Re-evaluating the implied cost of CO₂ avoided by clean energy investments

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Abstract

The authors present a graphical framework to evaluate the implied CO₂ abatement costs that can be used by policymakers and resource planners to provide clarity on cost-effective policy design, and on the implications of planning decisions for meeting future de-carbonization goals. The framework would allow for comparison of alternative investments, while distinguishing the extent, type and timing of resources they would displace since those factors are system-specific and can substantially impact abatement costs.

1. Implied cost of CO₂ abatement

In this article, we describe the implied cost of CO₂ abatement as the cost premium incurred for clean energy over traditional or market-based resource alternatives. Planners and customers would be willing to pay this cost if they believe the traditional or market-based mechanisms do not appropriately internalize the societal costs of emissions. In that sense, the implied cost metric can be alternatively viewed as some form of an implied “CO₂ externality value,” reflecting a willingness-to-pay for the CO₂ reductions, expressed as dollars per ton.

We apply a straightforward formula to calculate the implied cost, as shown below:

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\text{($/MWh cost of clean resource - $/MWh cost of displaced resource)} \div \text{tons/MWh emissions displaced} = $/\text{ton implied cost of CO₂ abatement}
\]

Although it is mechanically simple to calculate implied CO₂ abatement costs, it can be particularly involved to identify which resources would be displaced by the clean energy resource. As discussed later in this article, the cost and emissions characteristics of the displaced resources are as important as the characteristics of the clean energy resource itself, and they can vary over time and across areas.

2. Drivers of CO₂ abatement cost

In the past several years, a number of market and policy changes have shown that the cost of CO₂ abatement continues to be a moving and often confusing target. Abatement costs can vary quite a lot depending on a specific area’s technology costs and performance characteristics. Installed costs of wind and solar resources have declined and their performance has improved materially, creating lower-cost CO₂ abatement opportunities than before. At the same time, however, natural gas prices have remained low (albeit with increased volatility in some regions), keeping the costs of renewables still relatively high compared to natural-gas-fired generation in most parts of the country. Abatement costs depend quite a bit on the alternative resources displaced and their cost and performance characteristics, which can change dramatically over time due to market conditions and public
policies. Over the past several years since we published our first article on this topic, the alternative resources that are displaced by renewables have gradually shifted from coal-fired to natural-gas-fired generation in most regions, and from new to existing plants in regions with excess capacity.

Fig. 1 demonstrates a wide range of possibilities for the implied CO₂ abatement costs of new wind and solar projects. The table shows several (but not all) dimensions and variants to the cost calculation, and thus illustrates how difficult it can be to draw conclusions that are helpful for planning decisions. The rows show wind and solar resources under various levels of capacity factors, with and without federal subsidies. The columns show potential displaced resources. Values in italic font reflect the characteristics of the underlying resources, including cost, emissions, and capacity factors. Values in bold font are the resulting implied CO₂ abatement costs, ranging from −$50/ton to +$285/ton depending on the combination of clean energy resources and displaced resources, as well as the federal subsidies.

In Fig. 1, looking down the rows within one column illustrates the impact of varying costs in wind and solar technologies. For simplicity, our assumed costs include the capital and operating costs of the plants, but they do not consider any additional system costs needed for integrating renewable generation. Also, costs in Fig. 1 vary by assumed capacity factor and tax credits but they assume the same fixed $/kW capital costs by plant type. In reality, capital costs can vary a great deal due to a number of factors including location and vintage of the installation. With all of the factors combined, actual costs may fall outside of the range shown in the figure. For example, the Department of Energy (DOE) has reported that wind power purchase agreements (PPAs) are currently priced at approximately $20/MWh in Texas and the Great Plains portion of the Midwest. These low PPA prices likely reflect reductions from federal production tax credits (PTCs). But even without tax credits, and even with low natural gas prices, new wind generation in these areas may be competitive with existing natural-gas-fired CCs from a total cost perspective. This would yield implied CO₂ abatement costs that are very low or even negative.

