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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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1 *See, e.g.*, Ned Resnikoff, *Senate Committee Again Debates Existence of Climate Change*, MSNBC (Jan. 30, 2014), http://www.msnbc.com/all/senate-republicans-what-climate-change [https://perma.cc/7MWM-BNU5] (in which Senator Jim Inhofe repeated his view that climate change science is a hoax).

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,[5] cutting into coal's market share and causing cognitive dissonance among climate activists.[6] Further damaging coal-fired power's prospects are a group of Obama administration EPA rules,[7] the most important of which address mercury[8] and greenhouse gas emissions.[9] Those rules would force additional closures of coal-fired power plants,[10] and add compliance costs to natural gas-fired generators as well.[11] The Trump administration has pledged to repeal the greenhouse gas rule, though it would likely have to replace it,[12] and several of the rules face legal challenges.[13] Nevertheless,

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[5] *Annual Energy Outlook 2015*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/forecasts/aeo/data/browser/#/?id=14-AEO2015 [https://perma.cc/3MXH-P2AJ] (discussing future natural gas prices).

[6] Alison Ciaccio, *Coal Is Losing the Battle for the U.S. Market—Badly*, BLOOMBERG (Mar. 9, 2016), http://www.bloomberg.com/news/articles/2016-03-09/coal-is-losing-the-battle-for-the-u-s-market-badly [https://perma.cc/25J5-FF3] (chronicling the coal-fired generation's decline).

[7] For a summary of these rules, see David E. Adelman & David B. Spence, *Ideology vs. Interest Group Politics in U.S. Energy Policy*, 95 N.C. L. REV. 339 (2017).

[8] This rule is known as the "mercury and air toxics," or "MATS" rule. *See* National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units, 77 Fed. Reg. 9304, 9306 (Feb. 16, 2012) (codified at 40 C.F.R. pt. 63, subpart UUUUU).

[9] EPA's GHG regulation program is known as the Clean Power Plan, and comprises a new rule establishing emissions standards for new fossil-fueled power plants, as well as guidelines for the establishment of state standards regulating GHG emissions from existing fossil-fueled plants. *See* Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64510, 64512 (Oct. 23, 2015) (to be codified at 40 C.F.R. pt. 60, subpart TTTT) (standards for new sources); *see* Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64662 (Oct. 23, 2015) (codified at 40 C.F.R. pt. 60) (covering existing sources).

[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).

[12] Tatiana Schlossberg, *What to Know About Trump's Order to Dismantle the Clean Power Plan*, N.Y. TIMES (Mar. 27, 2016), https://www.nytimes.com/2017/03/27/science/what-to-know-about-trumps-order-to-dismantle-the-clean-power-plan.html?_r=0 [https://perma.cc/SBT3-23MU].

[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 grid[17] has fed optimism about rapid and "deep" decarbonization. Many proponents of the larger decarbonization project, including prominent academics[18] and environmental nongovernmental

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Fired Electric Utility Steam Generating Units, 80 Fed. Reg. 75025, 75026, 75027, 75028 (Dec. 1, 2015) (to be codified at 40 C.F.R. pt. 63). Twenty-seven states have challenged the Clean Power Plan in court. Jennifer A. Dlouhy & Andrew M. Harris, *Obama's Clean Power Plan Heads to Court: What to Know*, BLOOMBERG (Sept. 23, 2016), https://www.bloomberg.com/news/articles/2016-09-23/obama-s-clean-power-plan-heads-to-court-what-to-know [https://perma.cc/4UZE-ST6L]. The plaintiffs' motion to stay the effect of the rule pending their legal challenge was rejected by the D.C. Circuit in early 2016. Order at 2, West Virginia v. EPA, No. 15-1363 (D.C. Cir. Jan. 21, 2016), http://www.ago.wv.gov/publicresources/epa/Documents/Order%20granting%20expedition%20and%20declining%20stay%20(M0116449xCECC6).pdf [https://perma.cc/462R-RV5H].

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

15 *See* Courtney Fairbrother & Dan Cross-Call, *New York's Plan to Reach 50 Percent Renewable Energy*, GREENBIZ (Feb. 23, 2016), https://www.greenbiz.com/article/new-yorks-plan-reach-50-percent-renewable-energy [https://perma.cc/8QW6-35G6].

16 For California RPS targets, see *RPS Compliance & Reporting*, CAL. PUB. UTILS. COMM'N, http://www.cpuc.ca.gov/General.aspx?id=3856 [https://perma.cc/WE6W-PLJ2]. *See* MINN. DEP'T OF COMMERCE, MINNESOTA RENEWABLE ENERGY STANDARD: UTILITY COMPLIANCE 2–3 (Jan. 15, 2015), https://www.leg.state.mn.us/docs/2015/mandated/150096.pdf [https://perma.cc/U348-CVYM] (describing the Minnesota RPS targets). For a good summary of the New York RPS, see *History of the NYS Renewable Portfolio Standard*, NYSERDA, http://programs.dsireusa.org/system/program/detail/93 [https://perma.cc/5DTV-YVMQ] (summarizing the New York RPS).

17 *See infra* notes 54–55 and accompanying text.

