

Generating Electricity from Renewables: Crafting Policies that Achieve Society's Goals

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The National Rural Electric Cooperative Association

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by

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I. Executive Summary

Twenty-five states have indicated their dissatisfaction with the current electricity generation system by enacting binding renewables portfolio standards (RPS). They require that wind, solar, geothermal, biomass, waste or other renewable resources be used to generate up to 30% of the electricity sold by 2025. While the authors applaud using renewables to advance important social goals, we caution that forcing too rapid implementation of these technologies could lead to blackouts or unnecessarily high prices.

One reason for caution in forcing rapid deployment of renewables is that large scale wind and solar generation is qualitatively different from using fossil fuels, hydro-electric, or nuclear. Unlike the technologies that have served the industry for a century, wind and solar generation are variable and they generally do not generate electricity when demand is highest. In addition, generating companies face difficulties in fulfilling the RPS goals by the required dates. Getting sufficient wind turbines would require a major increase in manufacturing capacity, since there is about an 18-month delivery delay at present. Siting the wind farms and getting the power to market may be even more difficult because, while the public supports renewables in principle, there is formidable opposition to siting wind turbines and transmission lines. Cost is still another difficulty. Transmission costs can easily double the cost of delivered power. The fact that wind and solar generally do not help meet peak demand means that dispatchable generation is needed for peak demand and so renewables don't reduce the investment in dispatchable power, but rather only reduce fuel use. The variable nature of wind and solar generation requires backup generation or storage to fill the gaps when the wind dies or clouds obscure the sun. The low capacity factors for wind, and especially solar, mean that if they were the only means of meeting the 15-25% RPS, much of the renewable generation would be spilled until large scale electricity storage and transmission lines become much less expensive.

The authors favor continuing to press renewable technologies to solve, or at least mitigate current generation problems, but warn that eagerness to get the benefits of renewables must be tempered with recognition that forcing the timing increases costs and could reduce reliability. However, time pressure can raise costs and make it impossible to attain specified goals. The authors also urge increased R&D expenditures on these technologies, particularly on bulk storage of electricity, to increase reliability and drive down costs. We stress that dispatchable electricity at affordable costs is essential for the economy and our lifestyles. Legislators and regulators must monitor RPS implementation to prevent blackouts or electricity prices that threaten our economic health. Finally, we urge that, rather than focus on a mandate for renewable electricity, the focus should be on all appropriate technologies that meet the goals of pollution and carbon-dioxide abatement, healthy economic development, energy security, and a reliable electricity system that delivers power at a price that doesn't penalize consumers or the economy. In addition to renewables, the technologies may include conservation, more efficient generation, fossil fuels with carbon capture and sequestration, and nuclear power .

There are likely to be two problems in meeting near-term RPS mandates: timing and cost of electricity.

Timing

A combination of subsidies and requirements for small quantities of renewable power has provided incentives that have increased wind's share of generated electric energy to 0.6% of total USA generation and geothermal's to 0.4%. The renewable portfolio standards enacted by states require large increases in those percentages in a short time. Seven years from now, in 2015, eighteen states require that at least 10% of their electricity must come from renewables. California and New York require 25%. Meeting these requirements requires that huge numbers of these power plants be constructed. By 2015, New York must build 10,400 MW of new renewable power, an increase of 26% in its existing generation (that required a century to build). Illinois has legislated that 8,000 MW of new renewables be constructed, a 19% increase in its existing generation. Connecticut requires 1,700 MW of new renewables by 2015, an addition of 21% to its fleet of power plants. Massachusetts has one of the most ambitious near-term requirements: it requires that 3.5% of all electricity be renewable this year, with a half percent increase every year (the requirement is not being met, and utilities are paying penalties that they pass through to customers).

This magnitude of power plant building is not unprecedented, but it is not common. With the exception of the natural gas plant boom-and-bust construction cycle in 1999-2001, these building rates have not been achieved in any seven-year period in a quarter century. Assuming that current manufacturing and skilled labor shortages can be overcome, land use issues for renewable generation facilities and transmission are likely to cause delays in meeting RPS requirement dates. Illinois has mandated that 75% of their RPS be met by wind. This will require negotiations with the owners and neighbors of 1,000 square miles of land on which to site turbines.

In keeping with society's impatience to solve electricity's problems, the RPSs mandate investment that will stretch, or even exceed, industry's ability to meet the goals. For example, a new wind turbine ordered today may not be delivered for 18 months or more. Negotiating land leases and permits often takes years. Unless production facilities for wind turbines are expanded several-fold, the RPS requirements in aggregate cannot be met by the time required in the statutes. In February 2008, Congress refused to extend the production tax credit for renewable electricity beyond the end of 2008, discouraging investments in manufacturing capacity.

Getting renewable power to customers will be delayed by the need to extend transmission lines and get permission to interconnect (in some states, interconnection study delays are projected to last a decade or more). Getting the right of way and permission to build transmission lines is notoriously difficult. For lines more than 50 miles long, the median time to obtain permission and build the line has been 7 years, not counting the lines that never got permission.

States have passed renewables portfolio standards, but have not grappled with what is required to implement them: siting of generators and transmission lines in the time required by the RPS. As currently legislated, many states' RPS deadlines, especially those for 2015 and earlier, are unlikely to be met unless legislators in Congress and state capitals force change in permitting, obtaining the land and permission to build wind farms and transmission lines, and provide the resources to review interconnection applications quickly. While the public appears to support these goals in the abstract, individuals object vociferously to wind farms in some places and to

transmission lines nearly everywhere. In a democracy it is hard to imagine that elected representatives would ignore these intense objections, e.g., the wind farm off Cape Cod.

Cost

Wind is the fastest growing renewable resource. Electricity can be generated by wind turbines for an unsubsidized cost of 8-8.5 cents/kWh¹. Current wholesale daily weighted average power costs in Texas have ranged from 4-7 cents per kWh, 6-8 in Pennsylvania, 8-10 in New England, and 7-9 in California². Thus, the wholesale cost of wind power appears to be competitive in some locations. However, there are three principal problems with wind. The first is that good wind sites are generally located far from load centers. Transmitting the electricity 1,000 miles from wind site to city would double the delivered cost. The second is that the wind generally doesn't blow when electricity demand is high. The capacity factor of all the wind turbines used to generate utility power in the United States has been 21% over the past decade (the best wind locations have a capacity factor of 40-50%). Thus, investment in wind does not lower the amount of dispatchable capacity needed, i.e., the amount of capacity that can be turned on when the demand is high. Wind power saves fuel for other generators, but, for example, if wind supplied 15% of the electricity, it would save considerably less than 15% of fuel. The third is that wind is variable. Rather than wind turbines producing a steady stream of power, electricity from a wind turbine fluctuates continually. If wind produced much of the power required by an RPS, needed transmission, backup generation, and storage to control for variability would increase the cost considerably.

In good locations geothermal power is almost competitive with fossil generation. However, the best locations are clustered in the Southwest. Even there, transmission lines increase the time and cost to bring power to cities.

Biomass might cost-effectively supply a few percent of electricity generation, using farm waste, wood waste and thinnings, and energy crops that used little farm land, if supply chain, delivery, and processing issues can be resolved. Like geothermal, biomass electricity could be almost competitive with fossil generation. However, biomass is excluded from some RPS legislation, generally on the grounds that the most cost-effective use is co-firing biomass with coal, a fuel unfavored by RPS proponents.

The most popular renewable with the public is solar power, either photovoltaic (PV) or solar thermal. Current PV has a non-subsidized cost of 33-61 cents/kWh^{*}, almost ten times the cost of the current electric power generation mix. There are niche applications where solar PV dominates, but the current cost of PV makes it more a subject for basic research than widespread deployment. Solar thermal is cheaper, but, without subsidy, is not competitive except in special applications.

Many current laws assume that public and private R&D will bring down the costs of renewables; for solar photovoltaic they implicitly assume costs will fall by almost a factor of ten; some specify a technology, assuming that the legislature can predict the success of future R&D.

^{*} These costs are without the cost of supplying fill-in power when the solar PV arrays are not producing power. The lower number assumes 8% capital charge rate, \$5400/kW, 20 year life, and 20% capacity factor. The higher cost changes the capacity factor to 14% and uses a 12% cost of capital.

Since renewable sources are variable, when they are used at large scale they will be matched with natural gas turbines to supply steady power. Thus, renewable portfolio standards will increase natural gas demand and its price, increasing the cost of electricity.

RPSs are designed to speed the introduction of new renewable installations. Without careful planning, forced speedups can raise costs by requiring equipment makers to pay overtime to meet demands and by not allowing time for engineers to improve design in the next generation of facilities. The technology improvements in renewables have been significant. However, forcing the installation of facilities before they can benefit from R&D will raise costs. Finally, the current electricity system is not configured to accept rapid deployment of renewables. New transmission lines and approval for interconnections are needed. The former often take decades to get approved and built; MISO has indicated that they will not be able to review all the current applications for connecting wind and other renewables within a decade. The authors favor continuing to press renewable technologies to ensure that social goals are pursued, but warn that eagerness to get the benefits of renewables must be tempered with recognition that forcing the timing increases costs and could reduce reliability.

Conclusion

The authors fear that pressing the introduction of renewables too aggressively would result in high cost, unreliable electricity, leading to a public backlash against these policies. Less aggressive policies favoring renewables in the USA and the rest of the world have brought down the costs of these technologies. The authors favor continuing to press renewable technologies to attain social goals. Attaining the full range of social goals is important, including having an electricity supply that is adequate, reliable, and affordable; electricity is essential for our economy and society. Renewables can help meet the goals, but they are not the only technologies that can; conservation, increases in generation efficiency, fossil fuels with carbon capture and sequestration, and nuclear power can help attain the goals. Increased R&D for these technologies is promising, particularly for bulk storage of electricity. Rather than specifying the technology, the authors urge Congress and state legislatures to specify the goals: lower air pollution and greenhouse gas emissions, lower depletion of fossil fuels, increase energy security, and shift to a more sustainable generation mix that produces an adequate supply of reliable, reasonably priced electricity. Since no current technology meets all goals, legislators need to consider tradeoffs. Specifying the goals, rather than the technologies, will lead to a technology race that will serve society.

II. Background

Electricity is essential to modern life and economic activity. All of the lighting and equipment around us depend on electricity, from computers to natural gas furnaces to telecommunication to elevators and traffic signals. A blackout, such as occurred on August 14, 2003, literally stopped all economic activity and imperiled the health and well being of 50 million people.

This essential energy has come at a price. Generation, particularly that fueled by coal, has led to important environmental problems, from air and water pollution to carbon-dioxide emissions. Shown in Figure 1 is the current fuel-technology mix for USA electricity generation. Through the Clear Air Act, Clean Water Act, and other environmental legislation, society has been striving to get the benefit of electricity without paying such a large environmental price.

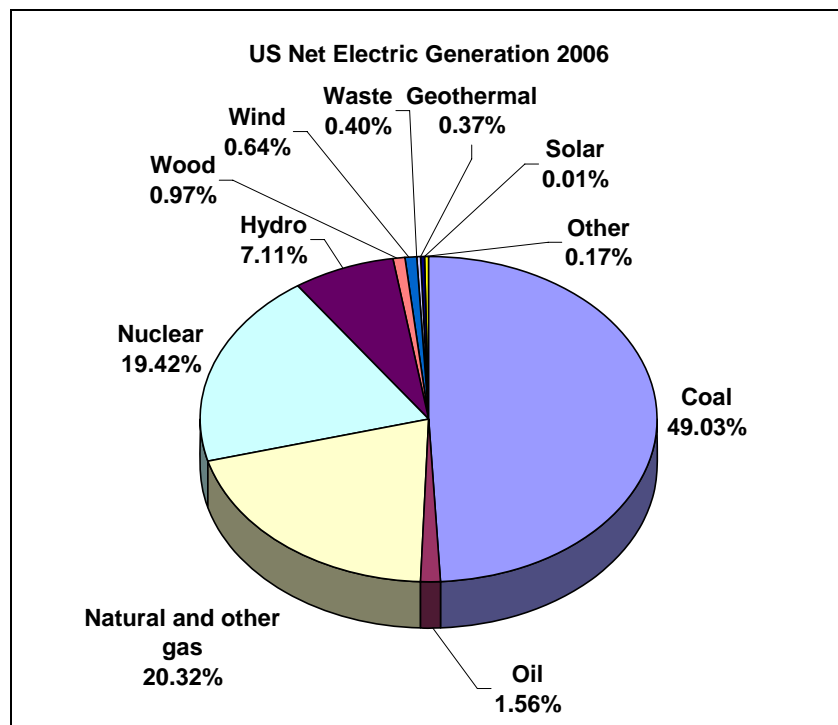


Figure 1. Fuels used to generate USA Electric power in 2006. Source: U.S. Energy Information Administration Annual Energy Review 2006 Table 8.2a.

Implementing environmental legislation has been difficult and time consuming. Coal-fired generation is still producing large quantities of air pollution and the overwhelming dependence on fossil fuel leads to new problems in controlling carbon-dioxide emissions and concerns about depleting fossil fuel resources, particularly natural gas. The US has a huge coal resource, enough to last 100 years or more, depending on how it is used³. Many states that tried deregulation regret it; investment in generation and transmission in these states isn't keeping up with demand. Regulatory and financial uncertainty is paralyzing investment in new coal-fired generation and is delaying investment in transmission. Rapid rises in fuel prices and in the costs of building new generation have added to uncertainty about when and what generation to build⁴.

The energy content of fossil fuels comes principally from the carbon they contain. Burning the carbon (i.e., combining it with oxygen from air), produces the heat to generate electricity, but also produces CO₂. Burning fossil fuels of all types generates 71% of USA electricity (figure 1).