Looking across columns within a single row in Fig. 1 illustrates the impact of displacing different types of resources. If existing resources are displaced, the cost premiums of wind and solar projects are calculated relative to the operating costs of these resources. If new resources are displaced, the calculations of cost premiums take into account the capital costs that would be avoided. Since new plants tend to have a higher all-in costs compared to existing resources (but not always), displacing new resources tends to put downward pressure on the

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3 Some states have recently considered or adopted subsidies to a broader range of no-emissions resources like existing nuclear plants. We do not explicitly discuss nuclear generation in this article but zero energy credit (ZEC) payments to support existing nuclear plants could fall within the same framework we present in the following sections.

multiple jurisdictions, or across various clean energy technologies. Most evaluate and benchmark implied CO2 abatement costs over time, across hours. In some regions with intentions for very high renewable pe-

Perhaps less peaking generation as their coincidence with net peak load penetrations, the marginal resources displaced by solar can shift to-

Can impact the displaced resources over time. For example, at high solar resources to lower-cost existing resources.

Declining renewable costs is partially o-

A regulator or utility can, from a planning perspective, “select” the displaced resource—for example, choosing to retire existing coal-fired capacity and build a new wind plant. But, for the purposes of understanding implied abatement value it is not enough to simply compare the annual costs and emissions of the coal and wind plant. In actual operations in a given hour, the wind plant may produce only part of what the coal plant would have produced, and a natural-gas-fired plant may ramp up to make up for the difference. In that case, the wind plant is not fully displacing the coal plant, and so we cannot say that the emissions from the coal plant are fully abated. The displaced resource depends on several factors, and identifying that resource (or mix of resources) requires a time-granular representation of plant operations, and a forward-looking view on market and policy conditions.

In many parts of the country the types and characteristics of the mix of generation resources that might be displaced by renewables continue to change over time. There has been a wave of retirements of coal plants as well as some nuclear plants in some regions, while in others policy-

Driven and merchant investments in renewables and demand-side re-

sources have significantly delayed the need to build more traditional capacity in at least some parts of the country and have called into question the economic viability of operating some of the existing power plants. In such areas, the alternative resources that would get displaced by clean energy resources would no longer be new fossil-fuel resources. Instead, displaced resources would likely be existing resources (e.g., gas CCs) with lower to-go or operating costs than a new plant. As a result, the downward pressure on CO2 abatement costs arising from the de-

Clining renewable costs is partially offset by the shifting of displaced resources to lower-cost existing resources.

Of course, it is essential to recognize that the clean investment itself can impact the displaced resources over time. For example, at high solar penetrations, the marginal resources displaced by solar can shift to-

Towards less peaking generation as their coincidence with net peak load declines. In some regions with intentions for very high renewable pe-

Netration, it could turn out that renewables displace each other during some operating hours, resulting in no net emission savings in those hours.

With all of these changing factors, it is not as straightforward to evaluate and benchmark implied CO2 abatement costs over time, across multiple jurisdictions, or across various clean energy technologies. Most of the public policies that are currently in place have cost containment mechanisms to limit maximum willingness to pay for clean energy. Some are more visible and explicit than others, such as California’s greenhouse gas cap-and-trade market (with cost containment reserve prices) or several states’ alternative compliance payments (ACPs) spe-

Cified under their renewable portfolio standards. Other states have strengthened and expanded their renewable procurement and integra-

Tion policies without explicitly measuring or defining a maximum willingness-to-pay for clean energy. If implemented, the Environmental Protection Agency’s rule on CO2 emissions would have added some clarity and transparency on abatement costs from a national perspec-

Tive. However, that rule has suffered many challenges, the most recent of which is the Trump administration’s moves to block or weaken the rule to the best of its ability. Absent a nationally coordinated effort, it is likely that more states and regional entities will address climate pro-

TECTION locally, and if so it will be helpful for them to consider benchmarking an implied CO2 abatement cost of new clean energy develop-

Ment. In the next section, we provide a graphical framework that can be used to compare resource options under multiple scenarios, over time, or across jurisdictions. Using this framework, we also discuss important considerations and challenges associated with defining displaced re-

Sources.