18 *See generally* Mark Z. Jacobson & Mark A. Delucchi, *Providing All Global Energy with Wind, Water, and Solar Power, Part I: Technologies, Energy Resources, Quantities and Areas of Infrastructure, and Materials*, 39 ENERGY POL'Y 1154 (2011) (discussing the feasibility and characteristics of a system that would provide worldwide energy entirely from wind, water, and sunlight) [hereinafter Jacobson & Delucchi, *Part I*]; Mark A. Delucchi & Mark Z. Jacobson, *Providing All Global Energy with Wind, Water, and Solar Power, Part II: Reliability, System and Transmission Costs, and Policies*, 39 ENERGY POL'Y 1170 (2011) (suggesting that worldwide energy could be provided solely by wind, water, and sunlight by 2030) [hereinafter Delucchi & Jacobson, *Part II*]; *see also* RHYS ROTH, CTR. FOR SUSTAINABLE INFRASTRUCTURE, REWIRING THE NORTHWEST'S ENERGY INFRASTRUCTURE: AN INTEGRATED VISION AND NEW INVESTMENT STRATEGY (2016), https://evergreen.edu/sites/default/files/sustainableinfrastructure/docs/Energy-Report-2016.pdf [https://perma.cc/YRL2-2NX4] (envisioning an electric grid running on 90% renewables by 2040); MATTHEW WRIGHT & PATRICK HEARPS, ZERO CARBON

organizations (NGOs),[19] 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,"[20] while others have set explicit goals to decarbonize by 2050.[21]

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).[22] 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,[23] supporting state and local policies favorable to renewable DERs, and spreading the aggressive decarbonization policies of California,[24] Minnesota, and New York (and Aspen

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AUSTRALIA STATIONARY ENERGY PLAN, AUSTRALIAN SUSTAINABLE ENERGY (2011) (offering a "10 year roadmap" to all-renewable electricity in Australia).

[19] GREEN PEACE INT'L ET AL., ENERGY [R]EVOLUTION: A SUSTAINABLE WORLD ENERGY OUTLOOK (4th ed. 2012); *Club: No More Gas Fired Power Plants*, SIERRA CLUB ATL. CHAPTER (Jan. 19, 2016), https://atlantic2.sierraclub.org/content/club-no-more-gas-fired-power-plants [https://perma.cc/5T8Y-2UT9].

[20] Erica Robbie, *Aspen Is Third U.S. City to Reach 100% Renewable Energy*, ASPEN TIMES (Sept. 1, 2015), http://www.aspentimes.com/news/17972193-113/aspen-is-third-us-city-to-reach-100 [https://perma.cc/BWE4-9BBD] (reporting on both Aspen's and Burlington's all-renewables policies).

[21] *See, e.g.*, Gavin Bade, *New York Assembly Approves Climate Bill to Eliminate Greenhouse Gases*, UTIL. DIVE (June 3, 2016), http://www.utilitydive.com/news/new-york-assembly-approves-climate-bill-to-eliminate-greenhouse-gas-emissio/420315/ [https://perma.cc/VT9S-YJJH].

[22] During high demand periods when reserve margins are constrained, DR can be used to avoid peaks in demand and the sharp spikes in wholesale spot market prices they cause. Because of the way electricity spot markets work, DR can have the effect of reducing the amount that other sellers of power are paid for power they sell. For a fuller explanation of spot market pricing, see *infra* note 41 and accompanying text.

[23] Recent orders by the Federal Energy Regulatory Commission (FERC) have required just this. *See* Integration of Variable Energy Resources, 139 FERC ¶ 61,246 (June 22, 2012) (codified at 18 C.F.R. pt. 35) (requiring grid operators to integrate wind and solar generation on relatively favorable terms); Demand Response Compensation and Organized Energy Markets, 134 FERC ¶ 61,187 (Mar. 15, 2011) (codified at 18 C.F.R. pt. 35) (requiring grid operators to compensate providers of DR on relatively favorable terms).

[24] California's renewable energy plan comprises a suite of laws and regulatory initiatives. *See California Renewable Energy Overview and Programs*, CAL. ENERGY COMM'N, http://www.energy.ca.gov/renewables/ [https://perma.cc/2GVX-4WVX].

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—paradoxes[26]—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

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25 Most national environmental NGOs, including Sierra Club, NRDC, and the Union of Concerned Scientists seem to be pursuing this strategy. *See, e.g.*, Andrea Issod, *Setting the Record Straight About EPA's Long Overdue Rule Eliminating Clean Air Act Loopholes*, SIERRA CLUB (Aug. 17, 2015), http://sierraclub.org/environmental law/planet/2015/08/setting-record-straight-about-epa-s-long-overdue-rule-eliminating-clean-air-act [https://perma.cc/6GH3-KAW5]; Brendan Pierson, *Sierra Club Seeks to Defend Calif. Emissions Limits*, LAW360 (Apr. 1, 2010), https://www.law360.com/energy/articles/159367/sierra-club-seeks-to-defend-calif-emissions-limits [https://perma.cc/7S2S-SS6D].

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.

27 Björn Nykvist & Måns Nilsson, *Rapidly Falling Costs of Battery Packs for Electric Vehicles*, 5 NATURE CLIMATE CHANGE 329, 329 (2015).

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

[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).[29] Some IOUs did so, but others did not; those in the Mountain West and Southeast opted not to do so.[30] At the same time, some states have restructured their retail markets along similar lines, offering consumers a choice of retail power suppliers.[31]

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;[32] (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.[33] Second, in all of these electricity-pricing regimes, the law requires that rates be "just and reasonable" and nondiscriminatory.[34] Both of these truths have important

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[29] FERC's Order 2000 established the parameters for creating regional transmission organizations. *See generally* Order No. 2000, Regional Transmission Organizations, 89 FERC ¶ 61,285 (Dec. 20, 1999). RTOs operate similarly to ISOs. FERC originally hoped that RTOs would be much broader geographically such that the entire country might be covered by as few as four RTOs. However, we now use the terms RTO and ISO interchangeably. *See* FEDERAL REGULATORY DIRECTORY: THE ESSENTIAL GUIDE TO THE HISTORY, ORGANIZATION, AND IMPACT OF U.S. FEDERAL REGULATION 180 (16th ed. 2014).

[30] For a map of existing ISOs and RTOs (and, by implication, of places where utilities declined to form ISOs or RTOs), see *Regional Transmission Organizations (RTO)/Independent System Operators (ISO)*, FED. ENERGY REGULATORY COMM'N, http://www.ferc.gov/industries/electric/indus-act/rto.asp [https://perma.cc/F7KM-9N6U] (last updated Jan. 11, 2017).

