Wind Integration and the Cost of Carbon

Renewables are greenest when displacing coal, not gas.

BY CONSTANTINE GONATAS

With the abandonment of a nationwide energy policy by the previous Congress, states continue leading carbon mitigation efforts. Indeed, existing state policies and renewable portfolio standards (RPS) are already having a significant impact on the U.S. generation portfolio. FERC now proposes to weigh state policy as a consideration in transmission filings. Should state policies guide federal action? Will they suffice to reduce carbon emissions?

The 30+ states with renewable energy or carbon regulations cover a wide range of policies. All have some degree of RPS, for which the dominant portion may be met only by physical delivery of power in state. Treatment of low-emission resources varies by state and technology. Policy makers in many states believe mature energy sources (such as hydroelectric) should not receive market preferences, but that only technologies not yet competitive should receive incentives. States also use incentives to drive local industrial policy, and hopefully, in-state job creation. They often select the particular technologies they believe will be ultimately successful in the marketplace. Furthermore, many states have preferences for local generation to advantage in-state industry.

Along with the frustration of progress toward a national carbon policy, 2010 was notable for the release of numerous wind integration studies. No fewer than five of these complex analyses were completed, covering multi-state regions such as NREL's Eastern and Western Interconnection studies, together with state and sub-regional studies covering SPP, New York and New England. These multi-million dollar studies used more sophisticated models than prior work did. They contain a wealth of results covering operational analyses and impact on ancillary services, over a range of high voltage transmission build-out scenarios.

The studies produced some controversial initial results, such as NREL's finding that Midwestern wind linked to the East via an EHV network could be somewhat less costly than scenarios depending more on local and off-shore wind resources in the East. These studies have sparked interest in more definitive work. To support this, the U.S. Department of Energy funded the Eastern Interconnect Planning Council and a parallel state effort in a multi-stakeholder process.

The success of renewables installations through 2010 indicates that the early demonstration project phase has passed. It's now appropriate to refocus on the ultimate purpose of adding renewables: reducing carbon emissions. To this end, the wind integration studies are useful because they analyze how renewables displace fossil generation. These displacements result in different carbon reductions across a wide range of scenarios considered in the modeling.

Adding renewables has a disparate impact on carbon depending on whether the facilities displace coal or gas-fired generation. Coal has twice the carbon content per MMBtu as natural gas, and steam-fired boilers are far less efficient than modern combined cycles. So coal generation produces more than twice as much CO_2 per MWh as gas-fired generation (*see Figure 1*).

Optimal Investment

The wind integration studies show the effect on fossil generation by renewable additions. Surprisingly, the NREL's Eastern Interconnection and the ISO New England studies show a striking difference in the impact on gas and coal-fired generation (*see Figure 2*).

In the Eastern Interconnection study, nearly all the wind generation displaces coal-fired steam generation. By contrast, in the New England footprint, wind displaces gas-fired combined cycles without affecting coal-fired generation much even up to a 24 percent wind addition. So wind integration in the ISO-NE

FIG. 1 EMISSIONS BY FUEL SOURCE

Prime Mover	Heat Rate (Btu/kWh)	CO_2/MMBtu fuel Combusted	CO_2 (tons)/MWh
Steam Turbine - Coal	10,148	0.103	1.04
Gas Combined Cycle	7,543	0.059	0.44
Steam Turbine - Gas	10,399	0.059	0.61
Gas Simple Cycle	11,497	0.059	0.67
New Gas Combined Cycle (nameplate)	**5,800**	**0.059**	**0.34**

Source: EIA 2008 electricity annual report

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FIG. 2 WIND AND GENERATION DISPLACEMENT