3. Evaluating CO2 abatement cost of clean energy investments

Fig. 2 provides a visual representation of the implied CO2 abatement costs for clean energy investments, while preserving the underlying cost and emissions information for both the clean energy resource and the potential resources that can displaced. The x-axis shows the CO2 emissions rate in tons per MWh and the y-axis shows the total leveled all-in cost of resources in $/MWh. The light blue/teal dot represents the clean investment with higher cost and the dark blue dot represents the displaced resource with lower cost but higher emissions. By drawing a line to connect these two resources, we can see the relationship be-

TWEEN the differences in both cost and emissions rates. The (negative) slope of this line reflects the CO2 abatement cost metric in $/ton, cal-

CULATED as: (A) the cost premium of the clean investment, divided by (B) the avoided emissions.

This graphical framework can be used in practice to evaluate CO2 abatement costs of any type of clean energy investments.

Fig. 3 demonstrates the usefulness of the framework. The panel (a) on the left shows the impact of alternative resources displaced by the clean energy resource. In this example, abatement cost is lowest if re-

Source 3 with relatively high costs and emissions gets displaced, which results in a flatter slope compared to when other resources are dis-

Placed. This could be helpful when alternative locations with different resource mixes are considered for a new investment or it could be used to capture the impact of changes in displaced resources over time.

The panel (b) on the right compares two clean energy investments. It shows that the clean investment 1 results in lower implied CO2 abatement costs despite having higher all-in costs than the other in-

Vestment. This is because the clean investment 1 displaces resources with higher costs and more emissions, which is captured as a flatter slope on the chart.

4. Sensitivity of abatement costs to technology displacement and performance

In this section, we apply the framework described above to develop various examples based on actual costs and performance data. Fig. 4 shows estimated all-in costs and CO2 emissions rates of fossil-fuel-fired generation resources that could be potentially displaced by clean energy investments.

On the left, gas CCs are shown with CO2 emissions rates ranging from 0.37 ton/MWh to 0.47 ton/MWh depending on the average heat rate (HR) of the plants. Existing gas CCs are dispatched at around $32–$36/MWh when gas prices are $4/MMBtu and $53–$60/MWh if
gas prices were to become $7/MMBtu. All-in costs of new gas CCs include capital costs, so they could be much higher depending on capacity factor (CF) of the plant. For example, with new gas CCs running at 70% CF would cost about $47–$66/MWh (depending on gas price scenario), while new gas CCs running at 30% CF would cost $70/MWh or more.

In the middle of Fig. 4, gas-fired peaking generators (gas CTs) are shown with emissions rates of 0.57–0.7 ton/MWh. Compared to gas CCs, the gas CTs typically emit about 50% more CO2 as they require more fuel to produce the same output. Accordingly, they are more expensive on a $/MWh basis. Existing gas CTs are dispatched at $52–$94/MWh depending on gas prices and heat rates, and new gas CTs would cost up to $164/MWh.

Finally, on the right, existing coal-fired generators are shown. They are much more emissions-intensive, with emissions rates of 1–1.2 tons/MWh that are approximately two to three times higher than gas CCs. On the other hand, their operating costs are relatively low, typically at $34–$38/MWh including fixed O & M costs.

We can see from this graphic that, regardless of where the clean energy resource lies, there are many possibilities for abatement costs depending on the resources displaced. Exactly which resources are displaced depends on a combination of market conditions and policy decisions, both of which can vary significantly over time and by location.

For example, say a resource planner considers building a new wind plant expected to run at 40% capacity factor with a levelized cost of $63/MWh (unsubsidized) under two different gas price scenarios.
Depending on other future market and policy uncertainties the wind plant might displace: (1) a new gas CC, (2) an existing gas CC, or (3) a 50/50 blend of existing gas CC during on-peak hours and coal during off-peak hours.

The costs and emissions rates, as well as the associated implied CO2 abatement costs are shown in Fig. 5.\(^5\)

At gas prices of $4/MMBtu, the CO2 abatement costs of the project would be $36–$44/ton if the wind resource displaced a new gas CC or a blend of existing gas CC and coal generation. Displacing a blend of gas and coal would result in higher CO2 emissions reductions compared to displacing a new gas CC, but it would also require a larger cost premium. On the other hand, if only existing gas CCs are displaced, the abatement cost would be $72/ton as shown in Fig. 4 above.

