plans to rely on DERs and DR, supra note 142.
164 Natural gas-fired generators ramp up and down efficiently and quickly, and
natural gas dominates each state’s electricity generation mix. See U.S. States: State Profiles
165 Average Electricity Prices Around the World: $/kWh, OVO ENERGY, https://
perma.cc/HG7Q-5UGH].
166 PIETER GAGNON ET AL., NAT’L RENEWABLE ENERGY LAB., ROOFTOP SOLAR
PHOTOVOLTAIC TECHNICAL POTENTIAL IN THE UNITED STATES: A DETAILED
ASSESSMENT, at vi–vii (2016) (estimating that as much as 39% of total U.S. electric generation could
come from distributed renewables).
[https://perma.cc/UZU7-HQUV] (describing price supports for two nuclear plants in New
York State).
Grid operators can try to ensure reliability using ad hoc arrangements with individual plants. But it would be better if policymakers tackled these reliability and cost questions head-on, and chose their favored transition paths with explicit recognition of the potential environmental, cost, and distributional effects of their choices. Otherwise, they could do more environmental harm than good during the transition. They could redistribute costs from rich to poor. They could compromise reliability (unlikely), or impose more costs on ratepayers than necessary to achieve the same environmental benefit during the transition (likely). Most voters, and most of their elected representatives, are not electricity policy experts. To the contrary, they rely on experts to help them understand the important dimensions of a transition to a decarbonized electricity future. To avoid the unintended consequences implied by the three paradoxes, experts should frame their analyses in ways that enable voters and elected officials to understand the tradeoffs in concrete terms.

For example, given the out-of-pocket cost to ratepayers of a rapid transition to an all-renewables grid, it is misleading to suggest that the obstacles to that transition are “not...economic.” Politicians and ratepayers deserve to know not only that the dollar value of the averted pollution harm exceeds the cost of investment in new renewable generation, transmission lines, storage, and rarely used back up generation. They also deserve to know what those out-of-pocket costs will be, and the extent to which estimates of those costs depend upon optimism about the relative costs of clean technologies in the future, or about the ability to secure siting approval for the necessary plants and transmission lines. They deserve to know how policies that discourage natural gas-fired generation and nuclear generation may affect system reliability and their out-of-pocket costs, and how those options compare to reliance on storage or other technologies to back up renewable generation. They deserve to know whether discouraging gas-fired and nuclear power now may slow the decline of coal-fired generation in the future and the health and environmental

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169 See Mark Jacobson: Barriers to 100% Clean Energy Are Social and Political, Not Technical or Economic, supra note 111. This is based on the notion that the averted pollution harm has a higher dollar value than the cost of implementing an all-renewables grid.
consequences of that choice. They deserve to know how the benefits and costs of net-metering policies are distributed across (and beyond) a utility’s distribution system.

Advocates of deep decarbonization would do well to be transparent about how they propose to make tradeoffs between cost, reliability, and environmental performance, particularly in the wake of the 2016 presidential election, which many have interpreted as a populist revolt against “liberal elites.” Policies that increase ratepayers’ out-of-pocket costs in order to reduce environmental costs may seem logical or sensible to some, but not to others. Moreover, the way individuals value these tradeoffs seems likely to be correlated with wealth. A relatively wealthy person may place a higher value on a clean environment than a poor person, and may be more willing to spend a larger sum of money to secure that benefit because that sum represents a smaller portion of her disposable income. And a relatively wealthy person may be more willing to accept a less reliable electric grid because she is better able to afford behind-the-meter backup power. That is, deep decarbonization involves decisions about tradeoffs that liberal elites might make quite differently from others.

While most experts acknowledge these tradeoffs in principle, the discussion becomes less transparent as it moves from analysis to advocacy. Advocates of renewable technologies may believe they have little to gain from transparency, or from acknowledging the attractive aspects of competing technologies or the unattractive aspects of their preferred technologies. For example, as discussed above, natural gas-fired generation is an affordable, flexible, and reliable complement to renewable generation; but inexpensive gas-fired power drives down electricity spot prices (and, therefore, revenue) for all electric generation technologies, not just coal-fired power. When natural gas prices increase, or when gas-fired power exits the system, all the competing electric generation technologies benefit, including coal-fired power. Nor do wind and solar firms benefit from a focus on the reliability of their more expensive zero-emission competitors—storage-mode hydroelectric power and nuclear power. Rather, they are satisfied with a market that makes cost distinctions, but not reliability distinctions, between different zero-emission technologies.

CONCLUSION

Thanks to market forces and state policies, decarbonization seems likely to proceed apace, despite the presidential transition.
How quickly and how deeply the U.S. grid decarbonizes remains a point of contention. Thus far, grid operators have managed to incorporate much larger percentages of renewable power than they anticipated. But the reckoning—hard choices about reliability-cost tradeoffs associated with very high levels of renewables penetration—is coming eventually. We will be better prepared to handle the reckoning later if we make policy decisions now with that objective in sight. The direct route to rapid, deep decarbonization seems to sidestep or ignore the reckoning, or relies on technological or economic breakthroughs that may never come to pass. When planning the path to a clean energy future, the shortest distance between two points may not be a straight line.