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LESSONS OF WIND POLICIES IN TEXAS

By Joshua Linn and Clayton Munnings†

I. INTRODUCTION

Since the late 1990s, Texas has experienced more wind generator investment than any other U.S. state. It now has the most installed wind capacity of any state,[1] and wind power accounts for a larger share of total generation in Texas than in most other states.[2] Favorable wind resources and the relative ease of siting large projects have contributed to Texas's prominence in wind investment and generation.[3] Numerous policies have also played important roles, such as the federal tax credit for wind generation, the state's renewable portfolio standard ("RPS"), and a regulatory environment conducive to new investment in the electric power sector.[4]

With nearly fifteen years of hindsight, the Authors derive lessons from the major federal and state policies that have helped wind generation in Texas. The Authors conduct this retrospective analysis at a time when many other states have ambitious renewable energy resource requirements; for example, California requires that renewables

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1. U.S. ENERGY INFO. ADMIN., http://www.eia.gov/electricity/data.cfm#gencapacity (follow "XLS" hyperlink in the row titled "Existing capacity by energy source, by producer, by state back to 2000 (annual data from the EI-860)") (last visited Feb. 1, 2014) [hereinafter USEIA 2000].

2. U.S. ENERGY INFO. ADMIN., http://www.eia.gov/electricity/data.cfm#generation (follow "XLS" hyperlink in the row titled "Net generation by state by type of producer by energy source, monthly back to 2005 (EIA-906, EIA-920, and EIA-923)") (last visited Feb. 1, 2014) [hereinafter USEIA 2005].

3. Jay Zarnikau, *Successful Renewable Energy Development in a Competitive Electricity Market: A Texas Case Study*, 39 ENERGY POL'Y 3906, 3908 (2011).

4. *Id.*

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account for 33% of generation by 2020.[5] At the same time, extensive debate over federal policy continues, including whether to continue or renew subsidies to renewables. The lessons from the Texas experience can help guide these future policy decisions.

To provide background, the next Section summarizes aggregate trends in investment and generation in Texas and considers these trends in the national context. The Authors also briefly describe the federal production tax credit ("PTC"), which has been claimed for many recent wind power projects, and the Texas RPS. Texas also has a "green power" market that creates market-based incentives for investment in renewables; however, the Authors are not aware of any detailed analysis of this program, so the Authors focus on the RPS. The Authors discussion includes the policies that encourage renewables investment directly and reduce pollution emissions, leaving aside other policy developments such as the deregulation of the electricity sector that occurred during the same time period.

The following Section looks at the economics of wind power, and distinguishes the market and environmental values of new wind generators. Market value arises from displaced generation and investment resulting from the new wind generator, and the environmental value from the avoided pollution emissions from fossil-fuel-fired generators. Because the Authors focus on policies that aim to reduce pollution emissions, the Authors do not include other environmental issues such as the effects of the policies on bird populations.

In the main Section, the Authors draw three policy lessons from the discussion of market and environmental values. While several other articles have analyzed wind policy in Texas, the Authors' focus is distinct in its attempt to draw important lessons for state and federal efforts to promote renewables. Briefly, the three lessons are as follows:

1. In Texas, the environmental benefits of wind power arise primarily from displaced natural gas generation and to a lesser extent from displaced coal generation.
2. Although existing Texas policies have promoted substantial wind investment, other policies would likely reduce pollution emissions at lower costs.
3. Coordinating policies for renewables and grid infrastructure can greatly lower the cost of reducing emissions.

The final Section offers a few concluding remarks for state and federal policy.

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5. DATABASE OF STATE INCENTIVES FOR RENEWABLES & EFFICIENCY ("DSIRE"), http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA25R (last visited Jan. 29, 2014).

II. Wind Investment and Policies in Texas, 2000–2012

In this Section, the Authors provide a brief summary of Texas wind investment since the year 2000, as well as an overview of the key federal and state policies promoting wind investment in Texas. The purpose of this Section is not to explain the wind investment, but merely to provide some background.

A. *Wind Investment and Generation in Texas*

Figure 1 shows wind capacity in Texas and all other states within the United States, measured in gigawatts ("GW") of capacity.[6] Wind capacity in other states increased from about 2 to 36 GW over the years 2000 to 2011; by comparison, the entire U.S. power system has approximately 1,100 GW of capacity.[7] Over the same period, wind capacity in Texas increased from close to 0 to about 10 GW.[8] Thus, Texas accounted for about 23% of total wind capacity in 2011, although the state accounts for only about 10% of total U.S. capacity.[9]

Texas far exceeds the national average in the contribution of wind generation to total generation.[10] In 2010, the share in Texas was about three times higher than the national average.[11] Figure 2 shows the share of generation accounted for by wind power for Texas, the United States, and Iowa, the state with the highest generation share.[12] Iowa, like other states in the upper Midwest and Plains, derives a large share of its generation from wind power.[13] But because fewer people live in the upper Midwest and Plains than in Texas, total wind capacity is higher in Texas.

Having some of the country's best wind resources partly explains why Texas has so much more wind capacity than any other state. Figure 3 shows a map of the United States that has been color coded to represent estimated onshore wind resources. Darker colors reflect more favorable wind locations, and a large section in western Texas is colored orange and pink, indicating fair to good wind resources.[14]

6. USEIA 2000, *supra* note 1.
7. *Id.*
8. *Id.*
9. *Id.*
10. USEIA 2005, *supra* note 2.
11. *Id.*
12. *Id.*
13. *Id.*
14. *Renewable Portfolio Standards*, Dep't of Energy and Mineral Eng'g, https://www.e-education.psu.edu/ebf200up/node/198 (last visited Jan. 30, 2014) (referencing the graph, which shows the quantity of electricity generated by each type of fuel since 1996).

B. *Federal PTC and Texas RPS*

Federal and state policies have also contributed to wind investment in Texas. The U.S. Congress created the PTC for renewable energy in the 1992 Energy Policy Act.[15] The PTC provides a corporate tax credit (equivalent to a subsidy) for each megawatt hour ("MWh") of electricity a renewable generator produces for the first ten years that the generator operates.[16] The credit currently equals $23 per MWh for wind generators and rises with inflation.[17] Wind power projects have claimed roughly two-thirds of the total subsidy value issued under the PTC to date.[18] The PTC nearly expired in 2013 before Congress extended it one additional year through the American Taxpayer Relief Act of 2012,[19] but it has since expired (the PTC will continue to be earned by wind generators that began construction prior to expiration).