Before the Clean Air Act, using coal or oil to generate electricity made life miserable for many people by emitting large amounts of pollution. Generating electricity from renewable resources has the potential to eliminate electricity related pollution; using renewables can stop depleting fossil fuel resources and eliminate greenhouse gas emissions. Renewable hydroelectric power from Niagara Falls and huge dams on the Tennessee River and throughout the west generate large amounts of electricity. Where it was available, hydroelectric power was seen as inexhaustible and clean. Proponents argued that dams could provide electricity, store water for irrigation, prevent floods, control erosion, and provide lakes for recreation. From being a marvelous, environmentally benign source of electricity, hydroelectric power from large dams has been downgraded to the point where it is not even classified as a renewable by many states. Americans no longer ignore the environmental damage that is caused by large dams, and have turned our attention to other renewable sources.

Electric generation from sources largely free of air pollution has waxed and waned as a percentage of the total. Beginning with the first Tennessee Valley Authority hydroelectric dam in 1936 and the Bonneville dam on the Columbia River in 1937, large-scale hydro power began to come on line. In 1949, hydroelectric power accounted for 32% of generation. After 1949, demand growth outpaced the growth of hydro power and the share of low air emissions generation fell to 18% before nuclear power began to take up the slack around 1970. Although the amount of electricity generated from uranium has benefited from increases in plant operating time and more efficient steam generators, no new nuclear plants have been ordered in the United States for thirty years. With little new low air emissions generation being built, over the past decade its share of generation has been diluted by increasing consumption (figure 2).

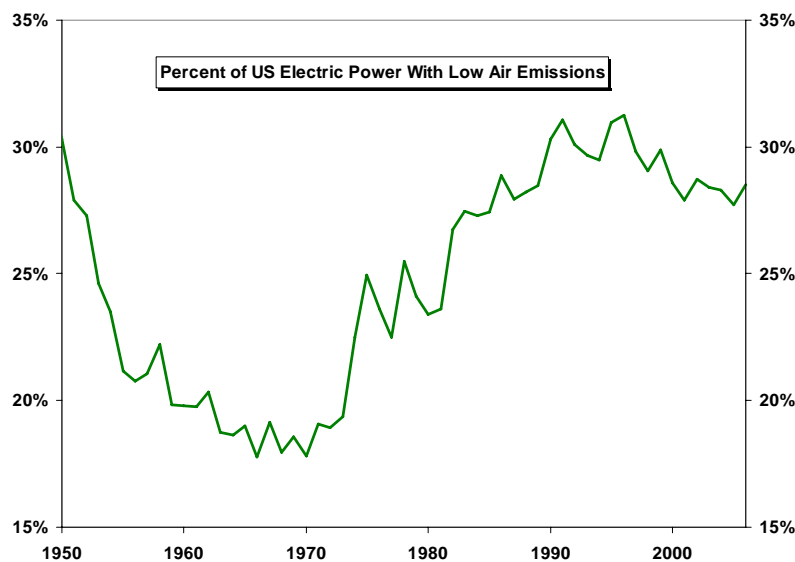


Figure 2. Percentage of net USA electric power generation from hydroelectric, nuclear, geothermal, solar, and wind, 1950-2006. Source: U.S. Energy Information Administration Annual Energy Review 2006 Table 8.2a. Annual fluctuations are largely due to changes in water available for hydroelectric power.

15-30% of all generation built each year has used low air emissions technologies, except during the 1980s when many nuclear plants were completed and during the natural gas generator building boom of 1999-2001 (figure 3).

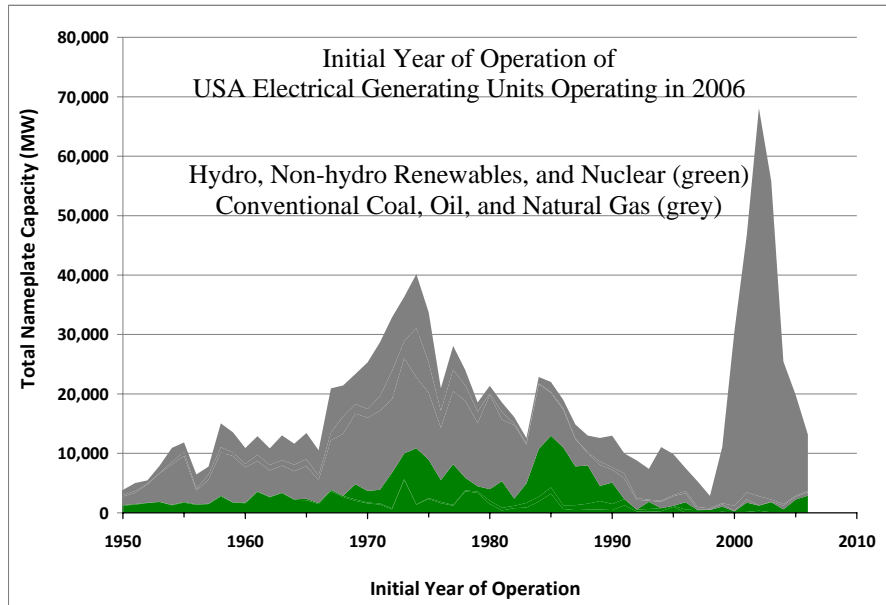


Figure 3. Low air emissions generation technologies (green) and total generation (grey) that were operating in 2006, by initial year of operation. The large construction spike in 1999-2001 was natural gas turbines.
 Source: U.S. EIA "Existing Generating Units in the United States by State, Company and Plant, 2006".

While CO₂ is not the only gas responsible for the greenhouse effect, it is the only one whose USA emissions are increasing significantly (figure 4).

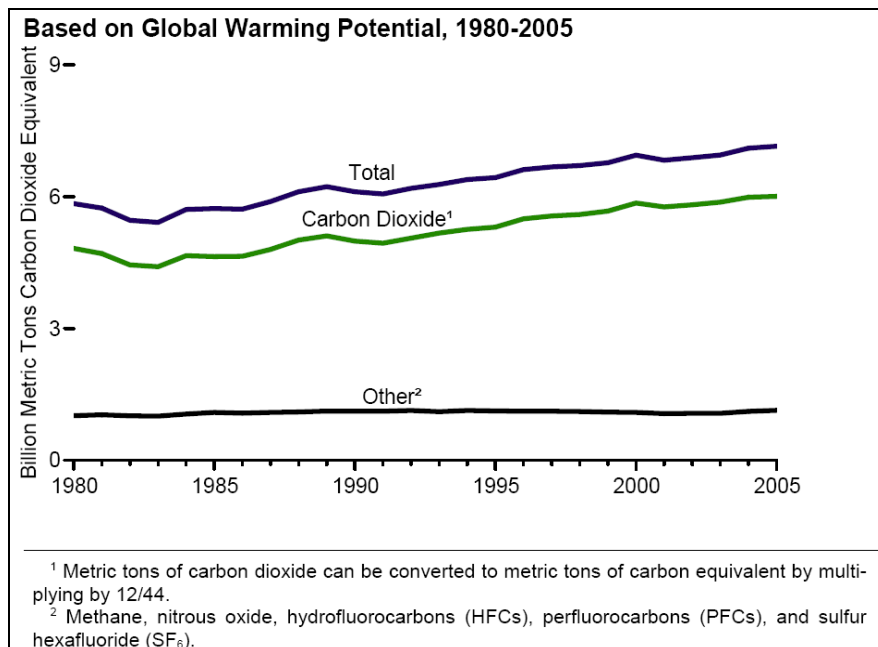


Figure 4. Greenhouse gas emissions in the United States, 1980-2005. Source: U.S. Energy Information Administration Annual Energy Review 2006, Figure 12.1, page 340.

Major air pollutants released by power plants include: oxides of nitrogen (NO_x), sulfur dioxide (SO₂), mercury (Hg), suspended particulate matter (PM) and carbon dioxide (CO₂). NO_x, SO₂ and PM emissions in 2006 were still two-thirds of what they had been 16 years earlier while CO₂ emissions were a third higher. Mercury emissions have been less well tracked, but they appear to have remained steady, or increased slightly (figure 5). The EPA analysis of the benefits and costs of abating air pollution from 1990 to 2010 indicates that the benefits are considerably greater than the costs, especially for air pollution from power plants.

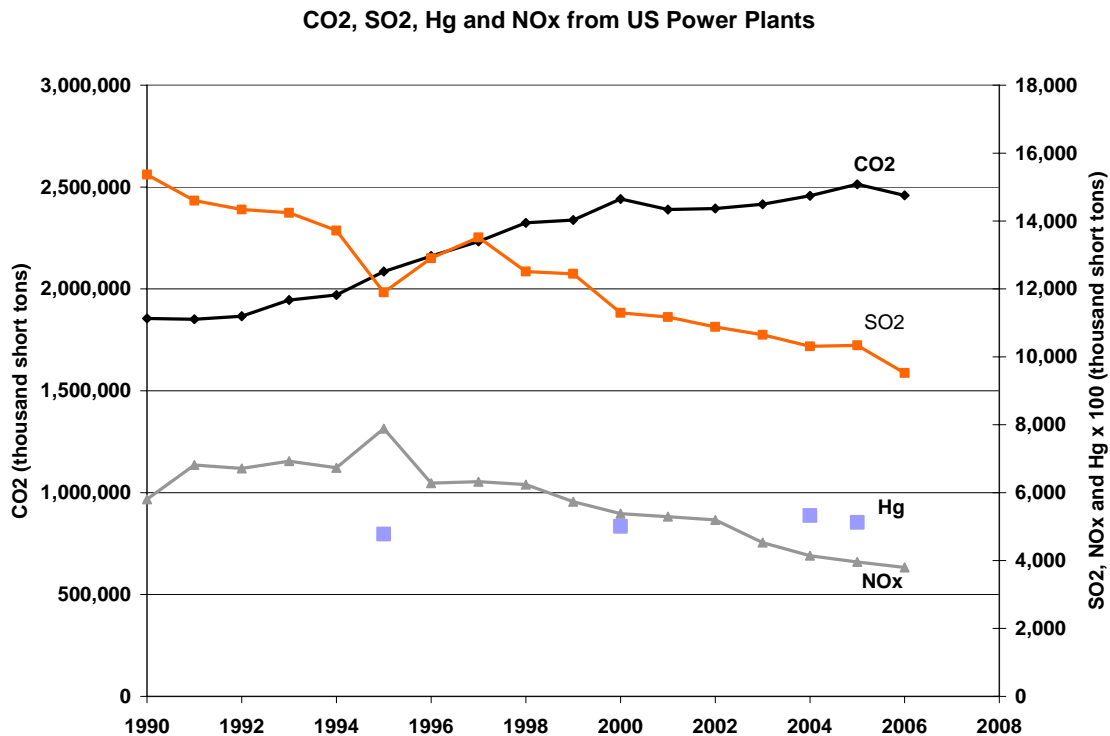


Figure 5. Emissions of the four major air pollutants from electric power plants. Source: U.S. Energy Information Administration Electric Power Annual and Annual Energy Outlook. Data for mercury emissions have been reported only sporadically.

The pollution control legislation of the 1970s has been continually updated and strengthened. Emissions of greenhouse gases that cause global climate change have extended the public's environmental concerns.

Given the limitations of expanding generation from hydro, other renewables, nuclear, oil, and natural gas, it is hard to see how the nation will generate sufficient electricity if no future coal plants are built.

New coal plants need not cause the environmental problems of past plants. Modern control technologies can eliminate over 90% of pollution emissions, and there is demonstrated technology for separating and sequestering carbon dioxide. There is a pressing need to show that geological storage of carbon dioxide will keep the carbon out of the atmosphere for many hundreds of years.

Natural gas fueled generator are the cheapest and fastest to build. As investment in coal-fired plants has decreased, investment has focused on natural gas-fired plants and renewables. Concern for depletion of fossil fuels is particularly evident for petroleum, but also true for natural gas.

Conservation and Energy Efficiency

In comparison with other developed nations, the USA is a profligate user of energy. For example, Americans use more than twice as much energy per capita and per dollar of GDP as Denmark. The comparison across nations or over time for the USA indicates a high potential for conservation.

Unfortunately, some groups are making unrealistic claims about the ability of conservation and renewables to satisfy demand over the next two decades. They claim that no new fossil fuel generation is needed because conservation and renewables can supply our needs. While there is a huge potential for conservation, the most ambitious and successful programs have not managed to do more than slow the growth in electricity demand per person. Insisting that renewables and conservation can eliminate investment in fossil fuel plants is likely to increase the cost of electricity or undermine the reliability of supply.

From 1980 to 2007, electricity consumption per capita in California grew only 9.3%, while per capita consumption in the rest of the nation grew 37.9%. However, total electricity consumption increased 72% in California due to increased population. Since Californians were highly supportive of energy conservation and the state spent billions of dollars to achieve this conservation, it seems unrealistic to expect that electricity demand in the nation will fall or even that demand per capita will fall.

Making Informed Decisions

The authors stress the distinction between the social and the private costs of producing electricity.⁵ The private costs don't account for air pollution or greenhouse gas emissions, as well as other environmental problems, and do not account fully for resource depletion. Environmental regulations since 1970 internalize much of the air pollution costs, but there remain significant health and environmental problems. Despite the decline in electric sector emissions, Congress and states have favored some technologies with large subsidies, such as the production tax credit, rapid depreciation, loan guarantees, limited liability, and portfolio standards. We focus on social, rather than private costs here. We attempt to account for the pollution and greenhouse gas emissions of fossil fuels and the social costs of having structures that people object to, such as wind turbines on the sea coast and transmission lines. The authors also attempt to eliminate tax and other subsidies to the generation alternatives because these distort markets and generally increase social costs.