[31] *See Electricity*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/electricity/policies/restructuring/restructure_elect.html [https://perma.cc/7RLN-48K2].

[32] This kind of rate regulation establishes rates at a level from which the utility retailer can recover its costs plus a fair return on any prudent investments in capital made for the provision of electric service. *See* JOEL B. EISEN ET AL., ENERGY, ECONOMICS AND THE ENVIRONMENT: CASES AND MATERIALS ch. 8 (4th ed. 2015).

[33] For a basic description of electricity markets, see *Electric Power Markets: National Overview*, FED. ENERGY REGULATORY COMM'N, http://www.ferc.gov/market-oversight/mkt-electric/overview.asp [https://perma.cc/3QLF-SADL] (last updated Feb. 29, 2016).

[34] *See* Federal Power Act, 16 U.S.C. § 824d (2012). State public utility laws contain analogous requirements for retail rates. *See e.g.*, 16 TEX. ADMIN. CODE § 25.242(k) (2009). For a discussion of how the just and reasonable standard is reconciled with market pricing, see California *ex rel.* Lockyer v. Fed. Energy Regulatory Comm'n, 383 F.3d 1006, 1013 (9th Cir. 2004) and La. Energy & Power Auth. v. Fed. Energy Regulatory Comm'n, 141 F.3d 364, 365 (D.C. Cir. 1998) (both approving market-based rates as

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.[35] Consequently, one of the longstanding, bedrock principles of grid management is that power plants should be dispatched on a least-cost basis.[36] 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.[37] 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.[38] Thus, the grid operates on a "security constrained economic dispatch" (SCED) rule[39] 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.[40] 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

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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).

[35] The Federal Power Act and its state analogues require that prices be fair to consumers—"just and reasonable," in statutory parlance. *See* 16 U.S.C. § 824d (2012). Grid operators and courts alike have interpreted this requirement to imply least-cost dispatch. For a discussion of the law governing the relationship between the just and reasonable standard and the environmental costs of power, see Emily Hammond & David B. Spence, *The Regulatory Contract in the Marketplace*, 69 VAND. L. REV. 141, 197–201 (2016).

[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.

[37] FED. ENERGY REGULATORY COMM'N, SECURITY CONSTRAINED ECONOMIC DISPATCH: DEFINITION, PRACTICES, ISSUES AND RECOMMENDATIONS 5 (2006), http://www.ferc.gov/industries/electric/indus-act/joint-boards/final-cong-rpt.pdf [https://perma.cc/WR8X-HGU6].

[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.[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.[42] Alternatively, one could incorporate a system of environmental dispatch, including "adders" representing the external costs of generation,[43] but grid operators do not because many consider it inconsistent with their statutory mandate that rates be just and reasonable.[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.[45] Management of the externalities of electricity generation, however, is mostly left to environmental laws like the Clean Air Act[46] and the Clean Water Act.[47] Because some believe that environmental laws mandate levels of pollution control that fall short of those necessary to maximize social net benefits,[48] the suite of federal, state, and municipal policies

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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].

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).

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).

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.*

45 *See* Hammond & Spence, *supra* note 35, at 206–07.

46 42 U.S.C. §§ 7401–7661 (2012).

47 33 U.S.C. § 1251 (2012).

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.[49] Utility-scale solar generation grew steadily from 543 gwh, in 2001, to about 1800 gwh in 2011.[50] Since 2011, solar generation has *doubled* annually.[51] All of this growth has occurred during a period in which electricity demand has been relatively flat.[52] As noted, rapid cost reductions have fed utility-scale renewables growth,[53] as have incentives like state RPSs and federal tax credits.[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,[55] and it has supplied significant amounts of generation in other locations for longer periods.[56] Sizeable cost reductions in electricity storage technology[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.[58] So-called

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Ambient Air Quality Standards almost always exceed costs and establish standards that fall short of the standard that maximizes net benefits).

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

50 *Id.*

51 *Id.*

52 Katherine Tweed, *U.S. Electricity Demand Flat Since 2007*, IEEE SPECTRUM (Feb. 6, 2015), http://spectrum.ieee.org/energywise/energy/environment/us-electricity-demand-flat-since-2007 [https://perma.cc/4YVQ-9TGE].

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].

54 *See supra* notes 3–4 and accompanying text.

55 Robert Fares, *Texas Sets All-Time Wind Energy Record*, SCI. AM. (Jan. 14, 2016), http://blogs.scientificamerican.com/plugged-in/texas-sets-new-all-time-wind-energy-record/ [https://perma.cc/THF7-VL2Y].

56 *American Wind Power Breezes Past 70-Gigawatt Milestone*, AM. WIND ENERGY ASS'N. (Dec. 21, 2015), http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=8255 [https://perma.cc/93VG-VPLX].

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

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.[59] 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.[60] 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.[61] 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.[62]

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.[63] At the national level, the Obama EPA's Clean Power Plan,[64] New Source Performance Standards for fossil-fueled generators,[65]

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[59] *See* V.S.K. Murthy Balijepalli et al., *Review of Demand Response Under Smart Grid Paradigm* 1 (2011), http://desismartgrid.com/wp-content/uploads/2012/07/review_of_demand_response_vskmurthy.pdf [https://perma.cc/6X8R-XYH6]; SOLAR ENERGY INDUS. ASS'N, SOLAR ENERGY FACTS: Q2 2015 (2014), http://www.seia.org/sites/default/files/Q2%202015%20SMI%20Fact%20Sheet.pdf [https://perma.cc/T7L5-SQJF].

[60] *See* Bade, *supra* note 21.

[61] H.R. Res. 540, 114th Cong. (2015).

[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).

[63] The Trump administration has pledged repeal of two key greenhouse gas regulation rules and to "cancel" the Paris Agreement on climate change. *See supra* note 13 (regarding repeal of the Clean Power Plan and the Paris Agreement); Paul A. Eisenstein, *Trump Rolls Back Obama-Era Fuel Economy Standards*, NBC NEWS (Mar. 16, 2017), http://www.nbcnews.com/business/autos/trump-rolls-back-obama-era-fuel-economy-standards-n734256 [https://perma.cc/CUA6-Y5JS].