Although no rigorous analysis has assessed the effects of the PTC on wind investment in Texas or elsewhere, recent experience suggests that the PTC has had an important effect. For example, the PTC lapsed three times—in 2000, 2002, and 2004—only to be renewed again each subsequent year.[20] Wind developers did not install any projects in Texas each year after the PTC lapsed, providing some evidence for the importance of the tax credit.[21] The PTC also contributes to negative wholesale electricity prices, which have been common in western Texas. Prices can turn negative when available transmission capacity cannot deliver all of the electricity generated by wind in western Texas to eastern Texas, where most of the electricity demand is located. During these times, owners of wind generators are willing to supply electricity at negative prices because they can still earn profits from the PTC. Prices would be less likely to turn negative in the absence of the PTC because wind generator owners would not offer to sell electricity below their marginal costs, which roughly equal zero.[22]

The Texas RPS has likely played an important role in wind investment, at least in the early 2000s. In 1999, the Texas legislature passed

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15. Kevin M. Walsh, *Renewable Energy Financial Incentives: Focusing on Federal Tax Credits and the Section 1603 Cash Grant: Barriers to Development*, 36 U.C. DAVIS L. REV. 207, 212 (2013).

16. DSIRE, http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F (last visited Jan. 29, 2014).

17. *Id.*

18. Harrison Fell, Joshua Linn & Clayton Munnings, Designing Renewable Electricity Policies to Reduce Emissions, Discussion Paper (Resources for the Future, Washington, D.C.), Dec. 2012, at 9, http://www.rff.org/rff/Documents/RFF-DP-12-54.pdf.

19. American Tax Payer Relief Act of 2012, H.R. 8, 112th Cong. § 407 (2012).

20. *See* Fell et al., *supra* note 18, at 9.

21. Walsh, *supra* note 15, at 233.

22. C. K. Woo et al., *Wind Generation and Zonal-Market Price Divergence: Evidence from Texas,* 39 ENERGY POL'Y 3928, 3931 (2011), *available at* http://www.sciencedirect.com/science/article/pii/S0301421510008700.

the RPS, which initially required 2 GW of new capacity to be installed by 2009.[23] The state exceeded this level far ahead of time,[24] and in 2005 the legislature increased the RPS to 10 GW by 2025.[25] The state also exceeded this increased level ahead of time, by 2010.

The RPS includes a system of renewable energy credits ("RECs"). A qualifying renewable generator creates a REC for each MWh of electricity it generates. Each load-serving entity, which includes retailers and certain cooperatives and municipal utilities,[26] must generate its own renewable electricity or purchase enough RECs to meet its RPS requirement, where the requirement depends on the firm's sales.[27]

A number of articles have assessed the success of the Texas RPS,[28] although the literature has not settled on a definition of success. The Authors consider the narrower and more fundamental question of whether the RPS has affected wind investment in Texas. During the early 2000s, installed wind capacity was only slightly above the levels required by the RPS, and REC prices were between $10 and $16 per MWh.[29] By the late 2000s, however, installed wind capacity exceeded the levels required by the RPS. In 2007, for example, wind developers had installed more than twice the amount of capacity required by the RPS,[30] and REC prices fell to around $2 per MWh;[31] see Figure 4. Although the RPS may have stimulated wind development in the early 2000s, clearly other factors were important by the late 2000s, such as the PTC.[32] We discuss this possibility further in Section IV.

Transmission policies have also been important in wind development. The western part of the state contains the best wind resources in Texas, as shown in Figure 3,[33] whereas most of the demand comes from the eastern part of the state.[34] Transmission lines must deliver the wind power produced in western Texas to the eastern part of the state, and Woo et al. show that between 2007 and 2010, transmission

23. Tex. S.B. 7, 76th Leg., R.S., § 39.904 (1999).

24. Woo et al., *supra* note 22, at 3930.

25. Tex. S.B. 20, 79th Leg., 1st C.S., § 3 (2005).

26. ERCOT, http://www.ercot.com/services/rq/lse/ (last visited Feb. 25, 2014).

27. *See* Zarnikau, *supra* note 3, at 3908.

28. Ole Langniss & Ryan Wiser, *The Renewables Portfolio Standard in Texas: An Early Assessment*, 31 ENERGY POL'Y 527 (2003); Zarnikau, *supra* note 3; M.C. Faconti, *How Texas Overcame California as a Renewable State: A Look at the Texan Renewable Energy Success*, 14 VT. J. ENVTL. L. 411 (2012); Richard Schmalensee, *Evaluating Policies to Increase Electricity Generation from Renewable Energy*, 6 REV. ENVTL. ECON. & POL'Y 45, 46–48 (2011).

29. Schmalensee, *supra* note 28, at 58.

30. U.S. ENERGY INFO. ADMIN., http://www.eia.gov/electricity/data/eia860/index.html (follow "2007 ZIP" hyperlink, file "Geny07") (last visited Feb. 1, 2014).

31. *See* Schmalensee, *supra* note 28, at 58.

32. Langniss & Wiser, *supra* note 28, at 530.

33. *See* PENN STATE COLLEGE OF EARTH AND MINERAL SCIENCES, https://www.e-education.psu.edu/ebf200up/node/198 (last visited Feb. 25, 2014).

34. Woo et al., *supra* note 22, at 3930.

capacity was often insufficient to deliver all of the available wind-generated electricity.[35] Such transmission congestion caused electricity prices to be lower in the western part of the state and higher in the eastern part than if there had been no congestion.[36] The transmission congestion may have reduced investment in new wind generators because the congestion reduced the revenues of new wind generators in western Texas.

To address the inefficiencies associated with transmission congestion, Texas has spent approximately $5 billion in increasing transmission capacity.[37] In 2005, Texas created competitive renewable energy zones ("CREZs"), which enabled the expansion of transmission capacity between regions with favorable wind resources and the rest of the state.[38] The transmission capacity expansions, which are nearing completion, will reduce the likelihood that prices in regions with high wind resources will fall below prices in other regions. This lower likelihood of regional price divergence should increase incentives for new wind investment, and the expanded transmission capacity is expected to support an additional 8 GW of wind capacity.[39] The additional capacity should also reduce the total cost of generating electricity, but whether the benefits of the transmission capacity investment turn out to exceed the costs is an open question.

III. Economics of Wind Generation

The Texas electricity market provides consumers with electricity, but also creates pollution emissions because of fossil-fuel combustion at coal- and gas-fired generators. As discussed above, considerable wind investment has occurred in Texas, and wind's share in total generation is much higher in Texas than in most other states. This Section discusses the value of wind generators to society.

A. *The Inapplicability of LCOE to Wind Generators*

The Authors use the term "market value" to describe the value of a hypothetical wind generator to a potential investor. Investors commonly use the levelized cost of energy ("LCOE") as part of their evaluation of whether to proceed with a particular project. The LCOE is, essentially, the average cost of providing a unit of electricity over the generator's lifetime. Investors can compare the LCOE with the average price of electricity that the generator would receive (for example, by selling into a wholesale market or under long-term contract with a

35. *Id.*
36. *Id*. at 3931.
37. Zarnikau, *supra* note 3, at 3910.
38. Tex. S.B. 20, 79th Leg., 1st C.S., § 3 (2005).
39. Diana Liebmann, *Market Headwinds Persist for U.S. Wind Capital*, N. Am. Windpower, at 1 (2011), https://www.haynesboone.com/files/Uploads/Documents/Third-Party%20Articles/NAW%20(Liebmann).pdf.

utility). For a potential investor deciding whether to invest in a particular wind project, if the project's LCOE is lower than the electricity price, the investor should go ahead with the project because expected revenues exceed expected costs. Thus, the LCOE can form the basis of a simple decision rule about whether to invest in a particular project.