One of the greatest difficulties is "path dependency." The decision of what to do next depends on where you are now. For example, if an extensive transmission system had been built, wind in remote locations would look much more attractive than if no transmission were available near

the best wind locations. Once a hydroelectric dam has been built, the generation cost is almost zero and there is little likelihood that the dam will be torn down. This path dependency means that mapping a path to a "desirable future" is likely to produce a better outcome than just "muddling through," taking one step at a time without long-term planning.

Renewable Resources

Frustrated with the pace of change on the national level, twenty-five states enacted legislation requiring that a specified amount of electric power be produced using specific technologies. Thirteen of these states require that at least 20% of their electricity will be generated from unconventional technologies, by dates that range from 2010 to 2025 (figure 6).

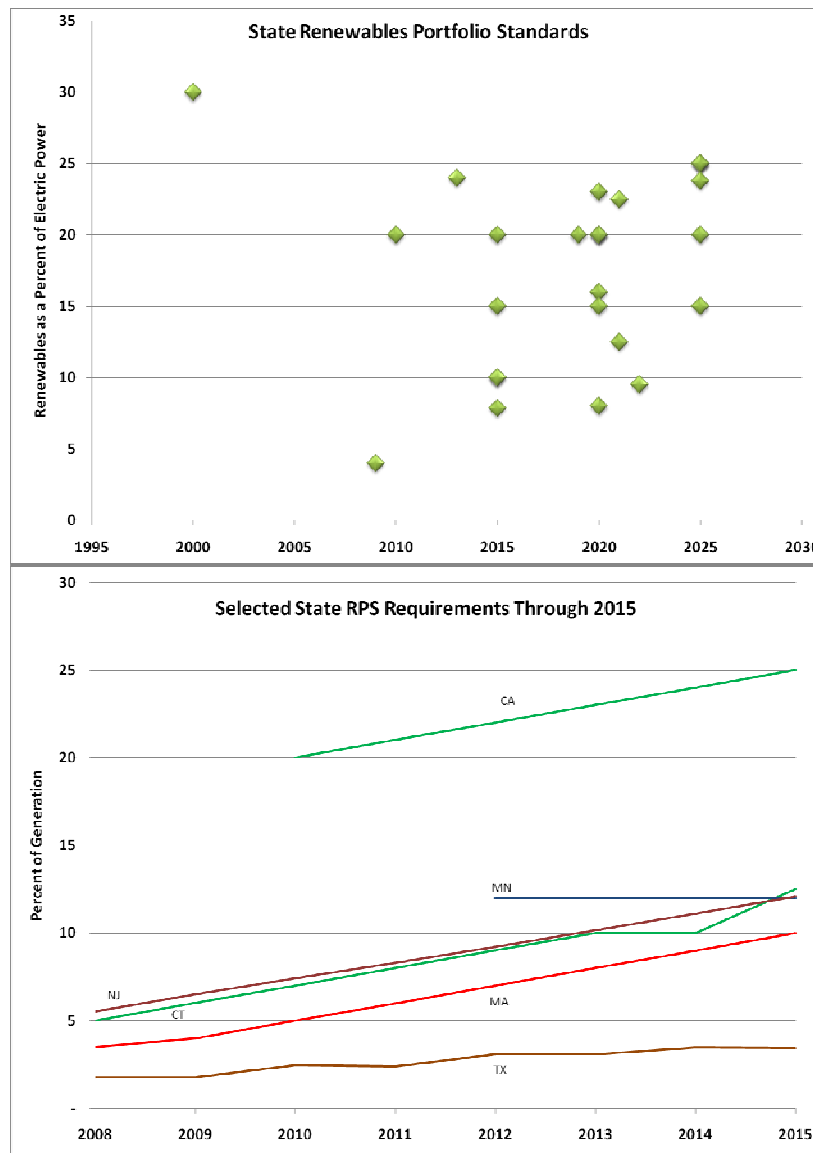


Figure 6. Top: dates and requirements of state renewables portfolio standards (only states with firm requirements are shown). Bottom: near-term requirements in selected states. Source: www.dsire.org.

Proponents of such legislation have argued that the laws will reduce air emissions of CO₂, NO_x, SO₂, PM and mercury, as well as address fluctuating prices of fossil fuels, energy independence, diversity of fuel supply, sustainability, and job creation.

Renewable sources are widely favored by the public as a way to improve emissions. In a survey done to assess willingness to pay for various methods of CO₂ emissions control⁶, the most favored technologies (in order) were solar, hydroelectric, and wind. A national renewables portfolio standard that would mandate that 15% of power come from such sources gathered much support in the Energy Independence & Security Act of 2007, but was removed to avoid a Presidential veto.

Clearly, renewables can be environmentally attractive technologies in terms of reducing pollution emissions, reducing depletion of fossil resources, and reducing greenhouse gas emissions. Unfortunately, renewables can have negative consequences, including changing land use and ecology, creating visually unattractive structures, and possibly increasing the price or undermining the reliability of electricity. These negative aspects mean that a sufficiently large, or unplanned, expansion of renewable resources could give us too much of a good thing.⁷

For example, Massachusetts's RPS is not being satisfied, forcing generators to pay a compliance payment of \$0.06/kWh over and above the cost of procuring power. An attempt to build a wind farm in the ocean off Cape Cod has resulted in bitter controversy and delays that may never be resolved.

The implicit assumption in this legislation is that Congress and some state legislatures know that the right answer for investing in electricity generation is different from what the market would invest in. This sort of "technology forcing" has been tried a number of times in the USA with mixed results. In the case of stringent workplace standards for exposure to vinyl chloride monomer, the results were entirely salutary. For automobile emissions standards, the goals were not achieved until long after the original deadline and society paid a high price that might have been avoided.

Rather than specifying a technology or class of technologies, legislators would be well advised to specify their goals and let the market find the cheapest way of satisfying them. Conservation, increased efficiency in generation, fossil fuels with carbon capture and sequestration, and nuclear power are ways to achieve lower greenhouse gas and pollution emissions, slow the depletion of fossil fuels, increase energy security, create a more sustainable electricity supply, and provide an adequate supply of reliable, affordable energy. Unfortunately, no technology satisfies all social goals. This means that legislators will have to examine the tradeoffs among goals and decide the importance of each. This is hard work, but is more likely to result in a solution that will satisfy society's goals by unleashing market forces to find a solution.

All electricity generation technologies have promising R&D opportunities. Many R&D opportunities exist for bringing down the cost of renewables, particularly photovoltaic. Perhaps the most productive R&D investment would be in improving bulk storage of electricity, the single largest barrier to widespread implementation of renewables. Inexpensive bulk storage would handle both the variability and dispatchability problems with wind and solar technologies.

A Brief Summary of Renewable Technologies

Our review of RPS and other attempts to promote renewables begins with praise for renewable resources, recognizing that they have much to contribute now and still more in the future as the technologies improve. However, the authors seek to avoid costly mistakes, from needlessly high electricity prices to blackouts that could result from uninformed policies. As we show, these unfortunate consequences are not just a hypothetical possibility, but are a likely result of some current policies to force the rapid expansion of renewable resources. Massachusetts has attempted to meet its RPS by adding biomass, wind, solar photovoltaic, and landfill methane. They have fallen far short of the mandate to build about 170 MW each year (for example, less than 5 MW of wind power has been built in the state, and only 3 MW is under construction). Power producers (and their customers) are paying "alternative compliance payments" (currently 6 cents per kWh, adjusted annually for inflation). Trading renewable credits would lower costs by utilizing the best wind and solar sites. However, a vast amount of additional transmission still would be needed and some regulations would have to be changed about where the generation could be located to count in the RPS.

Renewable energy sources promise to overcome pollution, fossil fuel resource depletion, and global climate change problems. Wind, solar, solar thermal, geothermal, run-of-the-river hydro, and ocean tides and currents don't use fossil fuel resources and so produce no direct emissions of pollutants or greenhouse gases in generation. Fossil fuels are used and emissions produced in manufacturing and maintaining the equipment, as well as in dealing with variability and dispatchability issues. Biomass is one of the most promising renewables at small scale, although it can produce significant pollution emissions. One of the goals of renewables portfolio standards is to force electricity generators to reevaluate the role of renewables and to force development of the technology to make them more competitive.

The authors recognize the inherent attractiveness of renewables and applaud actions to speed their development and allow them to compete fairly with fossil fuels in an industry that feels less comfortable with renewables than with the fossil fuel technologies with which they have had more than a century of experience.

Wind, solar PV, and solar thermal, the most popular renewable technologies, pose unique problems. Fossil fuel generators can be turned on and off when desired, running when and at the level desired. In contrast, wind, solar, and similar renewables provide electricity when the wind blows, the sun shines, the tide comes in, etc. In most locations, intermittent renewables cannot be depended upon to provide peak power, or any power, when demand is high. As long as customers want an adequate supply of reliable electricity when they want it, the systems operator will need dispatchable generation that can be dispatched to meet the peak annual demand (including a reserve). In most locations, no matter how much wind generation is available, this does not reduce the need for dispatchable generation (including storage).

Thus, having wind generation will not reduce the investment needed for dispatchable generation plus storage. Wind and solar generation will reduce fuel consumption by allowing renewable power to substitute for other generation when the wind is blowing or sun is shining. A recent GE report for ERCOT⁸ used actual data from Texas wind farms scaled up to 15,000 MW along with

actual load data to simulate the system when 30% of power, on average, was provided by wind. The results (figure 7) show that on one day of the 31 graphed, the wind output fell to zero; on four other days it fell nearly to zero. The systems operator must have sufficient capacity of dispatchable generation to satisfy the peak demand. In order to meet RPS requirements that call for large amounts of variable and non-dispatchable power, natural gas generators must be sited, permitted, and built at the same time the wind or solar is being built.

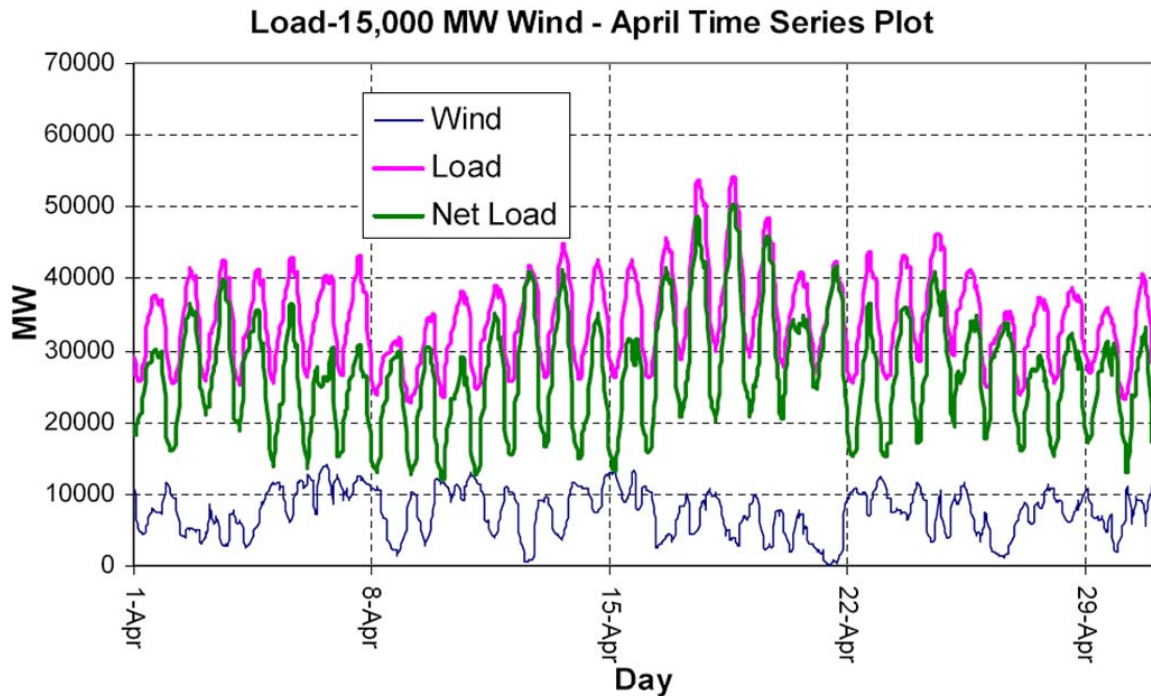


Figure 7. Estimation of 30% (15,000 MW) wind penetration in ERCOT scaled using measured data from existing wind. Wind is the lower curve, and falls to near zero output on five days of 31. Source: ERCOT

Consider the extreme case where wind or solar were the only power available. If so, electricity would either have to be stored in large quantity or people would have to live without electricity for much of the time. For example, the nation's largest photovoltaic array, in Arizona, had a capacity factor[†] of 19% over 2 years and generated little power between 5 and 6 PM when demand peaked⁹. Good wind farms in the East have a capacity factor of 32% while some in the West have capacity factors up to 49%.

In addition, each system has "must-run" generators that are needed for voltage support and where transmission capacity is inadequate. Finally, some baseload generators are not turned off because of the difficulties of shutdown and restart when they will be needed a few hours later. Nuclear plants are a prime example, although no one would shut down a baseload coal plant that would be needed later that day to meet demand. Finally, wind tends to be strongest at night and in the spring and fall, times when electricity demand is low. If the average demand for PJM in 2007 is indexed at 100, the lowest demand was 69. A RPS of 15% by total energy met by wind would

[†] There are 8760 hours in a year. If a 1 MW generator produced 8,760 MWh each year, it would have a capacity factor of 1. A capacity factor of 19% means that it produces $0.19 \times 8760 = 1,666$ MWh per year.

require wind capacity of 45, since the wind capacity factor is only 1/3 in PJM. If the 45 units of wind power were generating fully, they would produce almost 2/3 of the load at the lowest demand hour. The variable nature of wind means that gas turbines would be needed to fill in the gaps in wind generation. Finally, the must-run plants would be generating electricity even if supply exceeded demand. Thus, generation would exceed demand and a considerable proportion of the wind power would be wasted at low demand times.