[64] *See* Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64,510 (Oct. 23, 2015) (to be codified at 40 C.F.R. pt. 60, subpart TTTT) (standards for new sources); Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64,566 (Oct. 23, 2015) (covering existing sources) (to be codified at 40 C.F.R. subpart. UUUU). The Clean Power Plan would mandate significant reductions in greenhouse gas emissions from existing fossil-fueled power plants. Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. at 64,510; Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. at 64,566.

[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,[66] cooling water rule,[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.[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.[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.[70] Despite criticism that this practice forces the remaining grid users to subsidize rooftop solar owners' use of the grid,[71] most states, however, have retained net metering.[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.[73]

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would require significant reductions in greenhouse gas emissions from new fossil-fueled power plants.

[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.

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

[68] *See generally* Chris Nelder & Mark Silberg, *Congress Extends the Renewable Investment Tax Credit: What Now*, GREENBIZ (Dec. 28, 2015), https://www.greenbiz.com/article/congress-extends-renewable-investment-tax-credit-what-now [https://perma.cc/N742-C7TV].

[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].

[70] Kevin Karges, *Net Metering: Do Non-Solar Homeowners and Utility Companies Have a Legitimate Gripe?*, ARIZ. J. ENVTL. L. & POL'Y 1017, 1021 (2014), http://www.ajelp.com/wp-content/uploads/Karges11.pdf [https://perma.cc/32NB-YTNY].

[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).

[72] For the Solar Energy Industry Association's tracking of state net-metering policies, see *Issues & Policies*, SOLAR ENERGY INDUS. ASS'N, http://www.seia.org/policy/distributed-solar/net-metering [https://perma.cc/7SWA-AZN4].

[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.[74] 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

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and-see-approach-on-fracking-regulation/ [https://perma.cc/PJJ2-XAK2]. Hundreds of local communities have banned the practice as well. *Id.* For a good summary of the role of methane as a greenhouse gas, see *Overview Of Greenhouse Gases: Methane Emissions*, EPA, https://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html [https://perma.cc/MHF3-JTX4].

[74] *See supra* notes 55–56 and accompanying text.

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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[75] Wilson Ring, *100% of Power for Vermont City Now Renewable*, BOS. GLOBE (Sept. 15, 2014), https://www.bostonglobe.com/metro/2014/09/14/vermont-milestone-green-energy-efforts/fsLHJl4eoqv6QoFNewRYBK/story.html [https://perma.cc/MA4G-9XYS] (confirming that "all renewable" does not mean that all the power consumed by the city comes from renewable sources).

[76] *Id.*

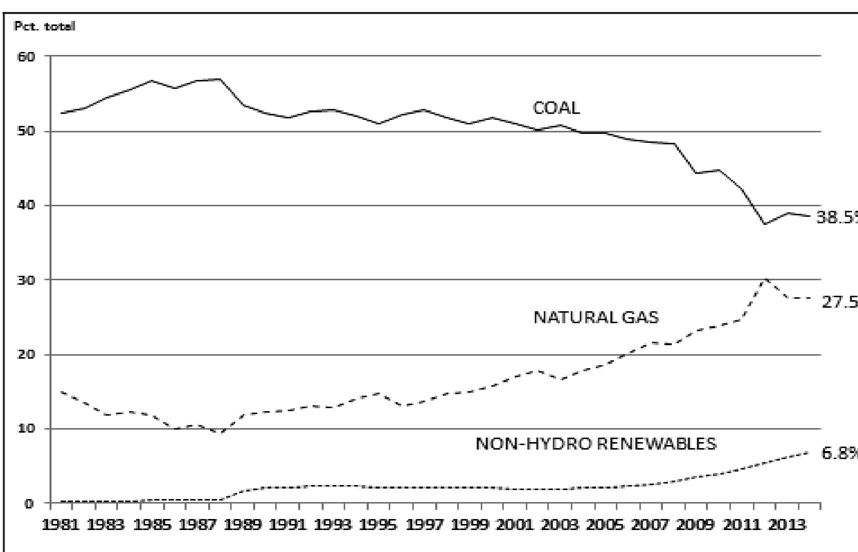
[77] *See supra* note 35 for an explanation of the legal origins of this requirement.

[78] *See supra* Part I.

[79] U.S. ENERGY INFO. ADMIN., LEVELIZED COST AND LEVELIZED AVOIDED COST OF NEW GENERATION RESOURCES IN THE ANNUAL ENERGY OUTLOOK 2015, at 6 tbl.1 (2015), https://www.eia.gov/forecasts/archive/aeo15/pdf/electricity_generation_2015.pdf [https://perma.cc/FA4N-YFWB].

to gas. 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.[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.[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.

FIGURE 1. Share of U.S. Electric Utility Generation by Fuel, 1981–2014 (%)[82]



[80] Gordon Pickering et al., *The Phenomenon of Coal-to-Gas Switching*, WESTERN ENERGY, Fall 2012, http://digital.apogee-mg.com/article/The_Phenomenon_Of_Coal-To-Gas_Switching/1241762/135766/article.html [https://perma.cc/9CK5-9JA5].

[81] Daniel Gross, *The Night They Drove the Price of Electricity Down*, 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].

[82] *See Electric Power Monthly*, U.S. ENERGY INFO. ADMIN. (Dec. 23, 2016), https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_2 [https://perma.cc/D8LB-LJUD].

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"[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.[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,[85] and slightly more in the western grid.[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[87] could provide a renewable storage solution, which is how

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[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].