Many analysts also use the LCOE to compare the expected profitability of different generation technologies. For example, the Massachusetts Institute of Technology study on the future of nuclear power compares the LCOE of hypothetical natural gas, coal, and nuclear generators.[40] This comparison is appropriate because all three technologies are "base load," meaning that they operate most of the time. Therefore, owners of these generators expect to receive the average price of electricity over the generators' lifetime—effectively, the technologies would all receive the same revenue per unit of electricity generation.[41] Comparing the profitability of these technologies, therefore, amounts to comparing their LCOE—the technology with the lowest LCOE is most profitable.

But as Joskow[42] and Fell and Linn[43] argue, comparing the LCOE of wind with those of other technologies does not provide information about whether the wind generator is more profitable than other generators. The fact that a wind generator produces electricity only when the wind blows, termed "intermittency," complicates the comparison between wind and other technologies. Because of intermittency, a wind generator cannot operate as a base load generator. A wind generator also cannot operate as a "peaking" generator, which operates only during periods of high demand. Instead, generation from a wind generator varies over time in accordance with wind speed.

Because wind generators produce electricity only under favorable wind conditions, the revenue of a particular wind generator depends on the temporal correlation between wind availability and electricity prices.[44] The four curves in Figure 5 show total electricity demand by hour on an average day in the Electric Reliability Council of Texas market, which covers most of Texas. Each curve represents a different season of the year. Demand is lowest in the early morning and increases over the day, peaking at around 5 p.m. in most seasons and decreasing at the end of the day. The figure also shows that the daily

40. Eric S. Beckjord et al., *The Future of Nuclear Power*, MASS. INST. OF TECH., at 42 (2003), http://mitei.mit.edu/system/files/nuclearpower-full_0.pdf.

41. Policies that affect the profitability of some of these technologies but not others, such as loan guarantees, would be included in the LCOE calculation and would not—in this comparison—affect revenue.

42. Paul L. Joskow, *Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies*, 3 AM. ECON. REV. 238, 239 (2011).

43. *See* Harrison Fell & Joshua Linn, *Renewable Electricity Policy, Heterogeneity and Cost Effectiveness*, 66 J. ENVTL. ECON. & MGMT. 688, 692 (2013).

44. *Id.* at 688.

pattern differs across seasons. Demand varies less over the day in winter and fall than in summer, for example.

Figure 6 shows the implications of intermittency for the revenue of a hypothetical wind generator in Texas. The figure illustrates the estimated wind generator capacity factors by season for western Texas. It has been constructed from simulated wind data and represents typical patterns observed at wind generators in western Texas. Comparing Figures 5 and 6 shows that wind generation correlates negatively with electricity demand. In fact, the correlation is negative both over the course of the day and across seasons. Demand tends to peak in the middle of the day and in the summer, when wind generation is lowest.

What does the negative correlation imply for the value of wind generation? Recall that the typical comparison of technologies, based on LCOE, relies on the premise that the technologies being considered receive the same average price over their lifetimes. For a base load generator, this would roughly equal average price across all hours. But in Texas and other regions with active wholesale electricity markets, the price is proportional to demand: prices rise and fall with demand. Because prices correlate positively with demand and wind generation correlates negatively with demand, wind generation negatively correlates with prices.[45] Because of the negative correlation, a typical wind generator in western Texas receives less than the average price. Therefore, although a hypothetical wind generator can have a lower LCOE than a hypothetical natural gas generator, the natural gas generator may still be more profitable than the wind generator because it earns more revenue. The Authors conclude that comparing wind and other technologies on the basis of LCOE is not appropriate; no investor would make a decision to build a new wind generator based only on the LCOE. Instead, the investor compares the costs of the wind generator with the value of the wind generator.

B. *Market Value of a Wind Generator*

The market value of a wind generator derives from two sources.[46] The first is the generation displaced by the wind generator. Figure 7 provides a useful approximation of the Texas electricity market in a particular hour. The vertical curve represents the demand curve. Electricity demand is vertical (or nearly so, in reality) because most consumers cannot adjust electricity consumption immediately in response to the price of electricity. This may change with increasing penetration of certain technologies, such as air conditioners that shut off when electricity prices rise, but presently electricity demand is approximately vertical over short time periods, such as within a month.

45. *Id.* at 689.
46. *Id.* at 692.

(The Authors do not argue that consumers do not respond to electricity prices, only that they do not respond immediately.)

The upward-sloping curve represents the supply curve. The curve plots the marginal cost of producing electricity against total supply. Wind, hydroelectric, and nuclear generators in Texas have the lowest marginal costs. Coal generators have historically been next in cost, with natural gas generators having the highest marginal costs, although recently the marginal costs of some natural gas generators have fallen below those of some coal generators because of low natural gas prices.[47] Nonetheless, for the purposes of our discussion, the Authors will treat coal generators as having lower marginal costs than natural gas generators, as this was the case throughout most of the 2000s.

The intersection of the demand and supply curves determines the electricity price. The price equals the marginal costs of the highest-cost generator in operation. If demand were lower, the price would also be lower; at very low levels of demand, a coal generator may operate at the margin, which means that it is the highest-cost generator in operation. Note that this diagram makes a number of simplifications; for example, in practice, the marginal costs of the generators may depend on whether they operated in the previous hour. Nonetheless, this diagram provides enough detail to illustrate the basic economics of wind generation.

Suppose that Figure 7 represents the Texas market for one hour in 2007. A particular natural gas generator sets the price in that hour. Suppose, further, that in 2008 a new wind generator is constructed. In our simple example, everything else stays the same between 2007 and 2008. The wind generator has zero marginal costs, so it effectively causes the supply curve to shift incrementally to the right. This causes the marginal gas generator from 2007 to decrease its generation by the same amount as the wind generation increases. Effectively, the wind generation displaces natural gas generation.

The market-wide cost of producing electricity consequently decreases in proportion to the marginal costs of the displaced natural gas generation. This avoided cost represents the first source of market value of the wind generation. When electricity demand is low, the avoided costs—and hence the market value—also tends to be low. Therefore, a wind generator whose generation is negatively correlated with demand has lower market value than one whose generation is positively correlated with demand. Fell and Linn[48] use a computational model to compare the market values from displaced generation

47. Joseph A. Cullen & Erin T. Mansur, *Will Carbon Prices Reduce Emissions in the U.S. Electricity Industry? Evidence from the Shale Gas Experience* 2 (Dartmouth Univ., Working Paper, 2013), http://www.josephcullen.com/resources/CarbonShale.pdf.