Integrating renewables into the grid gets more complicated as the proportion of renewables increases. Non-hydro renewables average about 2% of generation across the USA at present, with half of that from wood, mostly in pulp and paper plant co-generation (so only around 1% of grid-connected power is from non-hydro renewables). Although the output fluctuates, utilities treat renewables as reductions in load, rather than generation. Since load is variable, the system provides for fluctuations of 2% up and down to handle these fluctuations. A small amount of renewable power, say 1%, just adds to the fluctuation. If wind were uncorrelated with demand fluctuations, a utility would have to provide for fluctuations of 3% up and down. Load serving entities seem to have decided that providing 2% for regulation was too conservative and do not think that adding the current amount of renewables creates a problem. The authors note that adding the renewable power with increasing provision for fluctuations reduces the ability to deal with contingencies.

However, as renewables assume a larger role in generation, the system must provide explicitly for these fluctuations. It can do so with gas turbines or with hydroelectric generation that adjusts quickly to wind fluctuations. In the future, it should be possible to adjust for variability in generation with adjustments in load, but that is not possible today for most of the load.

Another difficulty with renewables is that many of the best generation sites are not located close to the load. For example, the best wind generation sites are located in North Dakota and Wyoming, 800 miles from the large loads. The best solar sites are in the desert Southwest. Good geothermal sites are concentrated in the Southwest. Building long transmission lines is expensive and is opposed by the public. Transmission lines are unsightly, are regarded as a health hazard by some people, and are opposed by people near the route of a long line on the grounds that they get no benefit from the line.

For a region such as the Southeast, there are no good wind or geothermal resources, and solar energy is limited by frequent clouds. Given the costs of other renewable technologies, the only cost-effective alternative is biomass. Whether generators in the Southeastern states can buy sufficient biomass at a reasonable price and adapt their boilers to handle it is unclear. If they have to buy electricity generated from wind, they may have to go a considerable distance to get it. If the states must actually take delivery of the wind power, large investments would be needed and public opinion in the states along the way would have to, at least, not strongly oppose the transmission. If the region need merely buy renewable energy credits, a different problem arises. In this case, the areas with the best wind resources would sell renewable energy credits while increasing renewables beyond the RPS. For example, areas like North Dakota and Wyoming might have wind provide most of their entire average load, with fast ramping fossil generations to fill the intermittency gaps and the times when the wind is not blowing.

An RPS generally specifies energy billed to the customer, not capacity (Texas is an exception). This leads to problems as the following example illustrates. Suppose the average system load were 50,000 MW, the system peak was 90,000 MW and the system minimum was 30,000 MW. If the RPS were 15%, wind or solar generation would have to average 7,500 MW (65,700,000 MWh/yr); if the RPS were 25%, wind or solar generation would have to average 12,500 MW (109,500,000 MWh/yr). To generate an average of 7,500 MW with a capacity factor of 33%, wind farms would have to have a capacity of 22,500 MW; to generate 12,500 MW, wind farms would have to have a capacity of 37,500 MW. Since its capacity factor is only 19% (even in Arizona), solar PV would require much more capacity: 39,474 MW for a 15% RPS and 65,789 MW for a 25% RPS.

Since both wind turbines and solar PV are variable and generate only a fraction of the time, the system would need an array of baseload generators and fast-ramping generators. Many of the baseload generators would be “must-run” and the fast-ramping generators would be needed when the renewables were generating power. A baseload coal or nuclear unit would not be shut down when the solar array was generating power because it would be needed in a few hours. Since system demand falls to 30,000 MW at times and since the must-run and fast-ramping generators are needed, there would be some times for the 15% RPS when wind, and especially solar, generation together with the dispatchable generation exceeded demand. For the 25% RPS, there would be many times when the combination of wind, and especially solar, generation together with the dispatchable generation exceeded demand. When that occurred, the renewable power would be spilled. One implication is that still more wind or PV capacity would be needed to meet the RPS for energy.

Table 1
Effect of an RPS

	Wind (capacity factor 33%)	Solar PV (capacity factor 19%)
15% RPS: 7,500 MW	22,500 MW	39,474 MW
25% RPS: 12,500 MW	37,500 MW	65,789 MW

To produce 15% of the annual electricity, renewables would have to generate 65.7 million MWh during the year. With a capacity factor of 33%, wind would require 22,500 MW of capacity; with a capacity factor of 19%, solar PV would require 39,474 MW of capacity. To produce 25% of the annual electricity, renewables would have to generate 109.5 million MWh during the year. This would require 37,500 MW of wind capacity or 65,789 MW of solar PV capacity.

The system average power demand is 50,000 MW and the lowest demand is 30,000 MW. Given the must-run generation and the fast-ramping generation, much of the renewable generation would be spilled, especially for solar PV and most especially for the 25% RPS.

If a state specifies the amount of electricity that must come from renewables, but does not specify how much a specific renewable must contribute, this is both good and bad. The good aspect is that the implementers have a relatively free hand, generally unconstrained by what the

state government assumed the right answer to be. The bad aspect is that it puts the implementers in the position of persuading the people who must live with new wind turbines and transmission lines that something they like in the abstract should be located close to them. Government gets to deal with the issue in abstract generalizations. The implementers must deal with the individuals who believe their vista is being ruined, who think that the transmission lines harm their health or degrade their property values, and who don't see why they should be singled out to bear the burden. Implementation would be helped if the government provided careful, convincing analysis to support the RPS and data to support a choice of which renewable and where it should be located.

The impatience of the public to solve current problems has resulted in strict deadlines for meeting the RPS. The authors favor continuing to press renewable technologies to solve, or at least mitigate current generation problems, but warn that eagerness to get the benefits of renewables must be tempered with recognition that forcing the timing increases costs and could reduce reliability. However, there is a considerable risk that the deadlines will not be met, despite the best efforts of generators. For example, generators in Massachusetts are forced to buy alternative compliance payments for part of the 3.5% RPS now in effect. The \$0.06/kWh price for these payments essentially doubles the cost of electricity generation. Despite this considerable cost incentive, generators have not been able to get regulatory approval for a large wind farm in the ocean off Cape Cod.

III. Detailed characteristics of available technologies for low air emissions

The authors begin with two observations:

1. "Low air emissions" and "renewable" are not synonyms. Some renewable power, such as burning wood products, can emit significant quantities of air pollutants. Some fossil fuel generation technologies, such as coal gasification with CO₂ capture, can emit less air pollutants than some renewable generators. Similarly, some non-renewable technologies, such as nuclear, produce no CO₂ emissions, do not deplete fossil fuels, and contribute to energy security.
2. What differentiates technologies that may look great in a laboratory or in a Sunday supplement article but not make a significant contribution from those that can is *scalability*: the ability to be deployed at large scale at affordable cost and with acceptable environmental and social consequences. One efficient wood-burning stove looks cozy; a city full of them would generate sufficient air pollution to be a health hazard as well as a nuisance.

Wind

Wind power has been deployed in 27 states, and generates about half a percent of USA electric energy. Wind and geothermal are, on a percentage basis, the fastest growing electric power sources. At the present rate of growth, wind will supply 2.5 to 10% of USA electric energy in 2020.¹⁰

Public opposition to wind has developed in both the USA and the U.K. even at the present low penetration of wind power, principally related to land use.¹¹ The American Wind Energy Association (a wind power trade group) recommends that wind farms be sized for about 60 acres per megawatt (MW) of wind capacity.¹² That compares to about 1 acre per MW for geothermal, 10 for solar photovoltaic, 6 for solar thermal, 0.4 acre for natural gas turbines, and 0.4 acre per MW for a coal plant if the area used for surface mining is included. While this acreage may be necessary for sizing wind farms, this does not mean that the land cannot continue to be used for other purposes, but it closes off some resale options. A wind farm that supplied present USA electric energy needs would cover an area roughly the size of the state of New York. Both visual impacts and other land uses have made wind farms controversial in areas such as Cape Cod, Long Island, and West Virginia.

Of course, the wind does not blow all the time. If a 1-MW wind farm's capacity factor were 21%, it would generate $0.21(8,760) = 1839$ MWh/yr. The capacity factor of all the wind turbines used to generate utility power in the United States has averaged 21% over the past decade.¹³ Moreover, the output power of a wind farm varies even on quite short time scales. The variability of the output power from wind farms can be somewhat reduced by tying the output of widely separated units together. However, even when that is done, a great deal of variability remains in the output power (figure 8). By comparison, a new baseload coal plant has a capacity factor of 80% and a nuclear plant has a capacity factor of 90% and each provides dispatchable power with no variability.

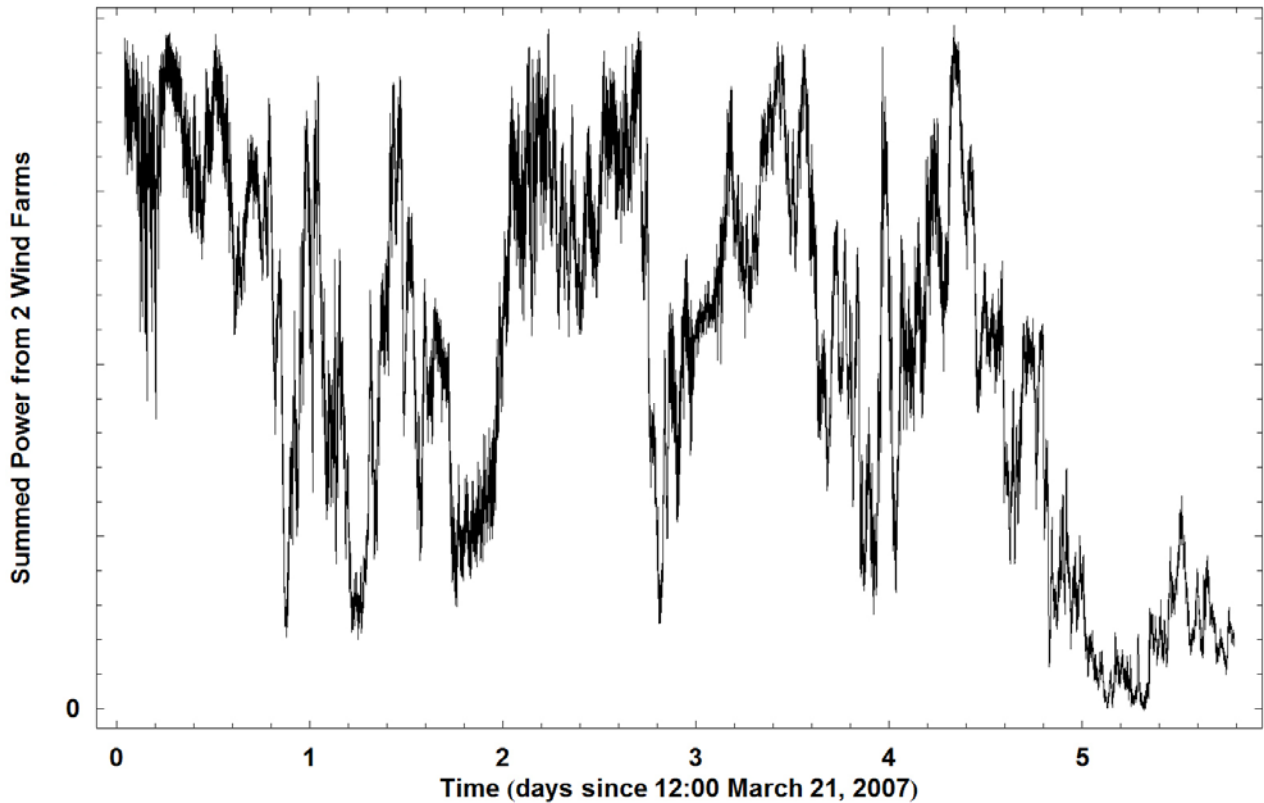


Figure 8. Summed output power sampled at 10 second intervals from two large wind farms in Texas and Oklahoma separated by 500 km for 6 days in March 2007.

When wind makes up a small percent of total generation, this variability is of little consequence. However, if wind is to be used at large scale, other power sources must be used to compensate. In West Denmark, wind produces 24% of the load, but large transmission lines to Germany and Scandinavia distribute electricity to other areas when wind generation exceeds local demand; the transmission lines also allow fast generators to compensate for fluctuations (wind makes up less than 3% of all electric energy produced in Europe as a whole). When one of the two lines to Germany was out of service for maintenance, all of the fossil fuel generators in Denmark were required to be running to provide support for wind fluctuations. Spain (9.8%), Portugal (7.6%), and Germany (6.8%) have lower contributions from wind, but variability is a concern.¹⁴

Compensating for wind's variability is generally feasible, however, there are two consequences. First, it increases the capital cost of the system, since the fast reacting power generator is operating below full capacity. To match wind's variability at different time scales, a range of power sources is needed.¹⁵ Fast devices including batteries, fuel cells, or super-capacitors, with relatively low power would match the short-period fluctuations, while slower ramp rate sources including gas turbines and coal plants with automatic generation control would match the longer period, higher amplitude fluctuations. In some areas, additional transmission must be built to get power from the firm power sources to where it is needed. Second, the non-wind sources are not operating at their maximum efficiency when they must ramp their power up and down to cancel out the wind's fluctuations. That means that they use extra fuel, and that their air emissions may

also increase. Using data from operating wind farms and natural gas turbines, Katzenstein and Apt at Carnegie Mellon University have shown that because of this effect the reduction in CO₂ emissions when wind is introduced into a power system is only 80% of what would be calculated ignoring the inefficiency caused by ramping the gas turbines up and down.