Source: NREL and ISO New England

Fig. 2-A: Displacement Effect Across Entire Eastern Interconnection

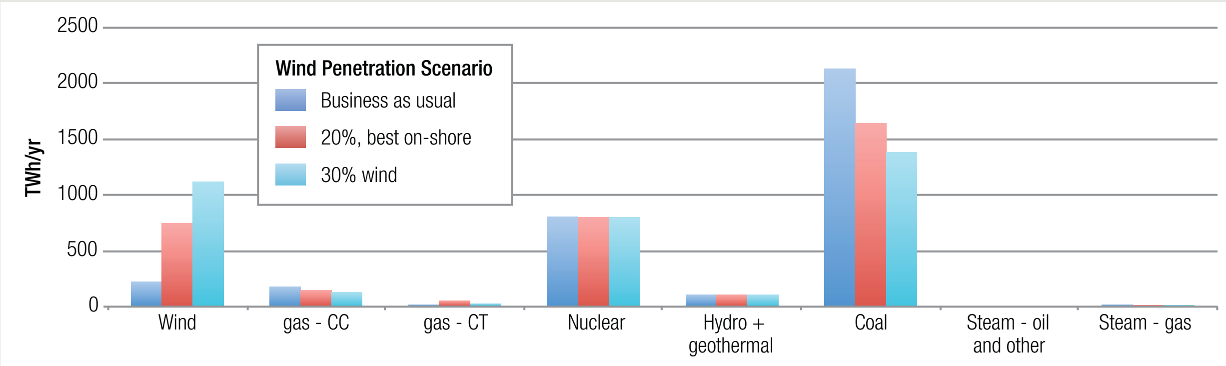
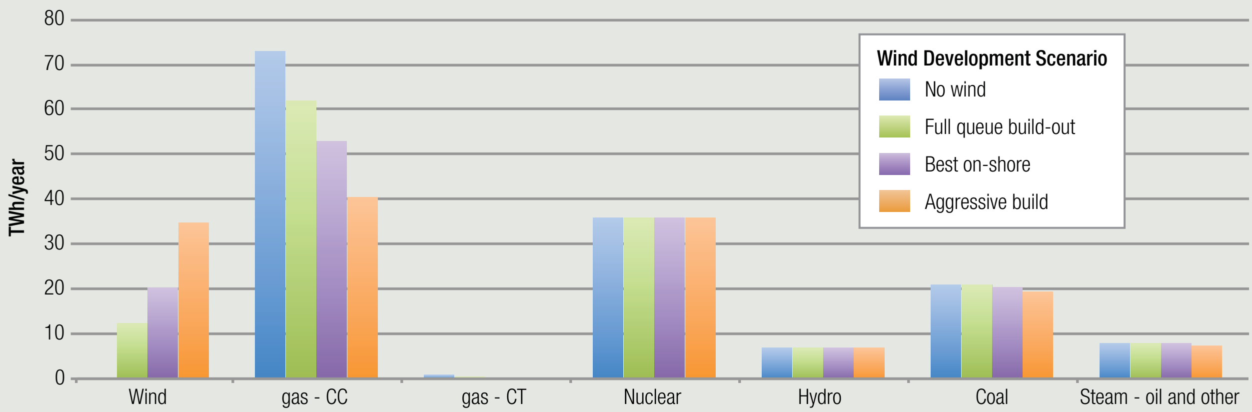


Fig. 2-B: Displacement Effect Across ISO New England



Wind integration in the ISO-New England footprint provides half the carbon mitigation per MWh as compared to the Eastern Interconnect footprint. Nearly all the wind generation in the Eastern Interconnect displaces coal-fired steam generation, while wind in ISO-NE mostly displaces gas-fired combined cycle generation.