48. Fell & Linn, *supra* note 43, at 702.

for different types of wind generators. The market value is slightly higher for hypothetical generators located on the Gulf Coast than for generators in western Texas because the western generators produce electricity that is more negatively correlated with demand.[49]

The wind generator has market value from the displaced generation, and the displaced investment is a second source of market value.[50] Firms choose to invest in new generators when the expected revenues exceed costs. An increase in wind generation causes the supply curve to shift right, thereby reducing expected revenues and the amount of investment in other generators. The actual value of the displaced investment depends on demand; wind availability; and other factors; and quantifying this value requires a detailed model of the electricity sector. Fell and Linn compare the value of avoided investment for hypothetical wind and solar generators, concluding that the value is substantial compared with the value of the avoided generation.[51]

C. *Environmental Value of a Wind Generator*

Wind generators may have value to society beyond their market values. Social values arising from the health and environmental benefits of reduced pollution emissions from fossil-fuel-fired generators would justify, on economic grounds, policies that create incentives for wind investment.

Similar to the common misperception about using the LCOE to compare wind and other electricity generation technologies, a common misperception exists about the environmental value of wind generators.[52] An often-repeated view of renewable electricity generators is that because they have zero emissions, they have the same environmental value as one another. But just as the market value derives from the displaced generation, environmental value derives from displaced emissions from fossil-fuel combustion at coal- and gas-fired generators.

In Texas, as in other parts of the United States, fossil-fuel generators operate at the margin most hours, but sometimes the marginal generator is coal-fired and other times it is gas-fired.[53] Whether the marginal generator uses coal or gas depends on a variety of factors, such as electricity demand and the composition of the generation fleet. In Texas, natural-gas-fired generators are usually at the margin, although sometimes, particularly when demand is low, coal operates

49. *See id.*
50. *Id.* at 693.
51. *Id.* at 704.
52. Fell et al., *supra* note 18, at 7.
53. Anya Castillo & Joshua Linn, *Incentives of Carbon Dioxide Regulation for Investment in Low-Carbon Electricity Technologies in Texas*, 39 ENERGY POL'Y 1831, 1839–40 (2011).

at the margin.[54] As Figure 5 shows, demand tends to be low at night, which is also when coal often operates at the margin. Because coal generators emit more particulates, nitrogen oxides, sulfur dioxide, and carbon dioxide than natural gas generators, much greater environmental benefit results from displacing coal than gas. Therefore, renewable generators that operate more at night and in the spring than at other times have higher environmental value.

Figure 8 shows the results of a simulation analysis of the Texas system using data from 2008.[55] The figure plots the probability that a coal generator operates at the margin by hour of the day. The probability peaks at night and in the early morning, when demand tends to be low. The figure also shows the capacity factor of hypothetical wind and solar generators and indicates that a wind generator is more likely than a solar generator to displace a coal generator. The environmental value therefore differs between wind and solar generators, and likewise the environmental value may differ between two wind generators. A wind generator with generation that is more negatively correlated with demand than another wind generator may have higher environmental value. Thus, it is not true that the environmental value of all wind generators is the same.

IV. Policy Lessons from Texas

The Authors are not aware of a rigorous assessment of the costs and benefits of the policies and regulations that have affected Texas wind development. However, despite this lack of analysis, the literature supports three central lessons:

1. *In Texas, the environmental benefits of wind power arise primarily from displaced natural gas generation and to a lesser extent from displaced coal generation.* Several articles have examined whether wind generators in Texas are more likely to displace coal-fired than gas-fired generation. Castillo and Linn use a computational model of the Electric Reliability Council of Texas ("ERCOT") market, which covers most of Texas, and conclude that 1 MWh of wind generation displaces about 0.75 MWh of natural gas generation and about 0.25 MWh of coal generation.[56] The Authors base the analysis on simulations of the ERCOT system, and the finding is consistent with those of several other studies that statistically estimate the effect of wind generation on fossil fuel–fired generation and emissions, including Cullen,[57] Kaffine et al.,[58] and Novan.[59]

54. *Id.*
55. *Id.* at 1839.
56. *Id.*
57. Joseph Cullen, *Measuring the Environmental Benefits of Wind-Generated Electricity*, 5 Am. Econ. J. Econ. Policy 107 (Nov. 2013), http://www.josephcullen.com/resources/measuringwind.pdf.

As we noted in Section III.B not only do wind generators displace generation from other generators, but they also displace investment in other generators. Fell and Linn simulated investment and generation over a twenty-five-year time period in ERCOT.[60] They concluded that future wind investment would displace some natural gas investment but no coal investment.[61] The finding is derived from the fact that low natural gas prices made it unprofitable for firms to invest in coal-fired generators, so without any wind investment, all of the investment would be in new natural gas generators.

2. *Although renewables have expanded greatly in Texas, other policies would likely reduce pollution emissions at lower costs.* Numerous economists have argued that putting a price on carbon dioxide emissions, as with a carbon tax or emissions cap, is less costly than other policies, both in theory and in practice.[62] An emissions price outperforms other policies by providing broad incentives to reduce emissions and by equating the magnitude of the incentives at the margin. For example, a carbon price creates equal incentives to reduce emissions by switching from coal- to gas-fired generation or by investing in wind-powered generators. On the other hand, other policies do not create uniform incentives; for example, an RPS creates incentives for investing in new renewables generators, but does not create incentives for switching from coal to gas. Therefore, to achieve a given amount of emission reductions, the RPS relies on more renewables investment than the carbon price. Failing to take advantage of low-cost emission reductions opportunities, like fuel switching, raises the overall cost of the RPS compared with the emissions price; the same argument applies to the PTC.[63]

58. Daniel T. Kaffine, Brannin J. McBee & Jozef Lieskovsky, *Emissions Savings from Wind Power Generation in Texas*, 34 ENERGY J. 155 (Jan. 2013).

59. Kevin Novan, *Valuing the Wind: Renewable Energy Policies and Air Pollution Avoided* (Univ. of California–San Diego, Working Paper, 2011), http://undergraduatestudies.ss.uci.edu/files/economics/news_events/2012/Novan_JMP.pdf.

60. Fell & Linn, *supra* note 43, at 688–707.

61. *Id.* at 689.