In most areas of the country, the wind is stronger at night than during the day (figure 9). The average capacity factor was 40% at night and 27% during the day for the data in figure 9. Demand for electricity, however, is highest during the day. This means that at night wind supplies a much larger fraction of energy than its average supply. For example, if wind supplies 15% of power averaged over all hours, it may supply more than half the power at night and only a small fraction during the peak use period.

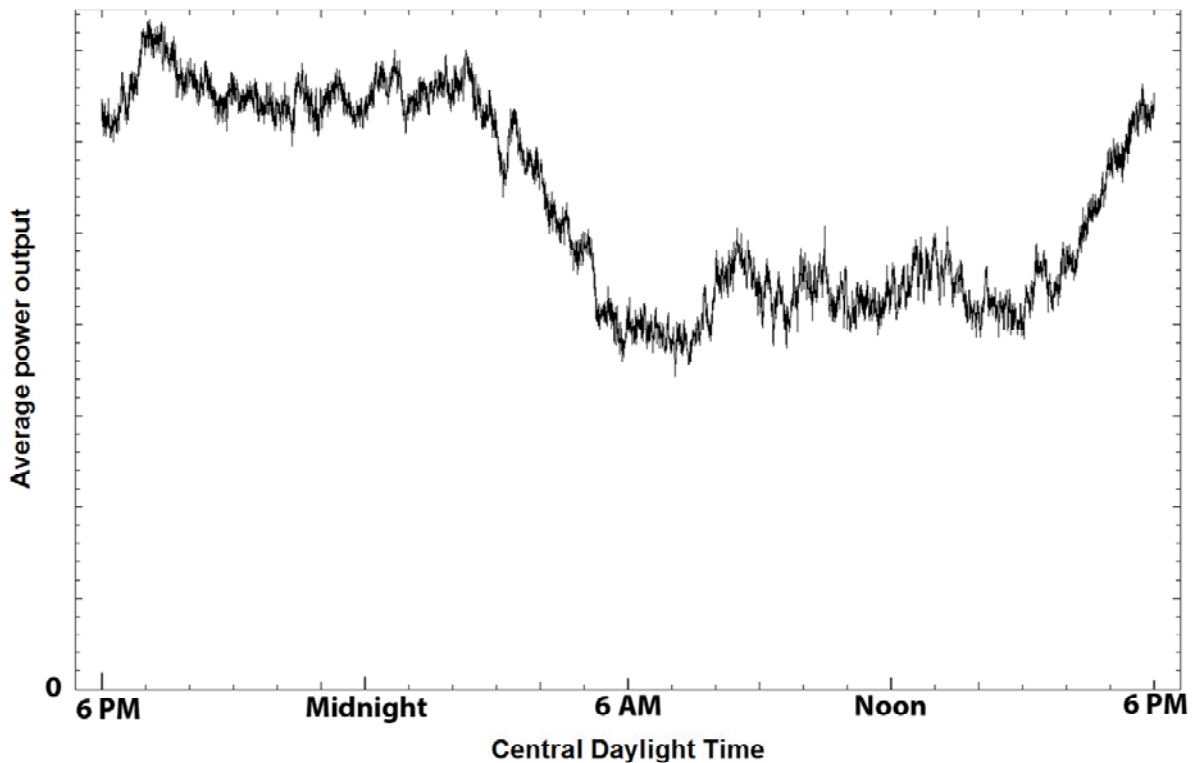


Figure 9. Output power from a large Texas wind farm by time of day averaged over 15 days in March 2007.

For most USA customers, the seasonal peak demand for electricity occurs in summer (due to air conditioning). The National Research Council studied electric demand and wind's capacity factor in the Allegheny mountain regions of West Virginia, Pennsylvania, Virginia, and western Maryland, finding that wind power production is strongest during the winter, while demand for electricity is stronger in the summer (figure 10).

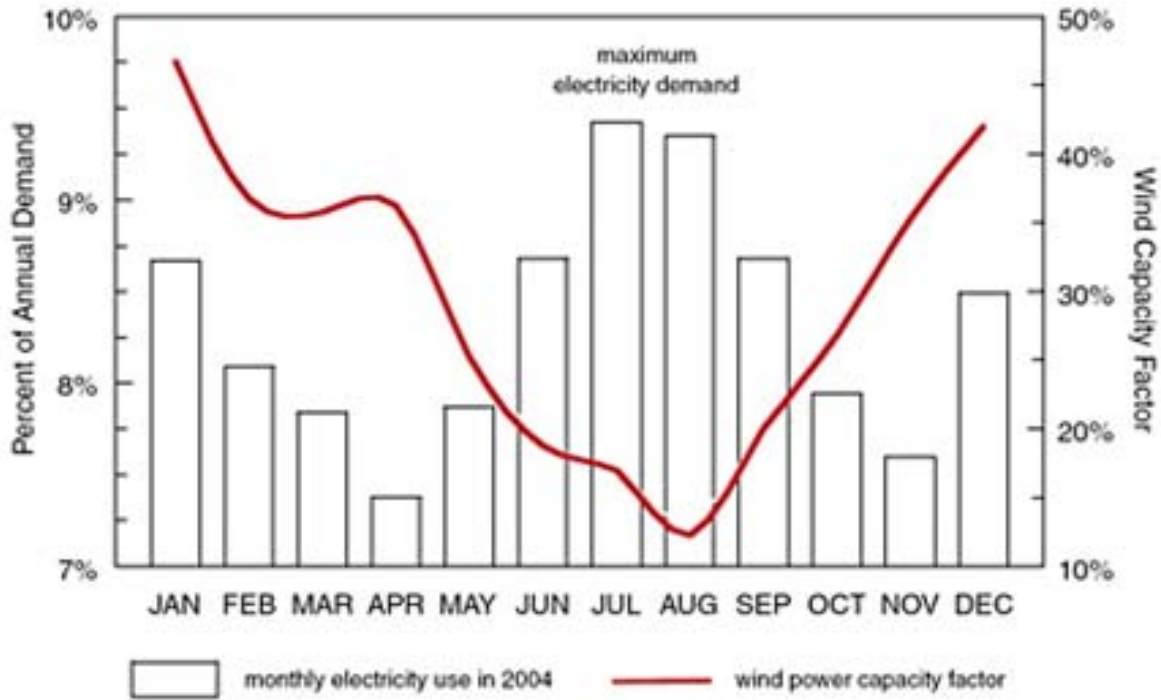


Figure 10. Monthly electricity demand and wind generation capacity factors in the Mid-Atlantic Highlands. Source: National Research Council

People do not tend to live where the wind blows strongly, so that long transmission lines are required to bring wind power to cities. In Texas, for example, the distance from the nearest windy area to Dallas is 300 km. Constructing a transmission line of that length is a billion dollar project. And while the median wind farm has been constructed in 3 years (much less time than required for a coal-fired plant, for example), the median transmission line of over 80 km length has taken 7 years to build (figure 11).

Time to construct USA transmission lines of greater than 50 miles

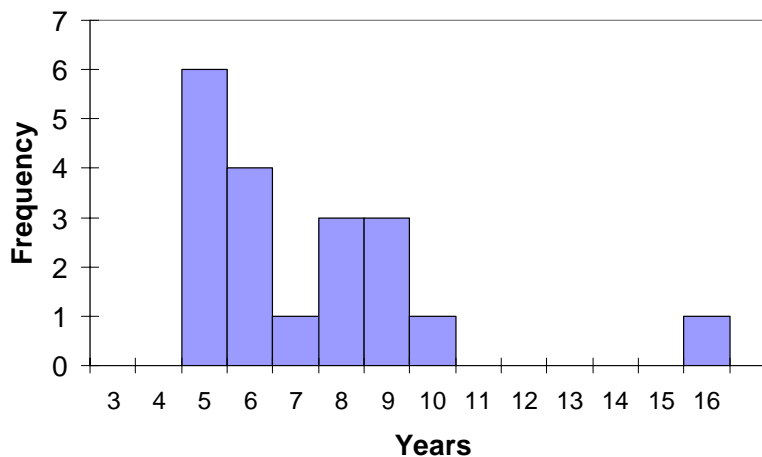


Figure 11. Time since public announcement to construct USA transmission lines of over 50 miles since 1990.

While a study done for the American Wind Energy Association by American Electric Power¹⁶ forecasts that an investment of \$60 billion of transmission projects is required to support a 20% wind RPS, transmission construction is virtually frozen in many states.

New work by Pattanariyankool and Lave at Carnegie Mellon University using actual wind farm data shows that generating power from wind farm and transmitting it 1,000 miles would cost about 15 cents/kWh, with half of the cost due to transmission. The 1,000 miles distance is about the distance from a good wind site in North Dakota to Los Angeles assuming that the transmission line could be sited. The 2005 Energy Act empowers the USA Department of Energy to designate "transmission corridors" to minimize delays in siting new lines. To date, the corridors designated have stirred intense opposition. It is far from evident that it will be possible to build transmission in these corridors.

NIMBY objections to transmission as being eyesores are more vehement for wind turbines. The best wind conditions are on the tops of mountains and ridges or in the oceans close to shore. Many Americans object to seeing a wind turbine in these places, believing that it ruins the natural beauty of the mountains and sea coast. The difficulties in siting wind turbines are exemplified by the proposed wind farm off Cape Cod in Massachusetts. Even some leading environmentalists have objected to siting the turbines in this location on the grounds that they ruin the natural beauty of the area.

The authors estimate the cost of electricity from a new wind turbine in a good site to be 7-8 cents/kWh. This cost does not include transmission to the customer, technology to correct for rapid fluctuations, and backup generators for when the wind is not blowing.

The wind resource is not uniformly distributed throughout the country (figure 12). The upper Great Plains states have very high potential for producing wind, while the southeast has little. As noted by the National Research Council,¹⁷ "93% of potential wind energy capacity occurs west of the Mississippi river."

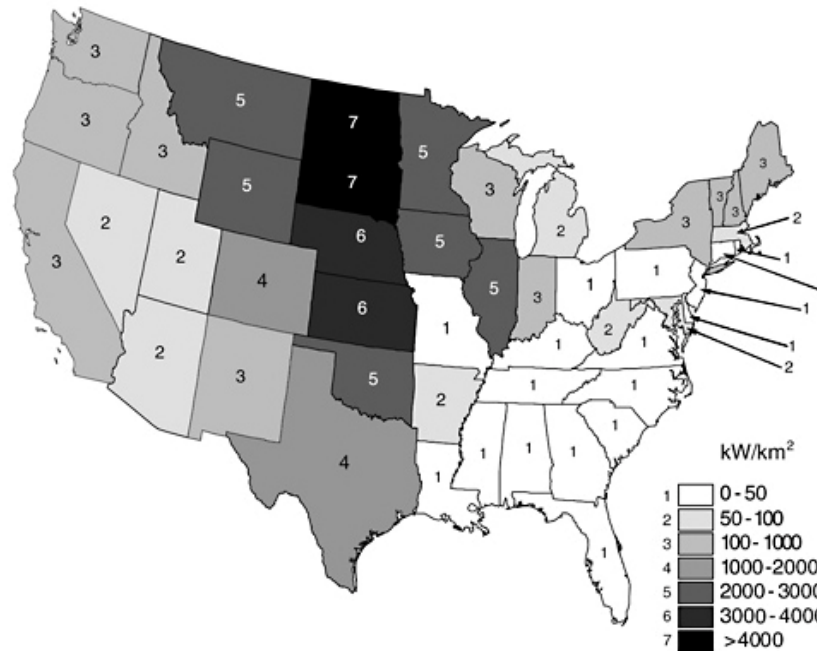


Figure 12. Onshore wind energy potential. Source: National Research Council

Finally, wind energy is a finite resource. At large scale, slowing down the wind by using its energy to turn turbines has environmental consequences. Locally, wind farms may significantly slow down the wind and changes the mixing of air near the surface, drying the soil under some conditions.¹⁸ At planetary scales, David Keith and co-workers found¹⁹ that if wind supplied 10% of expected global electricity demand in 2100, the resulting change in wind energy might cause some regions of the world to experience temperature changes of approximately 1 °C.

None of the foregoing is meant to imply that wind cannot be a valuable component of future electric supply. It is not a panacea, but can contribute to reducing air emissions in regions where the land use for the wind turbines and transmission lines is acceptable to the public and the wind blows strongly.

Solar

Using the sun's energy has captured people's imagination for many years. The amount of solar energy that reaches the United States each year is equivalent to approximately 4,000 times the nation's total electric power needs. Electric power can be supplied by solar photovoltaic (PV) arrays (semiconductor cells) and by solar thermal systems (the sun heats a fluid that generates steam, which drives a steam turbine).

Currently the largest solar PV array in the USA is in Arizona, a 4.6 MW system operated by Tucson Electric Power. Over two years of operation, the capacity factor for that generator has averaged 19%. Even in Arizona, clouds cause rapid fluctuation in the array's power output (figure 13).