[84] *See* MIT ENERGY INITIATIVE, MANAGING LARGE-SCALE PENETRATION OF INTERMITTENT RENEWABLES 26–27 (2011), http://energy.mit.edu/wp-content/uploads/2012/03/MITEI-RP-2011-001.pdf [https://perma.cc/4XGU-CQ2V] (describing cycling and ramping); *Wind Integration: Does It Reduce Pollution and Greenhouse Gas Emissions?*, INST. FOR ENERGY RESEARCH (June 23, 2010), http://instituteforenergyresearch.org/analysis/wind-integration-does-it-reduce-pollution-and-greenhouse-gas-emissions/ [https://perma.cc/STJ8-UPEK] (explaining how ramping coal-fired plants emits more pollution).

[85] *See* ENERNEX CORP., EASTERN WIND INTEGRATION & TRANSMISSION STUDY: EXECUTIVE SUMMARY AND PROJECT OVERVIEW 27 (2011), http://www.nrel.gov/docs/fy11osti/47086.pdf [https://perma.cc/2DGH-YQ84].

[86] GE ENERGY, WESTERN WIND AND SOLAR INTEGRATION STUDY ES-14–ES-15 (2010), http://www.nrel.gov/docs/fy10osti/47434.pdf [https://perma.cc/F283-5N2V]; BENTEK ENERGY LLC, HOW LESS BECAME MORE . . . WIND, POWER AND UNINTENDED CONSEQUENCES IN THE COLORADO ENERGY MARKET 8–9 (2010), https://docs.wind-watch.org/BENTEK-How-Less-Became-More.pdf [https://perma.cc/RD6W-66VB].

[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 hydrostation'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.[88] 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.[89] 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.[90] Barring strong environmental opposition, the FERC could instead sanction the construction of new pumped storage hydroelectric projects,[91] 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,[92] and newer systems that could be used to do so seem prohibitively expensive, at least in competitive electricity markets.[93] Nor is DR likely to be able to

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88 *See* EURELECTRIC, HYDRO IN EUROPE: POWERING RENEWABLES 7–8 (2011), http://www.eurelectric.org/media/26690/hydro_report_final-2011-160-0011-01-e.pdf [https://perma.cc/7CNN-AGD3] (describing how European hydro stations are operated in storage mode to support intermittent generation and to follow variations in load).

89 DOUGLAS G. HALL & RANDY D. LEE, IDAHO NAT'L LAB., ASSESSMENT OF OPPORTUNITIES FOR NEW UNITED STATES PUMPED STORAGE HYDROELECTRIC PLANTS USING EXISTING WATER FEATURES AS AUXILIARY RESERVOIRS (2014), http://hydropower.inel.gov/resourceassessment/d/pumped-storage-hydro-assessment-report-published-version-20mar14.pdf [https://perma.cc/3ES8-GHPQ] (summarizing the untapped storage potential in the United States and discussing barriers to its development).

90 ROCÍO URÍA-MARTÍNEZ ET AL., U.S. DEP'T OF ENERGY, 2014 HYDROPOWER MARKET REPORT 30 (2015), http://www.energy.gov/sites/prod/files/2015/04/f22/2014%20Hydropower%20Market%20Report_20150424.pdf [https://perma.cc/X9J7-Q947] ("For the most part, new projects will be operated as run-of-river, with limited flexibility.").

91 *See generally Pumped Storage Projects*, FED. ENERGY REGULATORY COMM'N, http://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp [https://perma.cc/8QYY-G9RX] (last updated Apr. 18, 2016) (describing the functionality and capabilities of pumped storage projects and noting that the FERC has approved twenty-four pumped storage projects).

92 *See* MIT ENERGY INITIATIVE, *supra* note 84, at 11 (describing the cycling and ramping rates for various technologies).

93 *See* Peter Taberner, *Licensing Process to Catapult US-SMR Export Potential*, NUCLEAR ENERGY INSIDER (Jan. 28, 2015), http://analysis.nuclearenergy

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,[94] and DR comprises only a relatively small percentage of the PJM capacity market.[95] 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.[96]

Finally, the environmental impacts of renewables penetration vary by region. California and the Northeast rely very little on coal-fired power.[97] 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,[98] 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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insider.com/small-modular-reactors/licensing-process-catapult-us-smr-export-potential [https://perma.cc/2Y2L-SGL5].

[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.

[95] *See* FED. ENERGY REGULATORY COMM'N, ASSESSMENT OF DEMAND RESPONSE & ADVANCED METERING: STAFF REPORT 12 tbl.3-3 (2015), http://www.ferc.gov/legal/staff-reports/2015/demand-response.pdf [https://perma.cc/JN2G-S2XJ].

[96] For a discussion of these issues, see Ahmad Faruqui & Jennifer Palmer, *Dynamic Pricing and Its Discontents*, REGULATION, Fall 2011, at 16, https://object.cato.org/sites/cato.org/files/serials/files/regulation/2011/9/regv34n3-5.pdf [https://perma.cc/2SDG-ECBA].

[97] This conclusion comes from a review of state energy profile data assembled by the U.S. Energy Information Administration, see *U.S. States: State Profiles and Energy Estimates*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/state/ [https://perma.cc/P27C-HT8U].

[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]

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[99] *See* PETER CRAMTON & STEVEN STOFT, THE CONVERGENCE OF MARKET DESIGNS FOR ADEQUATE GENERATING CAPACITY 8–11 (2006), http://www.cramton.umd.edu/papers2005-2009/cramton-stoft-market-design-for-resource-adequacy.pdf [https://perma.cc/V6JJ-SLR7] (describing the missing money problem); WILLIAM W. HOGAN, CTR. FOR BUS. & GOV'T, ON AN "ENERGY ONLY" ELECTRICITY MARKET DESIGN FOR RESOURCE ADEQUACY 5–8 (2005) (explaining an idealized energy-only model).

[100] For a description of how and why this problem loomed large in the crafting of the earliest public utility laws, see William Boyd, *Public Utility and the Low-Carbon Future*, 61 UCLA L. REV. 1614, 1642–43 (2014).

[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).