62. Dallas Burtraw, Curtis Carlson, Maureen Cropper & Karen L. Palmer, *Sulfur Dioxide Control by Electric Utilities: What Are the Gains from Trade?*, 108 J. POLITICAL ECON. 1292, 1318 (Dec. 2000); Hei Sing Chan, *How Large are the Cost Savings from Emissions Trading? An Evaluation of the U.S. Acid Rain Program* 32 (Univ. of Md., Job Market Paper, 2013), https://53a7a90a-a-62cb3a1a-s-sites.googlegroups.com/site/ronhschan/arpeval_chan_jmp.pdf?attachauth=ANoY7cqTRmZ9Gx7xBPxN3YEp3nNk2efeVURIgS_zOD1HU0hb4cYHj7Ff4oowuuiRtgPzIJaIs5BcAc_ocoJJGi8MrztnHS1arOuRGuMy1smfZORa0fkejNXRCT52VJRWFwo4b2JbcPa-iG5zTyD96AoZUk0KzBMbHmgx_xGlcj3jkCdMHqYWIG2qg_IlKEfeP5rWSLJJviH5DMoAxr2sDgHQ5wv482IIVg%3D%3D&attredirects=1; *see also* Lawrence H. Goulder, Ian W.H. Parry & Dallas Burtray, *Revenue-Raising versus Other Approaches to Environmental Protection: The Critical Significance of Preexisting Tax Distortions*, 28 RAND J. ECON. 708 (1997) (arguing that an emissions price may not be cost-effective after accounting for changes in product prices and labor supply).

63. Fell & Linn, *supra* note 43, at 690.

A further inefficiency of the PTC is that, by subsidizing investment, the PTC puts downward pressure on electricity prices, which increases electricity consumption in the long run. Greater consumption translates to greater fossil-fuel-fired generation and emissions, and the emissions increase offsets some of the initial emissions reductions caused by the PTC.[64]

While the existing literature has generally relied on theory or analysis of national or regional markets, Fell and Linn make a similar point using data and simulations that pertain directly to the case of Texas.[65] They show that an RPS and PTC cost much more than an emissions price or a sector-wide emissions rate standard (sometimes referred to as a clean energy standard).[66] The greater cost derives partly from the inability of the PTC or RPS to encourage fuel switching. Another shortcoming of the PTC and RPS is that both policies provide the same incentives for a wind generator with high environmental value as compared to a wind generator with a low environmental value. An emissions price, on the other hand, provides greater incentive for the wind generator that has the higher environmental value. Thus, the PTC and RPS do not recognize differences in the environmental value of wind generators, nor do they provide incentives for other types of emissions reductions, besides renewables investment.[67]

However, other policies could be more costly than the RPS or PTC. Fell and Linn also show that renewables policies that offer a flat subsidy that does not depend on the market value of the renewables generators—such as an investment tax credit or some types of feed-in tariffs—could have even higher costs than the RPS.[68]

3. *Coordinating policies for renewables and grid infrastructure can greatly improve the effectiveness of renewables policies in reducing emissions at low costs.* The entire ERCOT power system is located within Texas, making it the only system located within a single state. Transmission siting is much simpler than in other regions because Texas can adopt transmission policies with relatively little involvement from other states or the federal government.[69] The resulting flexibility likely made it much easier for Texas to build transmission capacity under the CREZ system. Because of the relative ease of siting new transmission lines in Texas, it was much easier to coordinate the renewables and transmission policies than it would have been in other states. In particular, the CREZ transmission capacity investments complemented the wind policies.

64. *See* Fell et al., *supra* note 18, at 20.
65. Fell & Linn, *supra* note 43, at 690.
66. *Id.*
67. *See* Fell et al., *supra* note 18, at 19–20.
68. Fell & Linn, *supra* note 43, at 705.
69. Faconti, *supra* note 28, at 421.

Nonetheless, Texas did not perfectly coordinate its transmission policies with the renewables policies, at least in the 2000s. Woo et al. document the effects of wind capacity on transmission congestion, and Figure 9 provides a simple picture of what happened.[70] For much of the 2000s, the ERCOT system included four zones: west, south, north, and Houston. The blue curve shows the probability that the price in the western zone was more than 10% different from the average price in the other three zones. The probability rises noticeably at the same time that the total installed wind capacity (the green curve) increased. The positive correlation between the two curves provides some simple graphical evidence of the effect of wind generation on congestion, which is consistent with the more careful analysis of Woo et al.[71]

The congested transmission lines could not handle considerable amounts of the available wind-generated electricity. Because wind generation has zero marginal costs and emits no pollution, the failure to use all of the available wind generation raised the cost of generating electricity in the system and raised emissions because fossil-fuel-fired generation replaced, to some extent, the unused wind-generated electricity. The Authors are not aware of research quantifying these costs.

Although Texas responded quickly to the congestion by creating the CREZ system, the experience in the late 2000s illustrates the costs that can arise when policy makers do not perfectly harmonize the transmission and renewables policies. Other states likely face far greater difficulties of harmonizing these policies because of the challenges of siting new transmission lines, such as in California.[72]

V. Conclusions

Texas has experienced the most investment in new wind generators of any state in the United States since 2000.[73] Favorable wind resources and policies have contributed to the state's prominence.[74]

The Authors have discussed three major lessons from the outcomes of this wind investment. First, the environmental benefits of wind generation in Texas derive mostly from displaced natural gas generation.[75] Wind generation could displace more coal generation in other regions of the country that rely more heavily on coal to generate electricity, in which case the environmental benefits of wind generation would be significantly greater. Other regions that rely heavily on nat-

70. Woo et al., *supra* note 22, at 3930.
71. *Id.*
72. Jim Rossi, *The Trojan Horse of Electric Power Transmission Line Siting Authority*, 39 Lewis & Clark Envtl. L. Rev. 1016, 1022 (2009).
73. USEIA 2000, *supra* note 1.
74. Zarnikau, *supra* note 3, at 3910.
75. Fell & Linn, *supra* note 43, at 689.

ural gas for electricity generation, such as California, would experience lower environmental benefits per unit of wind generation.

Second, Texas probably could have reduced pollution emissions at lower costs using other policies, such as a clean electricity standard or a price on carbon dioxide emissions. The reason is that the federal PTC and the state RPS reduce emissions only by promoting renewables investment and do not incentivize other, possibly lower-cost, opportunities to reduce emissions, such as switching from coal- to gas-fired generation.[76] The previous Section also discussed the inefficiencies of reducing electricity prices by subsidizing investment.

And third, transmission congestion in the late 2000s and the expanded capacity under the CREZ system demonstrate the importance of coordinating renewables and transmission policies. Because high-quality resources for wind and other renewables are often located far from the major sources of electricity demand, using policies to induce large amounts of renewables investment without coordinating transmission policies results in significantly higher system costs and emissions than if transmission and renewables policies are coordinated.

Many other states have adopted a suite of policies to aggressively promote renewables in the next several years. Therefore, Texas offers lessons that could help those states design their policies to reduce pollution emissions at low cost to electricity producers and consumers. Particularly relevant are (1) the need to coordinate renewables and transmission policies; and (2) the fact that, in some regions of the country, the environmental benefits will be relatively modest if renewables primarily displace natural-gas-fired generation. National policy should promote investment in renewable electricity generators that have the greatest combined market and environmental value. Additionally, considerable debate has been ongoing at the federal level over the continuation of the PTC and other subsidies to renewables, and the experience in Texas suggests that other policies could be less costly than the PTC and that they should be coordinated with transmission (and distribution system) policies.