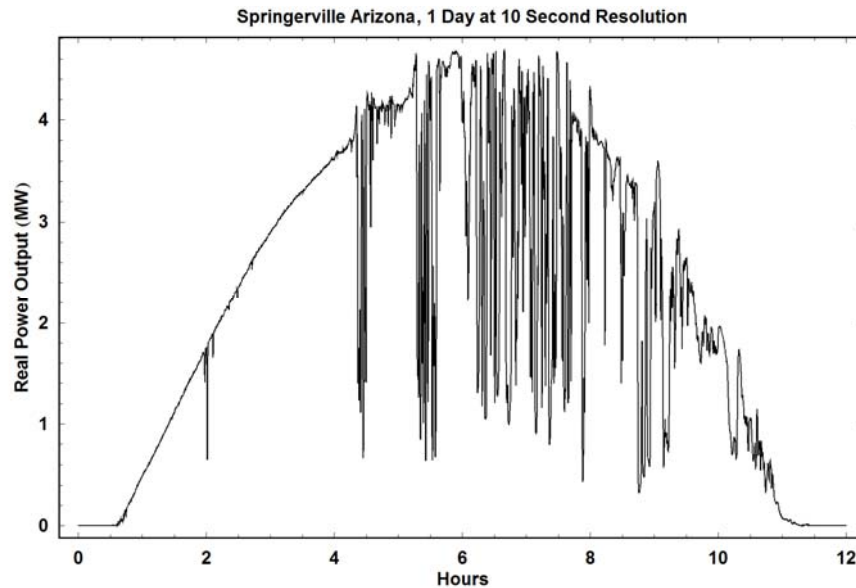


Figure 13. Power output of the Springerville, Arizona solar photovoltaic array on February 25, 2007 recorded every 10 seconds. The overall bullet shape is due to the amount of sunlight that falls on this fixed array through the day, while the rapid power fluctuations are due to clouds passing between the sun and the array. Over two years the average capacity factor was 19% (see reference 20).

The power fluctuations in the 10 minute to several hour range of four solar arrays studied in Arizona are relatively larger in magnitude for solar PV than for wind, and the smoothing due to combining PV sites separated by 300 km is less than for wind sites.²⁰ This implies an increased need, relative to wind, for other power sources or demand response to compensate for PV fluctuations in this frequency region. This increased need for quick response is likely to make compensating for the variability of solar PV more expensive than for wind.

Solar arrays produce more power, and for more hours, in the summer than in the winter. The capacity factor for three Arizona arrays in July 2006 was 26%; their capacity factor in January 2007 was half that value.²¹ In the desert southwest, that behavior is a good thing, since the air conditioning load is highest in the summer. The same would not be true in climates whose peak electric load is in the winter.

Assume that PV were the only renewable, it had a measured Arizona capacity factor of nearly 20%, and there was a 15% RPS. Assume that the average use was 100 MWh and thus PV had to contribute 15 MW on average (131,400 MWh/yr). To get that much generation, utilities would need to build 75 MW of PV capacity in order to get average generation of 15 MW (131,400 MWh/yr), an extraordinarily high capital cost. At noon on a mild June day, the solar array would generate 75 MW of power, which would likely exceed demand, considering the must-run generation and the fast-ramping fossil power needed to fill in the gaps in solar generation. To achieve the 15% RPS, more than 75 MW of solar capacity would be needed, since some of the generation could not be used.

Solar PV system costs are the same as they were five years ago, although there is a recent very slow decrease in module prices. Unsubsidized costs in the best sites can be as low as 35 cents per

kWh. However, in non-desert sites such as Florida they can be 45-50 cents per kWh. Solar thermal systems are roughly 2/3 the cost of solar PV systems.

The data from Arizona indicates that the PV is not producing much power at 5-6 PM, the time of peak demand. Thus, the utility would still need dispatchable capacity sufficient to supply the highest demand (plus a reserve). There would still need to be gas turbines to smooth the variability of PV output. However, since the air conditioning demand is highest when the sun is shining on a hot day, less of the PV generated electricity would be wasted.

Solar thermal systems such as the new 64 MW Nevada Solar One installation should have smoother output power than solar photovoltaic systems, since the thermal inertia of the oil used as a working fluid is expected to continue producing electricity despite the fluctuating thermal input. Since this facility became operational only in June 2007, a full year of data is not yet available. Published reports²² indicate that it is expected to have a capacity factor of 24%. The thermal inertia in the system takes care of the momentary fluctuations, but does not allow generation when the sun is not high. Molten salt energy storage will be used to store energy for a few hours in order to better match evening load.

The distribution of solar energy depends on the season, location, and cloud cover. The National Renewable Energy Laboratory has estimated the annual average solar energy that a solar PV or solar thermal system can make use of (figure 14); the resource is unevenly distributed in the USA. However, some of the fastest growing regions of the country are located where good solar resources exist.

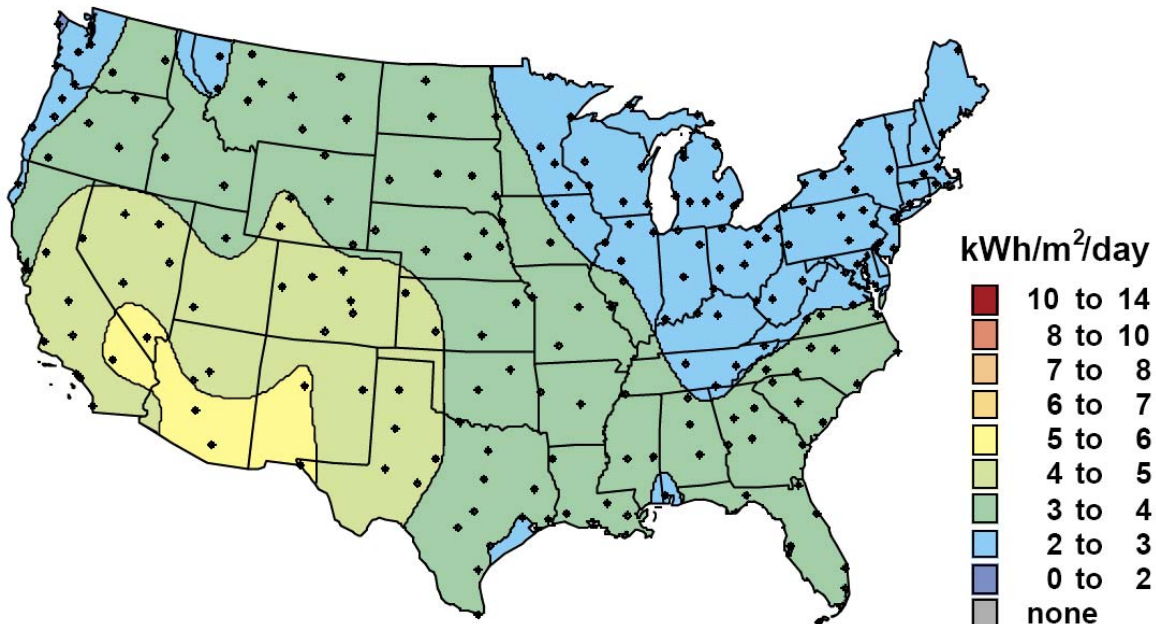


Figure 14. Solar Radiation Resource Map for a single axis parabolic trough solar concentrator.
Source: NREL, http://redc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/

Solar systems are not immune from land use controversy. California's Solar Shade Control Act has recently been used to force redwood trees to be cut down because they were shading a

neighbor's \$70,000 solar system even though the trees predated the installation of the solar panels.²³

Geothermal

At a good site, geothermal can generate electricity from hydrothermal sources at about 10 cents/kWh. Geothermal doesn't have intermittency or backup problem, but long distance transmission may be needed. Geothermal power is often overlooked in policy discussions. At present, it supplies almost as much power as does wind. It provides a fairly steady supply, called baseload electricity: the median geothermal plant averaged over a year has a 63% capacity factor, comparable to that of coal-fired generators. A 2006 MIT report²⁴ estimated that in the future enhanced geothermal power, obtained by cycling water through warm rocks at depths between 3 and 10 km, might be able to produce 100,000 MW of electricity in the USA at a cost of less than 8 cents per kWh. That scale-up would mean that 12% of current USA electric demand could be met by using the geothermal resource. Like wind and solar energy, the geothermal resource is unevenly distributed in the United States (figure 15).

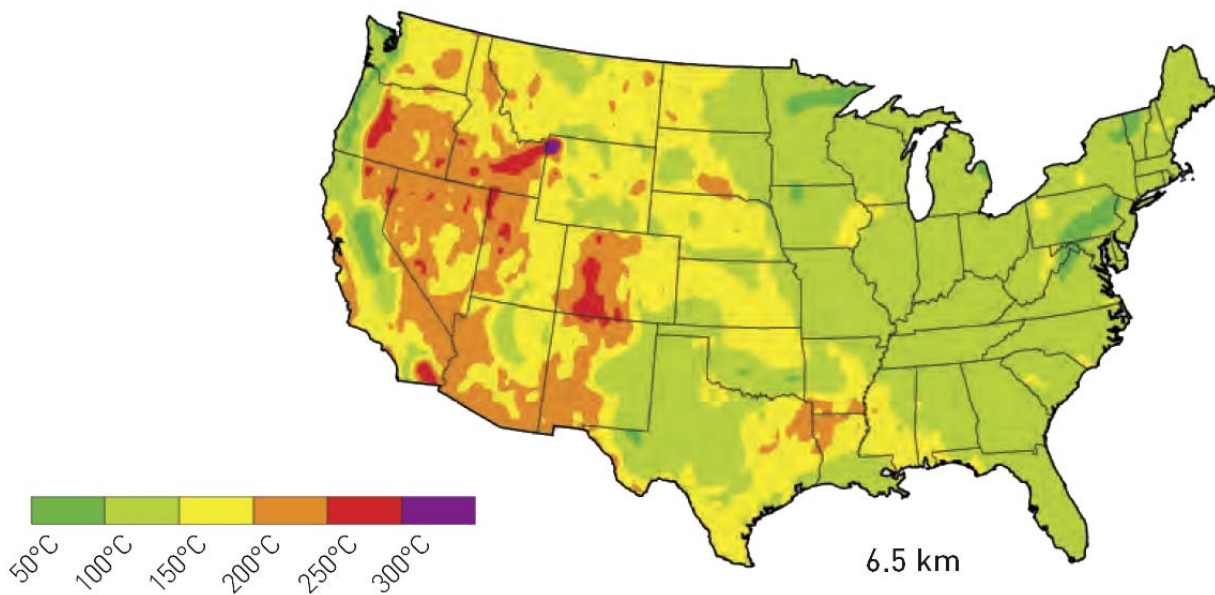


Figure 15. Temperature at a depth of 6.5 km. The cost of producing geothermal power is reduced if high temperature rocks are found at shallow depths. Source: The Future of Geothermal Energy, figure 1.4.

Although many geothermal sites are in the arid western United States, much of the water needed could be recycled (but may entrain undesirable chemicals such as boron and arsenic as it percolates through the warm rock before being pumped to the surface). The MIT report states,²⁵ "In the western part of the United States, where water resources are in high demand, water use for geothermal applications will require careful management and conservation practice." A full analysis of the water needs and environmental issues of large-scale enhanced geothermal power remains to be performed.

Run-of-the-river hydroelectric

Run-of-the-river hydro can be attractive, but only operates when the river is flowing. To get much energy, there would have to be a large, fast-flowing river. The potential power from this source is limited since many of the suitable rivers have already been dammed for high-head hydro.

Biomass

The USA has embarked on a program of encouraging energy crops. Biomass can be used either alone or in combination with other fuels to produce electricity, and can be transformed into a transportation fuel (potentially avoiding electricity that might be used in plug-in hybrid electric vehicles in the near future). Biomass, such as wood chips and switchgrass can be co-fired up to 10% with coal or can be burned in a specially designed furnace. According to the USDA, farm waste, mill waste, tree thinning, municipal solid waste, and energy crops could provide about 350 million tons at a price of \$60 per ton (roughly equivalent to \$120 per ton coal on a BTU basis) (figure 16). At \$90 per ton (roughly equivalent to \$180 per ton coal), biomass could provide about 430 million tons. However, it is expensive to transport biomass and so it is likely to be useful only near existing coal-fired power plants for up to 10% co-firing or in plants especially built for biomass. \$60 per ton biomass is roughly twice as expensive as current USA coal prices. Thus, biomass might provide a few percents of generation cost-effectively.

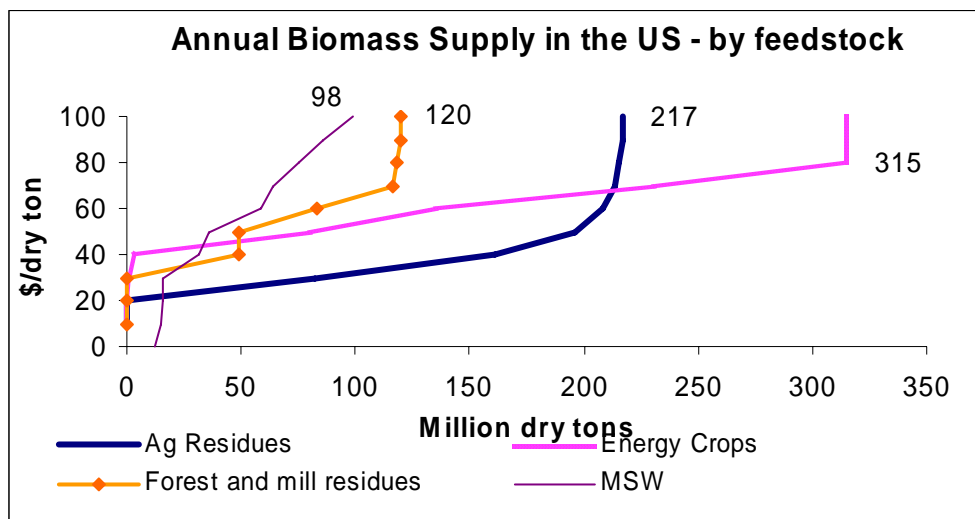


Figure 16. Estimated biomass supply curve (broken down by feedstock). Source: Kumarappan S., S. Joshi, H. MacLean, and A. Gronowska, 2008. "Evaluation of U.S. and Canadian bioenergy feedstock potential," Working paper, Department of Agriculture, Feed and Resource Economics, Michigan State University

At small scale the use of waste biomass that would otherwise be left in fields is economically attractive. However, removing crop residue can make soil less productive and decrease its ability to store carbon.²⁶ At large scale, recent work²⁷ has shown that the greenhouse gas (GHG) emissions from clearing land to produce biomass energy crops overwhelms the GHG savings from using biomass. Although the land must be cleared only once, the GHG debt is not repaid for a century.