TABLE 1. Levelized Cost of Energy Estimates, U.S. Energy Information Administration[103] and Lazard,[104] ($/mwh)

	EIA (point estimate)	Lazard (range)
Coal	95	65–150
Natural Gas—Combined Cycle	75	52–78
Nuclear	95	97–136
Hydroelectric	83	
Wind (onshore)	73	32–77
Solar PV (average)	125	
Solar PV—rooftop		184–300
Solar PV—utility scale		58–70

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.[105] States and RTOs/ISOs have

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[103] U.S. ENERGY INFO. ADMIN., WIND AND SOLAR DATA AND PROJECTIONS FROM THE U.S. ENERGY INFORMATION ADMINISTRATION: PAST PERFORMANCE AND ONGOING ENHANCEMENTS (2016), http://www.eia.gov/forecasts/aeo/supplement/renewable/pdf/projections.pdf [https://perma.cc/V4HH-JDXC].

[104] LAZARD, LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 9.0, at 13–14 (2015), https://www.lazard.com/media/2390/lazards-levelized-cost-of-energy-analysis-90.pdf [https://perma.cc/LUJ8-WAX5].

[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.[106] 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.[107] 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.[108] 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.[109] Nonetheless, Illinois and New York have considered similar arrangements to extend the useful life of nuclear power plants in those states.[110]

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.

UTIL. POL'Y 159 (2008) (arguing that the missing money problem can never be fully ameliorated, even with freely floating prices).

[106] For a discussion of capacity markets and other interventions designed to alleviate the missing money problem, see David B. Spence, *Naïve Energy Markets*, 92 NOTRE DAME L. REV. 973 (2017).

[107] *See Project 40000*, PUB. UTIL. COMM'N OF TEX., http://www.puc.texas.gov/industry/projects/electric/40000/40000.aspx [https://perma.cc/UE2N-V994] (providing information and documents).

[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].

[109] Jonathan Crawford, *AEP, FirstEnergy Face U.S. Review of Ohio Power Plant Contracts*, BLOOMBERG (Apr. 27, 2016), http://www.bloomberg.com/news/articles/2016-04-27/aep-firstenergy-face-u-s-review-of-ohio-power-plant-contracts [https://perma.cc/7UPA-BN4H].

[110] *See* Rebecca Smith, *Exelon Moves to Close Two Illinois Nuclear Plants*, WALL ST. J. (June 2, 2016), http://www.wsj.com/articles/exelon-moves-to-close-two-illinois-nuclear-plants-1464873850 [https://perma.cc/56WR-JEC8]; Robert Walton, *NY Gov. Cuomo: State Will Fight Entergy Plans to Shutter FitzPatrick Nuclear Plant*, UTIL. DIVE (Nov. 5, 2015), http://www.utilitydive.com/news/ny-gov-cuomo-state-will-fight-entergy-plans-to-shutter-fitzpatrick-nuclea/408667/ [https://perma.cc/53N7-UFWN].

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

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[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.

[112] Lazard published its first ever estimates of the levelized costs of storage in 2015, finding all forms of storage to be more expensive than gas-fired peaker plants. *See* LAZARD, LAZARD'S LEVELIZED COST OF STORAGE ANALYSIS—VERSION 1.0, at 9, 18 (2015), https://www.lazard.com/media/2391/lazards-levelized-cost-of-storage-analysis-10.pdf [https://perma.cc/85UT-7LEJ].

[113] *See* Ted Trainer, *A Critique of Jacobson and Delucchi's Proposals for a World Renewable Energy Supply*, 44 ENERGY POL'Y 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 POL'Y 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.[114]

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.[115] 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.[116] One rejoinder to the cost problem is that the costs of the current system exclude the externalities associated with fossil fuel generation.[117] In assessing the *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.[118] 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

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[114] 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 POL'Y 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.").

[115] See Trainer, *supra* note 113 for a discussion of system redundancy.

[116] 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 DE-CARBONIZATION OF ELECTRICITY GRIDS 1–2 (2015), https://www.jpmorgan.com/jpmpdf/1320687247153.pdf [https://perma.cc/X35W-BBFW].

[117] *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 POL'Y 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.

[118] See *infra* Section II.B for an estimate of the cost impacts of fossil fuel generation.

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.[119] 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.[120] 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.[121] 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.[122] Will the government provide this service if the market

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[119] *See* LAZARD, *supra* note 112.

[120] 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.

[121] *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.").

[122] 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 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)[123]

	Nitrogen Oxides	Sulfur Dioxide	Fine Particles	Mercury	Carbon Dioxide
Coal	457	2,591	2,744	0.016	208,000
Natural Gas	92	0.6	7	0	117,000

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

would be considerably less expensive than an all-renewables grid. *See* J.P. MORGAN, *supra* note 116, at 9–10.

[123] This data was taken from ENERGY INFO. ADMIN., NATURAL GAS 1998: ISSUES AND TRENDS 58 (1999), https://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/natural_gas_1998_issues_trends/pdf/it98.pdf [https://perma.cc/DU2A-NT6M].

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,[124] 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.[125] 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.[126] 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.[127] 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.[128]

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[124] For a summary of this debate, see David B. Spence, *The Political Economy of Local Vetoes*, 93 TEX. L. REV. 351, 366–67 (2014). Over its life cycle in the atmosphere, a molecule of methane traps about twenty-five times the heat of a molecule of carbon dioxide; over the twenty-year span during which that methane molecule persists in the atmosphere, it traps more than eighty times the heat of the much longer-lived carbon dioxide molecule. *See How Much Worse Is Methane than CO_2 as a Greenhouse Gas?*, CHEMISTRY STACK EXCH., https://chemistry.stackexchange.com/questions/40371/how-much-worse-is-methane-than-co2-as-greenhouse-gas [https://perma.cc/39AT-FNC3].

[125] *The Climate Impacts of Methane Emissions*, ENVTL. DEF. FUND, https://www.edf.org/energy/methaneleakage [https://perma.cc/6HAP-5RZN].