76. *See* Fell et al., *supra* note 18, at 19–20.

VI. Figures

Figure 1. Installed Wind Capacity (GW), 2000–2011[77]

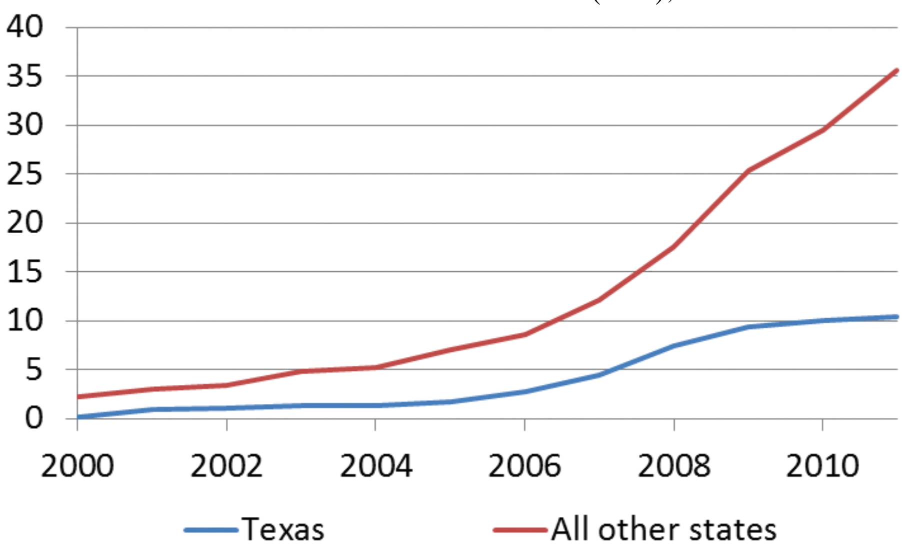
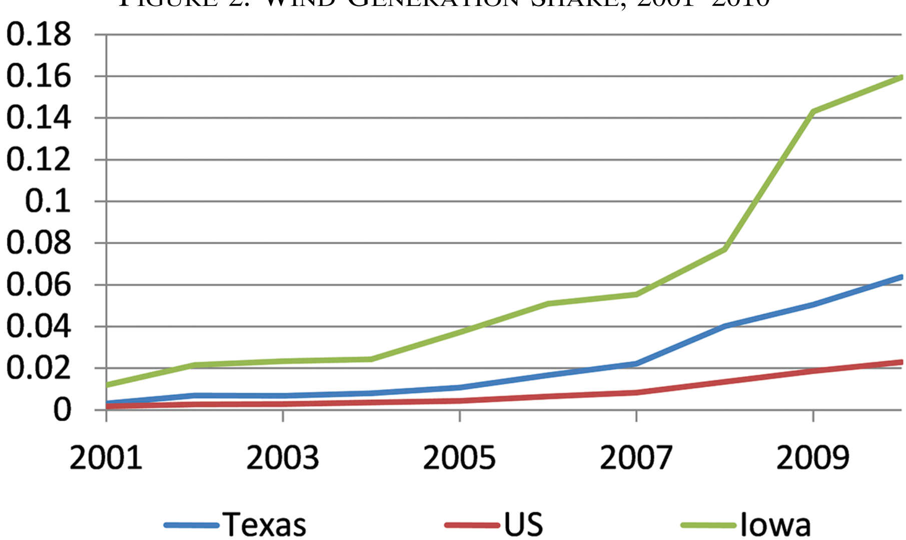


Figure 2. Wind Generation Share, 2001–2010[78]



77. U.S. Energy Information Administration, Existing Capacity by Energy Source, by Producer, by State Back to 2000, http://www.eia.gov/electricity/data.cfm#gencapacity. The data series for Texas shows the total installed wind generation capacity in gigawatts ("GW") from 2000 to 2011. The data series for all other states shows total GW of wind capacity for all U.S. states other than Texas.

78. U.S. Energy Information Administration, Net Generation by State by Type of Producer by Energy Source, Monthly Back to 2005, http://www.eia.gov/electricity/data.cfm#gencapacity.

FIGURE 3. U.S. WIND RESOURCES[79]

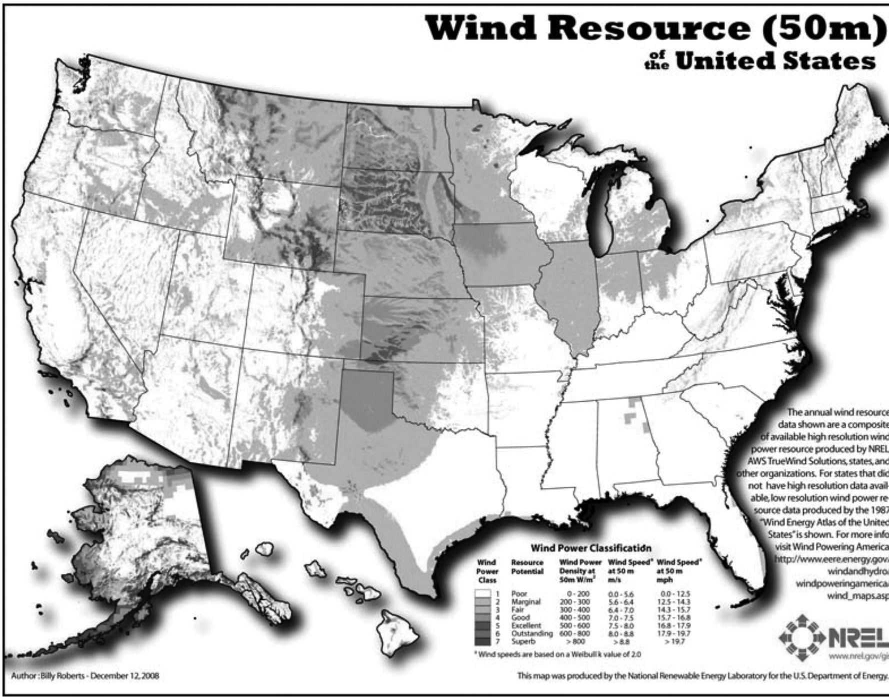
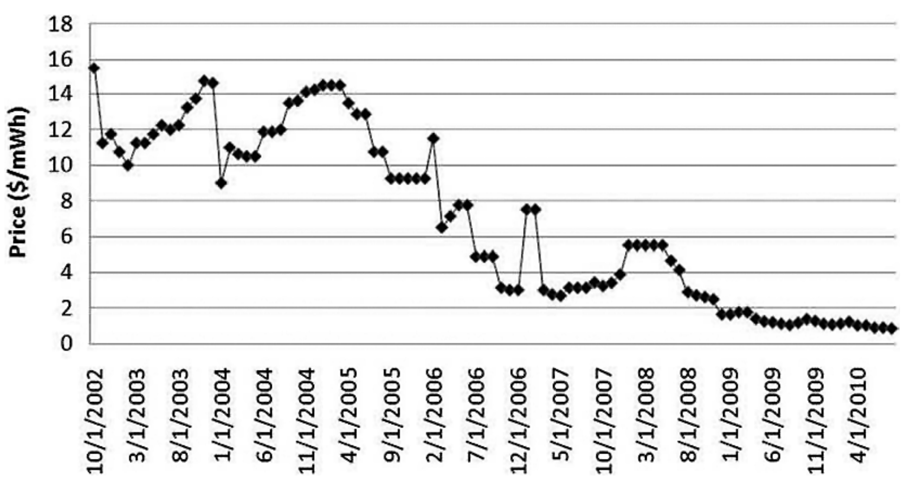