Ocean

Getting electricity from ocean tides, currents, waves, and thermal gradients are immature technologies whose costs and environmental effects are not fully known. The estimated global practical potential from tides and currents totals 70 GW,²⁸ about 2% of current global electric power generation.

Storage

An electricity storage system can be used to provide continuous power from the variable power supplied by wind and solar systems. At 38 sites in 18 states water is pumped into a reservoir by electric motors; when needed, the water flows back through the turbine to produce hydroelectric power. These pumped storage facilities are expensive to build, and have controversial environmental impacts; their median age is 40 years²⁹. The combined capacity of these pumped storage facilities is 19,400 MW, or about 1.8% of the nation's generation capacity. Where they have available capacity, they are good choices for storing variable power.

In many areas of the country, it is feasible to store electricity by using it to compress air, which is injected underground into depleted gas reservoirs, abandoned mines, or salt caverns.³⁰ When electricity is needed (for example, when the wind is not blowing), the compressed air is released, heated, mixed with natural gas, and burned in a turbine to produce electricity. Many areas of the country have suitable geology. A 110 MW compressed air energy storage facility of this type has been operating since 1991 in Alabama, and can provide power for 26 hours. At current natural gas prices, these storage facilities have capital and operating costs of approximately 8 cents per kWh of electricity produced.³¹

Storage batteries are often used in small scale, off-grid solar or wind systems. For large scale application, sodium-sulfur batteries, based on a high temperature chemical reaction have been deployed in several USA locations. These remain expensive.³² It is plausible that widespread use of plug-in electric hybrid vehicles may provide grid storage. With the present cost of batteries and the degradation of their lifetime when they are subject to additional charge-discharge cycles, it would not be economic for a car owner to offer the vehicle for grid storage³³. However, lithium-ion battery technology may make distributed grid storage more economical.

Demand-side management

Demand in the three main sectors has shifted dramatically in the past fifty years. All three sectors grew exponentially at a combined rate of 8% annually until 1973, with residential having the fastest growth rate, followed by commercial (figure 17). It is probable that this was primarily due to growth in air conditioning. The residential and commercial sectors transitioned to much slower exponential rates growth following the oil embargo of 1973. Residential growth has averaged 2.7% yearly, commercial 3.5%. Industrial use of electricity stopped its strong growth in 1980, and its use in 2006 was less than it had been in 1994.

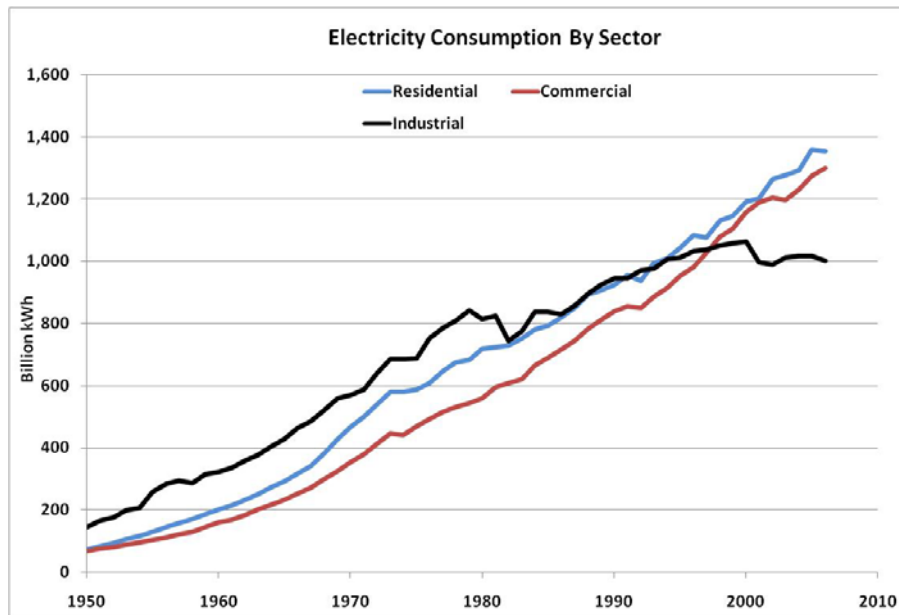


Figure 17. Sales of electricity for the three largest sectors (transportation is not shown).
Source: U.S. Energy Information Administration Annual Energy Review 2006 Table 8.2a.

While some of the growth in the residential and commercial use of electricity is due to population increases, a large portion is due to each person using more power. The average person in the USA used half again as much electricity in their home in 2006 as they had just 25 years previously, in 1981. Commercial use per capita was up by two-thirds in the same period. Both residential and commercial use per capita has been growing linearly since the mid-1970's. It is in this context that the authors consider demand-side management of electric power.

Reducing electricity demand growth reduces air emissions, and has been used effectively in certain areas. Techniques used include government mandates (e.g. high efficiency appliance standards, bans on the sale of incandescent light bulbs, building codes), utility demand-side management programs, consumer education programs, capital equipment decisions by consumers (e.g. installing a combined heat and power plant) and pricing electricity by time of use.

A 2004 study³⁴ estimated that electricity demand growth was reduced by 80 billion kWh annually in the residential sector and 40 billion kWh in the commercial sector by mandatory appliance standards. The same research estimates that utility demand-side management programs (such as the air conditioner and pool pump programs offered by Georgia Power and Florida Power & Light) annually save an additional 60 billion kWh, spread across all sectors. Residential use has been growing at the rate of 25 billion kWh each year, and commercial use by 30 billion kWh. Thus, it is possible that very strong appliance standards and utility programs could counteract the current annual growth in per capita consumption. Although it hardly seems possible that even stringent standards could counteract rising electricity demand in fast growing areas, these programs could be an effective part of emissions control.

Experience in Vermont and California shows that aggressive policies can significantly reduce the growth of electricity demand. Residential per capita use in California grew 4% from 1980 to

2005, while use for the rest of the USA grew by 89% (figure 18). The per capita demand in the commercial sector in California grew by 37% over that period, much less than the 228% growth of the rest of the country. In terms of "electric intensity", kWh per dollar of GDP, California used 4% more electricity per dollar of gross state product in 2005 than in 1980, while the rest of the country used 40% more.

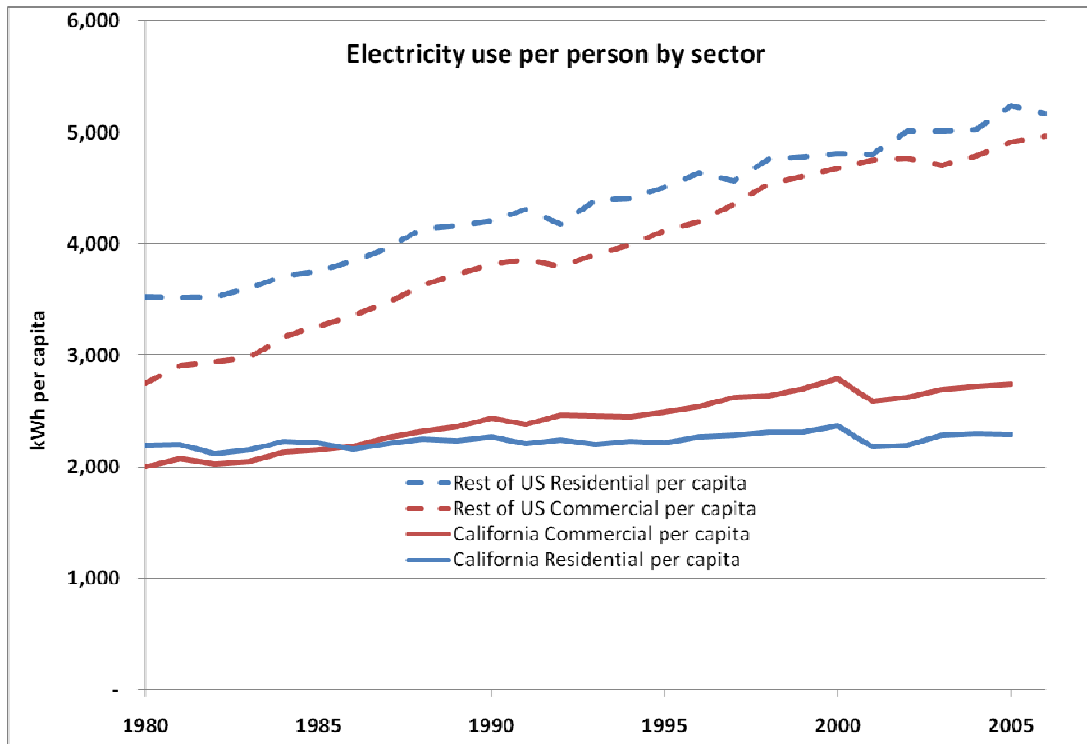


Figure 18. Electricity consumption per person in California and in the remainder of the country by sector. Source: U.S. Energy Information Administration Monthly Retail Electric Sales Revenue and California Energy Commission

Population increases have contributed to the growth in overall electricity consumption: the USA population has grown 20% in the past 15 years and California's by 26%. It is clear that both per capita demand reduction and control of population are required if demand-side reduction is to make a large contribution to reducing CO₂ emissions from the generation of electric power.

Another instrument for demand-side reduction of electricity use is to change from an average price charged for power to prices that reflect the actual cost of power at any given time. On hot summer afternoons expensive generators that supply the last bit of peaking power needed are turned on; they may run only a few dozen hours in a year and drive the price of power to very high levels when they are required. If customers pay the actual price at the time they use electricity, they are likely to use less at that time. However, as pointed out by Holland and Mansur,³⁵ real-time pricing may increase pollution emissions in certain regions of the country if customers switch their use from daytime when natural gas is the predominant generation source on the margin to night when coal dominates. Spees and Lave³⁶ have modeled a range of consumer behavior, finding that at plausible levels of response to price,³⁷ peak load would be reduced by 10 to 15% in the Mid-Atlantic states with real-time pricing. However, they find that total demand would increase by 1 to 2% as consumers took advantage of lower rates at off-peak

hours and shifted their use to night hours. Thus, real-time pricing would take advantage of wind's greater nighttime production, but would make solar power somewhat less valuable.

Low emission non-renewable generation

While the nation has focused on renewable sources of electricity so far, using conventional fuels with low pollution and CO₂ emissions has been proceeding.

For a time in the 1990s, electricity generators were switching from coal to **natural gas**. Natural gas plants emit about half as much CO₂ per kilowatt-hour as do coal plants. They emit less oxides of nitrogen (NO_x) than pulverized coal generators, but still require special systems to reduce such emissions to satisfy ambient air quality standards. Addition of a post-combustion CO₂ absorption system appears feasible for natural gas plants. The supply of North American natural gas is limited and additional imports will be minor until huge fleets of liquefied natural gas tankers ply the seas. The inevitable result of fixed supply and increased demand arising from vast increases in natural gas generating capacity over the past decade was a four-fold increase in gas prices. As a result, investment in new natural gas electric generators virtually ceased in 2005 to 2007. Due to current difficulties siting new coal facilities, the industry is once more turning to natural gas-fired combustion turbines/combined cycle units.

Conventional coal-fired plants, which burn pulverized coal in boilers, emit more carbon dioxide per kilowatt-hour than any other method of producing electricity. **High performance coal plants**, called supercritical plants, and very high performance plants, called ultra supercritical plants, are more efficient. Replacing an old, inefficient coal plant with a supercritical plant or ultra supercritical plant can reduce CO₂ emissions by one-third.

Emissions can be reduced much more by chemically capturing the CO₂ produced during combustion and injecting it deep underground, a process called **carbon dioxide capture and deep geological sequestration (CCS)**. The technologies to gasify coal efficiently have been demonstrated for some coals. Once gasified, the technology for capturing the CO₂, transporting it long distances by pipeline, and injecting it into underground reservoirs exist at commercial scale today. Technologies for capturing the CO₂ from flu gas are being demonstrated at pilot plant scale. The technologies to inject CO₂ for secondary oil recovery exist today and there is limited experience with injection into saline aquifers.

A few pilot coal-fired plants use a method in which coal is burned, but in the presence of a much higher percentage of oxygen than is present in ordinary air (95% instead of 20%). This "**oxyfuel**" method produces an exhaust gas with much higher concentration of CO₂, eliminating the need to separate CO₂ and nitrogen, thus decreasing most CCS costs.

At 130 coal-burning facilities around the world—including some plants that produce electricity—coal is used in a very different fashion. Instead of being burned in open flames, it is fed into a refinery vessel along with oxygen. The process results in exhaust streams of CO₂, hydrogen gas, sulfur powder, and a glassy slag containing various other impurities. The CO₂ gas stream can be injected deep underground instead of being released into the atmosphere; these plants can reduce CO₂ emission by up to 90%. When used to produce electricity, these plants are

called **integrated gasification combined cycle (IGCC)** plants. Additional experience with a range of fuels for coal gasification would increase industry operational confidence.

Among low air emissions electricity sources, **nuclear power** is the largest deployed technology. If nuclear power is to keep its present 20% share of electricity production—from 104 plants now operating in the USA—30 new nuclear plants must be brought into service by 2020 to keep up with increasing demand. After 2020, many existing nuclear plants may close because of age, and construction will have to reach very high levels if market share is to be maintained. A new generation of nuclear plants has been designed, and Westinghouse Nuclear, Areva, and GE Hitachi Nuclear Energy each are seeking orders from utilities in the United States.

IV. Electric energy policy for low air emissions

Stabilizing atmospheric CO₂ at about twice the preindustrial level will require reducing CO₂ emissions by roughly 60-80%. Increasingly stringent air pollution regulation will require dramatic emissions reductions for SO₂, NO_x, mercury, and particulate matter. Both reductions could be accomplished with additional costs that are 1% of GDP or less, half again what the nation spent during the peak years of compliance with the Clean Air Act.