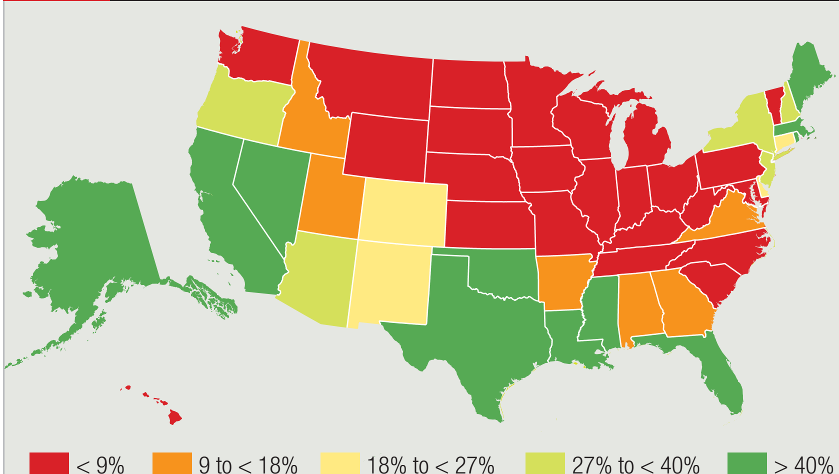
footprint provides half the carbon mitigation per MWh as compared to the Eastern Interconnect footprint. In the NYISO and WECC studies, wind also displaces gas only, while in SPP, wind displaces an even mix of gas and coal-fired resources. Combustion turbines provided little generation in most of the base case scenarios, while both hydro and nuclear units are unaffected due to their zero marginal costs.

The results for ISO-NE, NYISO and WECC are expected because model assumptions for gas prices exceed comparable coal costs. Adding zero marginal cost renewables displaces units higher in the generation stack: combined cycles over coal units. By contrast, the impact of wind on coal in SPP and in the Eastern Interconnection as a whole is surprising.

NREL explains that more spinning reserve is needed in the respective study footprints due to wind intermittency. Only gas-fired units can provide these reserves, with their quick-start, flexible characteristics. These reserves must be in

FIG. 3 GAS-FIRED POWER PENETRATION (MWH)

Source: EIA, 2008



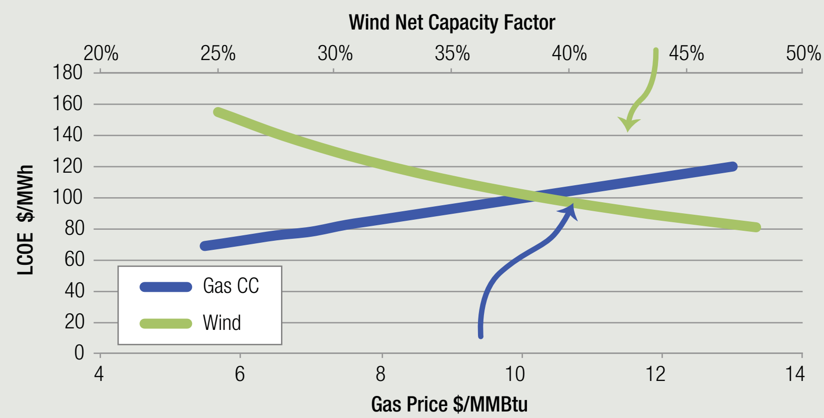
Natural gas-fired generation as a percentage of MWh produced. Gas dominates along the coasts, except in hydro-rich Washington. So along the coasts, wind displaces gas.

FIG. 4 WIND'S CARBON DISPLACEMENT BY FUEL

Region	Fuel Displaced by Wind	CO_2 Reduction (tons/MWh Wind)
ISO-NE	gas cc	0.44
NYISO	gas cc	0.30
NREL - East Interconnect	coal	0.73
NREL - WECC ($9.50 gas)	gas cc	0.45
NREL - WECC ($3.50 gas)	coal	0.79

Source: EIA 2008 electricity annual report

FIG. 5 WIND VS. GAS COSTS



Levelized Cost of Electricity (LCOE) of on-shore wind compared to gas-fired power. Capital cost assumptions including construction were $1,000/kw installed for a combined cycle with a 6,800 Btu/kWh heat rate and a 65 percent capacity factor, and $1,700/kW for a wind turbine unit. No subsidies (ITC, PTC or accelerated depreciation) were included for the wind unit. Common assumptions include after-tax return on equity of 10 percent; 50 percent debt/asset ratio with 7 percent interest rate on 12-year debt, 37 percent tax rate, 25-year project life, $5/kW-month transmission charges. Capacity revenues of $2/kW-month are included for gas units.