[126] *See* CTR. FOR CLIMATE CHANGE & ENERGY SOLUTIONS, LEVERAGING NATURAL GAS TO REDUCE GREENHOUSE GAS EMISSIONS 21 (2013), http://www.c2es.org/docUploads/leveraging-natural-gas-reduce-ghg-emissions.pdf [https://perma.cc/N83J-RSLX].

[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).

[128] Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews, 77 Fed. Reg. 49,490 (Aug. 16, 2012) (codified at 40 C.F.R. pts. 60, 63); *see also* Gina McCarthy, *EPA Taking*

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

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Steps to Cut Methane Emissions from Existing Oil and Gas Sources, EPA CONNECT (Mar. 10, 2016, 9:13 AM), https://blog.epa.gov/blog/2016/03/epa-taking-steps-to-cut-methane-emissions-from-existing-oil-and-gas-sources/ [https://perma.cc/YH8R-SK6Y] (stating that "EPA will begin developing regulations for methane emissions from existing oil and gas sources. We will start this work immediately to address methane from existing sources. We intend to work swiftly, and will involve stakeholders in meaningful ways, as we have been doing all along.").

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 Powe*r, 47 ENVTL. SCI. & TECH. 4889, 4891 (2013).

132 Press Release, Nat'l Acads., Report Examines Hidden Health and Environmental Costs of Energy Production and Consumption in U.S. (Oct. 19, 2009), http://www.usclimatenetwork.org/resource-database/NAS%20study%20on%20costs%20of%20energy.pdf [https://perma.cc/JJC9-S6ZU] (estimating the cost of coal combustion at more than $62 billion annually).

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).[135]

This matters because, as Figure 1 indicates,[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 *Energiewende,* has demonstrated clearly that the aggressive promotion of renewables does not necessarily imply reduced carbon emissions.[137] German policies that disadvantage nuclear power[138] and gas-fired power[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;[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. The Fairness Paradox

Some commentators[141] and policymakers[142] see distributed energy resources, particularly rooftop solar and DR, as central

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[135] *Id.* at 1670, tbl.5.

[136] *See supra* Figure 1.

[137] Robert Wilson, *Why Germany's Nuclear Phase Out Is Leading to More Coal Burning*, THE ENERGY COLLECTIVE (Jan. 20, 2014), http://www.theenergycollective.com/robertwilson190/328841/why-germanys-nuclear-phase-out-leading-more-coal-burning [https://perma.cc/5MJ4-ALGG].

[138] Tim Smedley, *Goodbye Nuclear Power: Germany's Renewable Energy Revolution*, GUARDIAN (May 10, 2013), http://www.theguardian.com/sustainable-business/nuclear-power-germany-renewable-energy [https://perma.cc/GTZ7-73V6].

[139] *See* Harriet Torry, *German Cabinet Approves Anti-Fracking Draft Law*, WALL ST. J. (Apr. 1, 2015), http://www.wsj.com/articles/german-cabinet-approves-anti-fracking-draft-law-1427896555 [https://perma.cc/X5SV-YLD8].

[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. *See* Steven Mufson, *Vintage U.S. Coal-Fired Power Plants Now an 'Aging Fleet of Clunkers'*, 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. *See* Adelman & Spence, *supra* note 7, 153 tbl.3.

[141] For a recent discussion of this literature, see Shelley Welton, *Clean Electrification*, 88 U. COLO. L. REV. 571 (2017).

[142] New York's "Reforming Energy Vision" initiative is the most prominent of the state policies. *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,[143] and many traditional markets lack RPSs and the market for renewable power they create.[144] Furthermore, state law in some hybrid and traditional markets inhibits non-IOU, third-party ownership of rooftop solar power.[145] 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.[146]

Decarbonization through DER, however, poses a fairness problem in most traditional and hybrid states. In competitive states, unbundling implies that customers pay separately for

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at 3, 11, No. 14-M-0101 (N.Y. P.U.C. Feb. 26, 2015) [hereinafter Order Adopting Regulatory Policy Framework] (emphasizing the need to tap the "enormous and largely untapped resource" of the "customer side of the grid"). There are similar initiatives in Massachusetts, Minnesota, Hawaii, California, and Maryland. *See, e.g.*, Investigation by the Dep't of Pub. Util. on Its Own Motion into Modernization of the Electric Grid, at 1 (Mass. Dep't of Pub. Util., June 12, 2014) (initiative designed, in part, to "empower customers to manage and reduce their energy costs"); Proposed Decision on Order Instituting Rulemaking on the Commission's Own Motion to Conduct a Comprehensive Examination of Investor Owned Electric Utilities' Residential Rate Structures, the Transition to Time Varying and Dynamic Rates, and Other Statutory Obligations, R. 12-06-013 (Cal. P.U.C. Apr. 21, 2015); EXHIBIT A: COMMISSION'S INCLINATIONS ON THE FUTURE OF HAWAII'S ELECTRIC UTILITIES 1–3 (2014), http://puc.hawaii.gov/wp-content/uploads/2014/04/Commissions-Inclinations.pdf [https://perma.cc/RRP6-SV55]; Nancy Lange et al., Building a Minnesota Conversation on Grid Modernization with a Focus on Distribution Systems (May 12, 2015), http://mn.gov/puc/documents/pdf_files/grid_modernization_5-12-2015.pdf [https://perma.cc/9XDF-6SLY] (outline of presentation) (also aimed at helping customers become more active managers of their consumption).

143 Welton, *supra* note 141, at 588 ("States where the electricity industry remains 'vertically integrated' . . . may be less inclined to adopt a full-throated version of the participatory grid than their counterparts that have more fully opened their electricity sectors up to competition.").