The electric power industry emits approximately 2.5 billion metric tons of CO₂ per year. A number of technologies are available for low emissions generation or demand reduction at \$60 per ton of CO₂ or less. That totals \$140 billion a year, or a 40% increase in what customers pay for electricity, 1% of GDP.

It is important to achieve low air emissions as well as other goals, specifically low cost. If the USA mandates technologies that achieve CO₂ reduction at, say, \$100 per ton, the increase in our electric bill would be 75%, or nearly 2% of GDP.

Some of the air emissions associated with cars and light trucks may be shifted from their gasoline or diesel engines to electric power plants, if plug-in hybrid gasoline-electric vehicles become popular. That would underscore the importance of finding effective ways to lower both pollution and CO₂ emissions, while keeping control costs low cost, since it would cause a substantial increase in demand for electricity.

Costly mandates that undermine electricity reliability are likely to lead to a public backlash. For example, Pennsylvania has enacted a requirement that 0.5% of electricity be generated by solar PV by 2020. Using the fairly modest growth in demand for power projected by the system operator, that works out to 800 MW of solar PV. The innocuous-sounding half percent requirement will add 6% to the average electric bill. If wind were allowed to generate the electricity, wind generation would do the job for \$75 million per year for wind vs. \$400 million per year for solar PV.

Solar subsidies in Japan and Germany, as well as solar set-asides in domestic state legislation have been enacted on the assumption that the prices for solar PV systems will decline as economies are achieved in manufacturing. At present, solar PV in states such as Pennsylvania can produce wholesale power at 50 cents per kWh.[‡] Costs for the solar PV system (solar cells, electronics, packaging, installation) would need to fall by a factor of 6 to produce power at rates competitive with other low-emissions sources, even before considering additional costs due to the variability of solar power.

The economics may be more favorable for specific power applications. For example, air conditioning loads in Arizona cause the demand for electricity to peak in the afternoon and early evening. A solar thermal system with a few hours energy storage matches this load profile well and can produce power at prices competitive with those of natural gas peaking generators. Arizona Public Service has recently announced a plan to install a 280 MW system of this type by

[‡] Using the following data: installed full system costs of \$5400/kW, 20-year life, 15% capacity factor, ½ % of capital cost for annual operations & maintenance, 10% capital cost.

2011, and has signed a 30-year power purchase agreement for its electricity at 14 cents per kWh.³⁸

V. Electric generation as a system

While it is tempting to consider a mandate for a particular technology in isolation, that approach leads to undesired results. One could argue, for example, that building a particular amount of wind power in Hawaii displaces old and dirty oil-fired generators (the state produces 78% of its electricity using oil³⁹). At night the wind blows strongly and demand for power is low, so wind supplies over a third of the island's nighttime electric energy. Oil generators that are not required are shut down. On three nights during one week in June 2007 on the Big Island, the variability of the wind overwhelmed the ability of the single oil generator that remained running to compensate, as the strength of the wind gradually fell. While the system operators urgently tried to get a second oil unit warmed up, the frequency of grid power fell from its normal 60 Hz to 58 Hz (emergency procedures are usually implemented in most grids to prevent frequency from falling below 59.8 Hz).

What was missing on Hawaii was a system that can employ a combination of generators, electric storage, and curtail customer demand that can protect the electricity system when wind varies.

On February 26, 2008 the power system in Texas was saved by quick action in dropping load. At 3:45 PM, wind power was supplying roughly 4% of demand. But over the course of the next 3 hours an unforecast lull in the wind caused the amount of wind power to fall from 1700 MW to 300 MW just as evening demand was increasing. Grid operators went immediately to the second of four emergency stages, and called on 1100 MW of emergency interruptible load in a successful attempt to avoid a system collapse. According to the Electric Reliability Council of Texas, "This was not the first or even the worst such incidents in ERCOT's area. Of 82 alerts in 2007, 27 were 'strongly correlated to the drop in wind'."⁴⁰

When a variable generation source (wind or solar) is installed, the size and costs of the required standby supply or load curtailment have to be accounted for. When variable generators are a tiny fraction of the total, the standby requirement can be swept under the rug, but that plan is not scalable when wind or solar make up a large fraction of total generation.

Table 1 illustrates the case for an RPS of 15% or 25% satisfied with wind or solar PV. The example shows that very large amounts of renewable capacity would be required and that much of the renewable power would be spilled, particularly for the 25% RPS satisfied with solar PV. Since neither wind nor PV is dispatchable, the system still needs 100,000 MW of dispatchable capacity, but will use less fuel since the renewable generation supplies 15% or 25% of the power. However, since the wind generated power is variable, some gas turbines (or hydro power) will be required to operate in order to deliver power when the wind drops momentarily. When the turbines operate this way, they are inefficient and so less than 15% or 25% of the fuel is saved.

If the system did not have vast electricity storage, it would need power for 2/3 of the day when the sun was not shining or was too low to generate much power. The power would be most

cheaply supplied by baseload generators. A baseload coal or nuclear unit would not be shut down when the solar array was generating power because it would be needed in a few hours.

Figure 19a shows the output of four wind farms in Pennsylvania supplying electricity for January through June, adjusted upward so that it provides 25% of the electricity supplied to PJM. Also shown is the PJM east demand for each hour during the period. The graph assumes that all the nuclear and hydro units are operating as baseload capacity, 9.7 GW. The graph shows that there are some hours where the generation exceeds load. In practice more than 418,031 MWh would be spilled because some gas turbines would have to run to fill in the gaps in variable wind generation.

Figure 19b assumes that baseload generation would be 20 GW, reflective of the current nuclear, coal, and hydro baseload plants in PJM east. The graph shows that generation from the baseload plants and wind would exceed load for a considerable amount of time. The graph shows that there are some hours where the generation exceeds load. With the assumption that nuclear and hydro would run at their 2004 capacity factors, on an annual basis over 800,000 MWh of the wind power would be spilled (exceed load) if wind was required to supply 25% of the electric energy in PJM. In practice, some gas turbines would have to run to fill in the gaps in variable wind generation, leading to more wind power being spilled. Since gas turbines would have to run to account for wind's variability, more MWh would have to be spilled in practice.

When wind energy is spilled, an additional complication arises since, for example, the RPS in California refers to MWh billed to customers, not to renewable capacity or renewable generation. To satisfy the RPS in many states, still more wind capacity would be needed to provide power during the times when wind energy was not spilled.

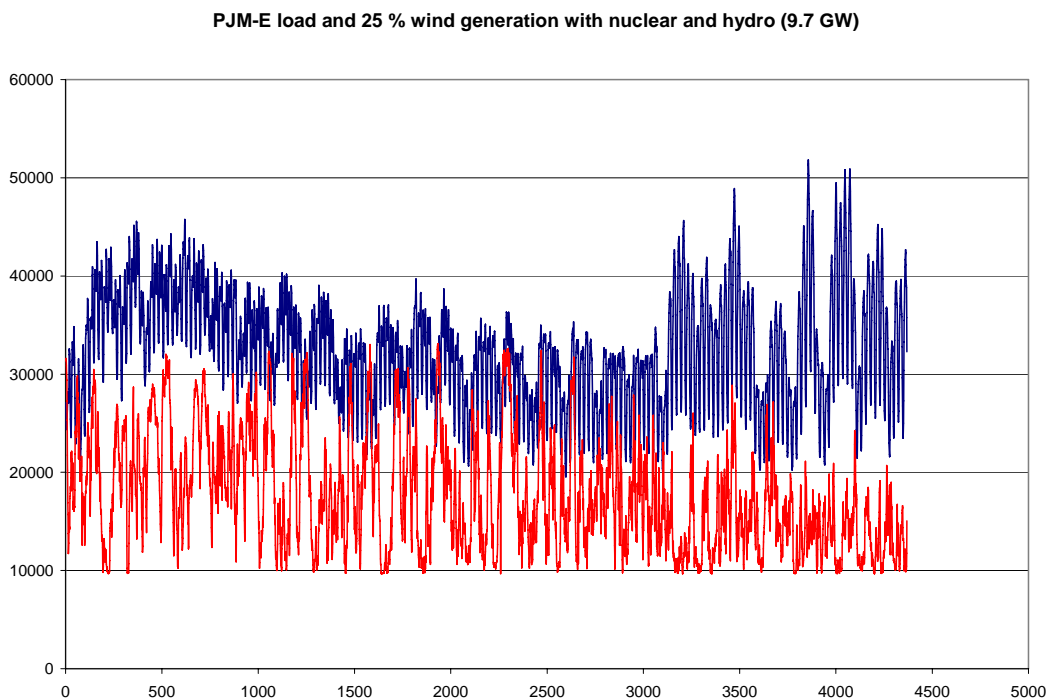
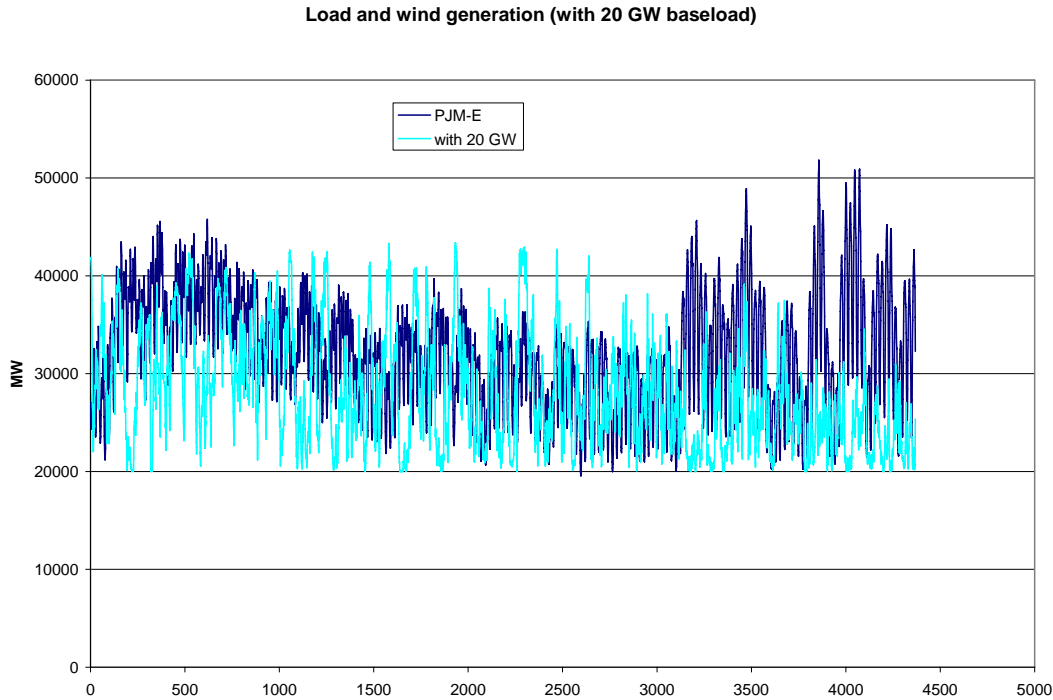


Figure 19a. Hourly load in PJM in the first six months of 2004 (blue curve) and hourly wind output from 104 1.5 MW wind turbines in 4 locations in PJM scaled to supply 25% of load, with 9700 MW of must-run generation (red).



Figure

Figure 19b. Hourly load in PJM in the first six months of 2004 (blue curve) and hourly wind output from 104 1.5 MW wind turbines in 4 locations in PJM scaled to supply 25% of load, with 20,000 MW of must-run generation (turquoise).

VI. Conclusion

Radical change is needed if something more than business as usual in the electric power sector is to achieve the 60-80% reduction in CO₂ emissions required to keep global climate change from causing major harm.

The aspirations of radical change that are embodied in renewables portfolio legislation can both provide a guide and the social consensus to lead to that "change".

Many people agree that something must be done to lower carbon dioxide emissions. There is much less consensus about renewability as a goal. Renewability has meant different things at different times: large-scale hydroelectric power was hailed as a perfect renewable solution half a century ago. It is still renewable (and supplies seven times as much power as wind, geothermal, and solar combined), but its adverse effects on the ecosystem have now been recognized. In any case, renewables portfolio standards do not permit carbon dioxide reduction from energy savings to count toward satisfying the RPS.

The nation cannot lower carbon dioxide emissions by 60-80% at affordable cost without using every carbon-dioxide mitigation option. If the nation tries to exclude some technologies that can reduce air emissions, we tie our hands needlessly. Moreover, if the nation picks technologies that

turn out to be expensive, we risk having society turn against technologies that are an essential part of reaching our social goals.

The authors fear that pressing the introduction of renewables too aggressively would result in high cost, unreliable electricity, leading to a public backlash against these policies. Less aggressive policies favoring renewables in the USA and the rest of the world have brought down the costs of these technologies. The authors favor continuing to press renewable technologies to attain social goals. Attaining the full range of social goals is important, including having an electricity supply that is adequate, reliable, and affordable; electricity is essential for our economy and society. Renewables can help meet the goals, but they are not the only technologies that can; conservation, increases in generation efficiency, fossil fuels with carbon capture and sequestration, and nuclear power can help attain the goals. Increased R&D for these technologies is promising, particularly for bulk storage of electricity. Rather than specifying the technology, the authors urge Congress and state legislatures to specify the goals: lower air pollution and greenhouse gas emissions; lower depletion of fossil fuels; increase energy security; and shift to a more sustainable generation mix that produces an adequate supply of reliable, reasonably-priced electricity. Since no current technology meets all goals, legislators need to consider tradeoffs. Specifying the goals, rather than the technologies will lead to a technology race that will serve society.

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