Source: Author's analysis

FIG. 6 REPRESENTATIVE CARBON REDUCTION COSTS

Carbon Reduction Costs	$/ton CO_2 ($6 gas)	$/ton CO_2 ($8.50 gas)
Wind displaces Coal (30% NCF)	99.8	99.8
Wind displaces Gas CC (30% NCF)	190.4	147.7
Gas CC displaces Coal	72.8	99.2
Offshore Wind displaces Gas CC (37.1% NCF)	528.2	485.5

Offshore cost assumptions used include the 37.1 percent net capacity factor (NCF) disclosed for the Cape Wind project together with capital costs of $4,000/kW, a two-year construction period and the same capitalization assumptions as for the other cases, giving a levelized cost of energy of $278/MWh without subsidies.

Source: Author's analysis

the same balancing area as the wind additions to comply with contingency conditions. So in the Midwest and Great Plains states, where there is little gas to displace, significant gas-fired resources have to be added, forcing coal units to turn down.

Figure 3 shows where active gas-fired generation might be sufficient for reserve requirements. To avoid considering inactive units, generation by MWh rather than MW of capacity is depicted. Gas predominates along the coasts (East, West and Gulf), except for Washington, where hydro provides ample reserves. So along the coasts wind displaces gas, with commensurately less carbon reduction than in coal-dominated areas.

The wind integration studies quantify this pattern (*see Figure 4*). Notably, the WECC study includes a low gas price scenario ($3.50/MMBtu) along with the base case ($9.50/MMBtu). In the low gas price scenario, coal is the marginal resource instead of gas, so adding wind has approximately twice as much impact on carbon emissions as compared to the base case.

Because wind and other renewables incur above-market costs, building generation where it displaces the most carbon is the most cost effective option. A high quality, unsubsidized wind resource near load can compete with gas-fired generation, when gas is selling for pre-shale discovery prices. Offshore wind, currently double the cost of on-shore wind, needs both a very high capacity factor and a major cost reduction to compete. This is illustrated by quantifying the levelized cost difference between wind and gas-fired combined cycle generation in a financial model showing the dependence on the most sensitive parameters: gas prices and wind net capacity factor (NCF). The model assumes the gas unit is non-urban and the wind turbine capital and construction costs are moderate with siting in accessible terrain (*see Figure 5*).

Putting all the economics together, the cost of carbon reduction per ton can be quantified. As above, wind resources might reduce emissions by displacing either gas or coal. Although it has received somewhat less overt attention by policy makers, replacing coal units with gas-fired combined cycles also reduces carbon. The cost for carbon reduction by offshore wind displacing gas is also included for comparison (*see Figure 6*).

Substituting gas for coal is the lowest cost alternative at current gas prices. By contrast, substituting wind for gas bears the highest cost. Of course, large scale substitution of gas for most of the coal generation in the U.S. isn't feasible because it would place enormous pressure on gas prices. However, it might be considered on an incremental basis. In an ideal world, a carbon price would guide the market toward the optimal generation mix. Current state policies on the three coasts result in the more costly outcome, substituting wind for gas.

Adding renewables has a disparate impact on carbon depending on whether the facilities displace coal or gas-fired generation.

Regional Carbon Strategies

Even though Congress hasn't introduced carbon pricing, federal regulators and policy makers can still pursue cost effectiveness in carbon reduction. They could support state policies in transmission filings and provide rate incentives to encourage projects with the greatest relative impact. Instead of providing across-the-board subsidies regardless of location, as is with current investment and production tax credits, scarce funds could be allocated to projects with the greatest carbon reduction per dollar.

States can also take more effective action. Because action only by low-carbon-emitting states has limited results, the cooperation of coal generating states is essential. States must accept the challenge of developing regional and inter-regional carbon reduction programs, integrating coal-dependent states together with the most progressive states that today appear willing to pay any price for carbon reduction.

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