144 The correlation is evident particularly in the southeastern United States. *Compare Most States Have Renewable Portfolio Standards*, U.S. ENERGY INFO. ADMIN., (Feb. 3, 2012), http://www.eia.gov/todayinenergy/detail.cfm?id=4850 [https://perma.cc/CK8K-7R3R] (demonstrating the U.S. Energy Information Administration's map of states with RPSs), *with* Seth Blumsack, *Deregulation or Restructuring?*, PENN STATE UNIV., https://www.e-education.psu.edu/eme801/node/534 [https://perma.cc/JU8K-JRED] (displaying its map of states that have restructured their retail markets).

145 In many traditionally regulated states, only utilities can engage in retail sales. Thus, any financing arrangement under which a third-party owner of rooftop solar panels would sell power generated by the panels to the homeowner on whose roof the panels sit is prohibited. For a discussion of this issue, see Neil Peretz, *Growing the Energy Efficiency Market Through Third-Party Financing*, 30 ENERGY L.J. 377, 391–92 (2009).

146 Under the New York plan, utilities would become distribution system providers, platforms over which consumers and producers alike would participate as both buyers and sellers of a broader array of electricity services (including demand response and distributed generation services).

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,"[150] 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

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[147] *See, e.g.*, Griselda Blackburn et al., *Solar Valuation and the Modern Utility's Expansion into Distributed Generation*, ELEC. J., Jan.–Feb. 2014, at 26; Ryan Hledik, *Rediscovering Residential Demand Charges*, ELEC. J., Aug.–Sept. 2014, at 84.

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

[149] *See, e.g.*, David B. Raskin, *The Regulatory Challenge of Distributed Generation*, 4 HARV. BUS. L. REV. ONLINE 38, 40–42 (2013).

[150] *See, e.g.*, *Net Metering*, NV ENERGY, https://www.nvenergy.com/renewables environment/renewablegenerations/NetMetering.cfm [https://perma.cc/YGD2-CHAK] (describing Nevada Energy's separate charges for capacity (called a "basic service charge") and energy for net metering customers).

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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[151] *See* TOM STANTON, NAT'L REGULATORY RESEARCH INST., STATE AND UTILITY SOLAR ENERGY PROGRAMS: RECOMMENDED APPROACHES FOR GROWING MARKETS, at iv (2013); Welton, *supra* note 141, at 576; Troy A. Rule, *The Power of Pricing: Smarter Rate Design for the Rooftop Solar Age* (Sandra Day O'Connor College of Law, Arizona State University, Working Paper, 2017) (on file with author).

[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).

[153] *See, e.g.*, CLEAN POWER RESEARCH, 2014 VALUE OF SOLAR AT AUSTIN ENERGY 2 (2013), http://www.austintexas.gov/edims/document.cfm?id=199131 [https://perma.cc/KLS3-ANA3] (explaining in detail the value of solar calculation for the City of Austin municipal utility); CLEAN POWER RESEARCH, MINNESOTA VALUE OF SOLAR: METHODOLOGY (2014), https://www.cleanpower.com/wp-content/uploads/MN-VOS-Methodology-2014-01-30-FINAL.pdf [https://perma.cc/RU9E-5J96].

[154] *See, e.g.*, CAL. ISO, WHAT THE DUCK CURVE TELLS US ABOUT MANAGING A GREEN GRID, https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf [https://perma.cc/8CV5-BCKM] (explaining how California's sudden absence of solar power at sundown poses grid management problems there).

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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[155] PETER BRONSKI ET AL., ROCKY MOUNTAIN INST., THE ECONOMICS OF GRID DEFECTION: WHEN AND WHERE DISTRIBUTED SOLAR GENERATION PLUS STORAGE COMPETES WITH TRADITIONAL UTILITY SERVICE 6 (2014).

[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.[158] Grid-scale storage could include batteries, compressed air storage,[159] flywheels,[160] and the aforementioned pumped storage hydroelectric power. Consumer-scale storage would include mostly batteries or some forms of thermal storage.[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.[162] Environmental NGOs and other proponents of a renewables-only strategy may have this experience in mind when advocating for a system without natural

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[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, *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.

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

[160] For a description of how flywheels work, see *Flywheels*, ENERGY STORAGE ASS'N, http://energystorage.org/energy-storage/storage-technology-comparisons/thermal [https://perma.cc/CG6A-B2LA].

[161] For a description of how distributed thermal storage might work, see *Thermal*, ENERGY STORAGE ASS'N, http://energystorage.org/energy-storage/storage-technology-comparisons/thermal2 [https://perma.cc/H9DL-DNHE].

[162] *See* Winston Harrington et al., *On the Accuracy of Regulatory Cost Estimates*, 19 J. POL'Y ANALYSIS & MGMT. 297, 314 (2000) (confirming this general truth).

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.[163] Both states rely extensively on natural gas-fired power to back up renewables now.[164] 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.[165]

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.[166] 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,[167] and discussions of "reregulation" in Ohio and Michigan.[168]

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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 and Energy Estimates*, *supra* note 97 (listing U.S. EIA State Profiles).

165 *Average Electricity Prices Around the World: $/kWh*, OVO ENERGY, https://www.ovoenergy.com/guides/energy-guides/average-electricity-prices-kwh.html [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).

167 *See* Robert Walton, *With Clean Energy Standard, New York Looks to Save Nukes, Skirt Legal Challenges*, UTIL. DIVE (Aug. 4, 2016), http://www.utilitydive.com/news/with-clean-energy-standard-new-york-looks-to-save-nukes-skirt-legal-chall/423673/ [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."[169] 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

[168] *See* RAYMOND L. GIFFORD & MATTHEW S. LARSON, WILKINSON BARKER KNAUER, LLP, STATE ACTIONS IN ORGANIZED MARKETS: STATES STRIVE TO 'FIX' MARKETS AND RETAIN BASE LOAD GENERATION 4–9 (2016), http://e67ti2w9ws71al8xmnhsozd3.wpengine.netdna-cdn.com/files/2016/09/BaseloadWilkersonEtcPaper0916.pdf [https://perma.cc/9FQY-QSSQ] (describing efforts by utilities to secure income guarantees for existing generating units in competitive markets).

[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.