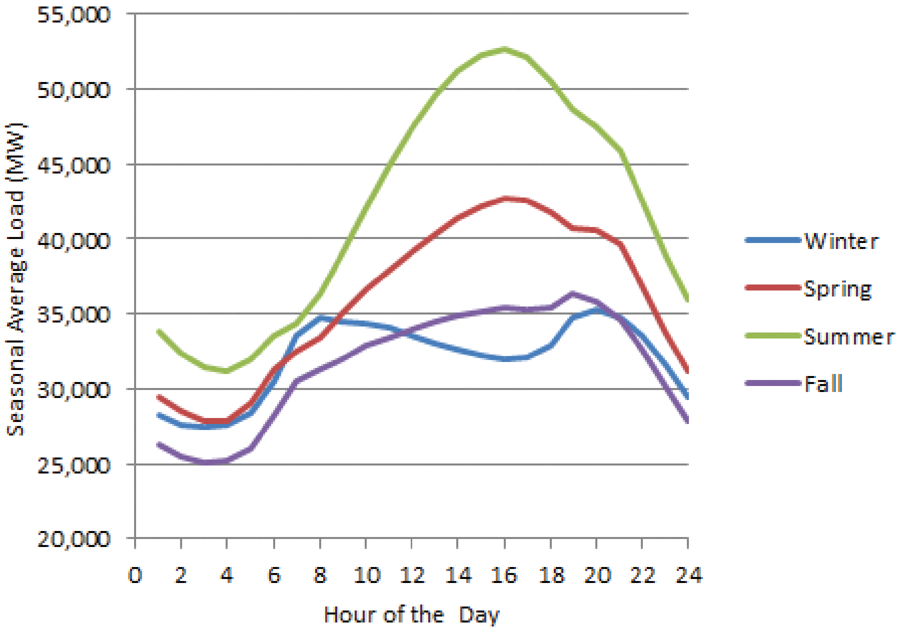
FIGURE 4. RENEWABLE ENERGY CREDIT PRICES IN TEXAS (DOLLARS PER MWH), 2002–2010[80]



79. PENN STATE COLLEGE OF EARTH AND MINERAL SCIENCES, RENEWABLE PORTFOLIO STANDARDS, https://www.e-education.psu.edu/ebf200up/node/198.

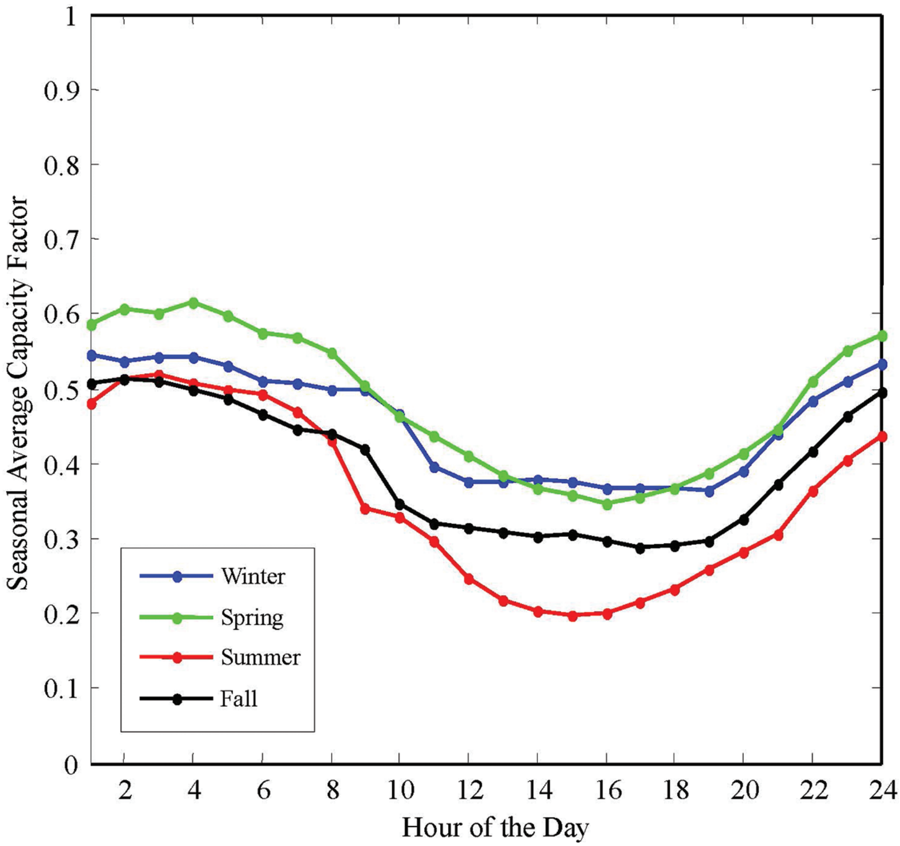
80. Richard Schmalensee, *Evaluating Policies to Increase Electricity Generation from Renewable Energy*, 6 REV. ENVTL. ECON. & POL'Y 45, 45–64 (2012).

FIGURE 5. HOURLY ERCOT LOAD BY SEASON[81]



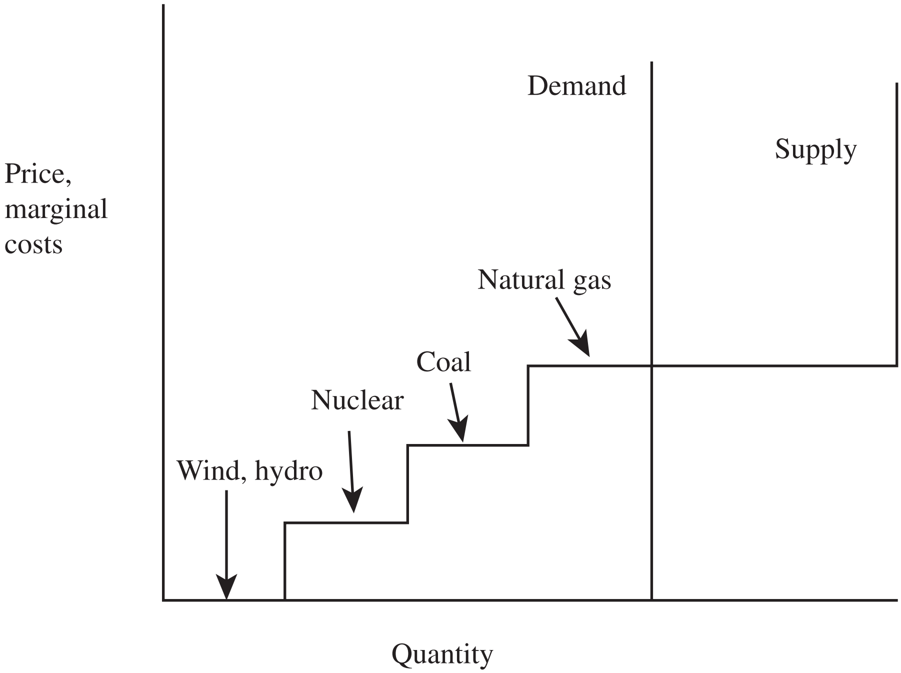
81. ERCOT, HOURLY LOAD DATA ARCHIVES, http://www.ercot.com/gridinfo/load/load_hist/. Each series in the figure plots the hourly load in the ERCOT System for the indicated season, where hourly load is the average across days in 2008.

FIGURE 6. SIMULATED WIND GENERATOR CAPACITY FACTORS[82]



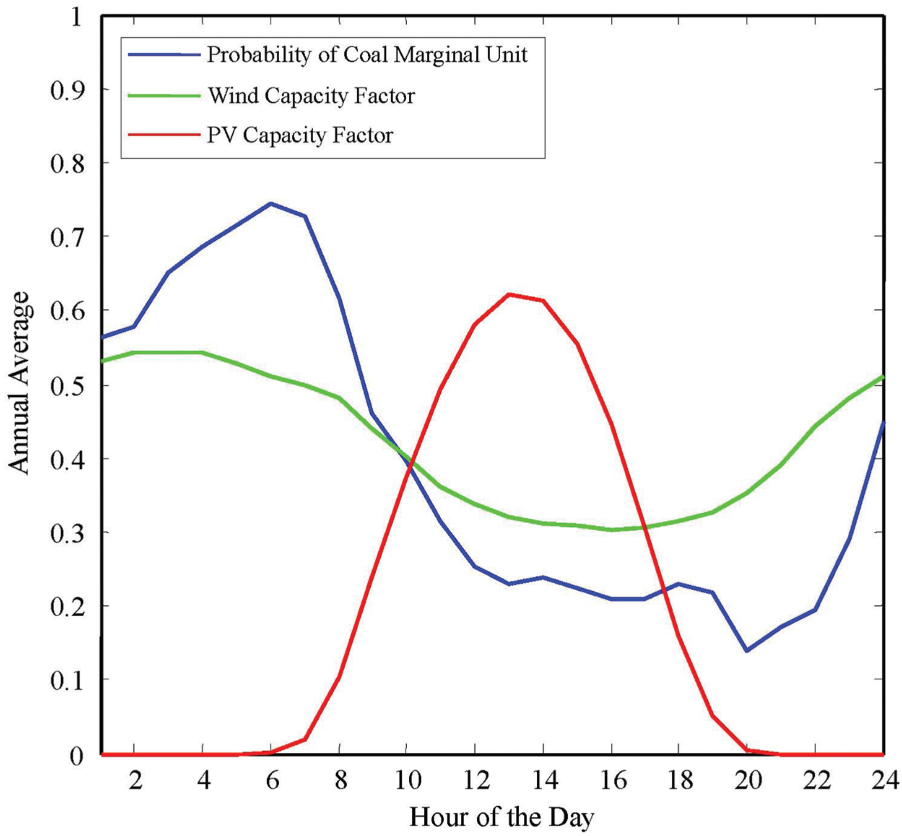
82. Anya Castillo & Joshua Linn, *Incentives of Carbon Dioxide Regulation for Investment in Low-Carbon Electricity Technologies in Texas*, 39 ENERGY POL'Y 1831, 1831–1844 (2011). The figure plots the average hourly capacity factor by season for wind generators in Texas using data from simulated wind generation data from AWS Truwind. The capacity factor is the ratio of simulated generation to maximum generation for the corresponding wind generator, season, and hour. The average is computed over all wind generators in the sample.

FIGURE 7. SIMPLIFIED REPRESENTATION OF ELECTRICITY SUPPLY AND DEMAND IN ERCOT[83]



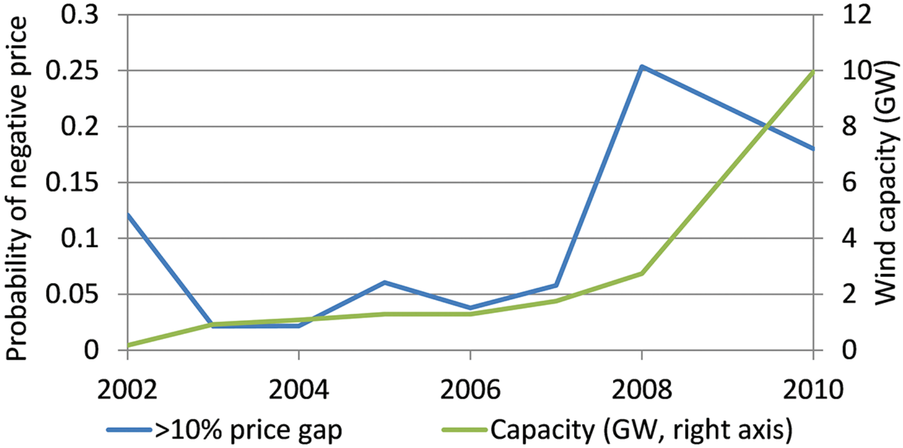
83. The figure plots the vertical demand curve and a simplified supply curve for a particular hour in the ERCOT market. The supply curve is the marginal cost of supplying electricity as a function of the amount of electricity supplied. Each horizontal portion of the supply curve represents the indicated technology. Marginal costs and quantities are not drawn to scale.

FIGURE 8. THE PROBABILITY OF WIND DISPLACING COAL[84]



84. Castillo & Linn, *supra* note 82. The green and red curves show the simulated capacity factors for wind and solar photovoltaic generators, constructed similarly to Figure 6. The blue curve plots the probability that a coal generator is operating at the margin in the corresponding hour.

FIGURE 9. THE PROBABILITY OF LARGE PRICE DIVERGENCE BETWEEN WESTERN TEXAS AND THE REMAINDER OF ERCOT[85]



85. The probability is computed using price data from ERCOT, www.ercot.com. The installed wind capacity is constructed as in Figure 1, from U.S. ENERGY INFORMATION ADMINISTRATION data, http://www.eia.gov/electricity/data.cfm#gencapacity.