With higher gas prices, the cost premium for investing in a new wind project would be smaller, because the supply costs are more comparable, resulting in lower CO2 abatement costs. In our examples, if gas prices were to rise to $7/MMBtu, new wind resources (unsubsidized) would be less expensive than new gas CCs, implying a negative CO2 abatement cost as shown in Fig. 5 above. If displacing existing gas CCs (still at $7/MMBtu) or a blend of gas and coal generation, the wind project would have an abatement cost of $24/ton.

Comparing these two scenarios demonstrates the significance of gas prices on CO2 abatement costs both in absolute dollar terms and sensitivity with respect to displacement alternatives. Also, it can help identify the range of potential short- and long-run outcomes. For example, it could be that in a coal-heavy region, the wind investment would initially displace a blend of gas and coal generation, with the mix of displaced resources shifting towards more gas generation over time as a result of increasing gas prices and retirement of the coal fleet. Similarly, it is possible that the wind project would displace CCs initially but then delay or substitute for a new CC in the longer run.

While this simplified example illustrates the drivers of CO2 abatement costs for a single resource, it would need to be extended across multiple types of clean energy resources and time frames with additional sensitivities on future costs and performance, in order to inform resource planning and investment decisions.

In Fig. 6, we compare the CO2 abatement costs of wind plants against utility-scale solar PV plants. On the left, we show the same chart used in Fig. 4 above, with abatement costs of wind ranging from $36/ton to $72/ton depending on the resources displaced. On the right, we show the corresponding abatement costs of solar PV generation. At a capital cost of $1790/kWAC based on the NREL's cost benchmark for 1-axis tracking systems installed recently and assuming 30% capacity factor, we estimate the all-in levelized costs of new solar PV to be $75–$102/ton, which is significantly higher than the $36–$72/ton range estimated for wind. However, solar generation tends to be higher during on-peak hours and it typically provides higher capacity value compared to wind. Accordingly, the mix of resources displaced by solar could be very different than the resources displaced by wind (even if they are located in the same region), which should be taken into account for a fair comparison of abatement costs. For example, if solar generation displaced a blend of 25% new gas CCs, 25% existing gas CCs, 25% new gas CTs, and 25% existing gas CTs (with much higher heat rates, hence avoidable emissions), its implied CO2 abatement costs would be only $17/ton. This is well below the range of abatement costs calculated for wind, even though the solar PV resources considered in our example are more expensive on an absolute $/MWh basis.

As illustrated above, when comparing alternative clean energy investments, it is important to distinguish the extent, type, and timing of the resources they would displace in the system as those factors are very system-specific and can substantially impact abatement costs. Of course, it is essential to recognize that the clean investment itself can impact the displaced resources over time. For example, at high solar penetrations, the marginal resources displaced by solar can shift towards less peaking generation as their coincidence with net peak load declines. In some regions with intentions for very high renewable penetration, it could turn out that renewables displace each other, resulting in no net emissions savings in those hours.

Abatement costs depend heavily on the performance of the underlying clean energy resource and tax credits. Fig. 7 illustrates this sensitivity assuming existing gas CCs as the marginal resource displaced. For wind, we estimate the abatement cost to be $123/ton for a plant running at 30% capacity factor (unsubsidized). At 50% capacity factor, the cost premium relative to displaced resource would be much lower, translating to an implied abatement cost of $41/ton unsubsidized and $12/ton assuming the plant receives a federal production tax credit. For solar, we show abatement cost to range from $265/ton at 15% capacity factor to $102/ton at 30% capacity factor unsubsidized, and $52/ton at 30% capacity factor assuming the plant receives a federal investment tax credit.

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\(^5\) For simplicity, the examples discussed in this paper assume that clean energy investments would displace conventional resources on an annual MWh basis. For example, if a wind plant running at 40% capacity factor were to displace a new gas CC running at 70% capacity factor, then we would assume that each MW of wind investment would displace 0.57 MWh of new gas CC capacity in order to achieve the same annual energy output of 3504 MWh/year. Depending on system needs, adjustments may be necessary to account for differences in other resource attributes such as capacity value. Due to its intermittent output, if a wind plant gets a 20% of capacity credit, then each MW of wind investment would only have 0.20 MW of capacity value that can be relied upon for resource adequacy. Accordingly, it may be more appropriate to assume that each MW of wind would displace a blend of 0.20 MW of new gas CC capacity (with an annual generation of 1226 MWh/year) and additional existing resources of 3504 – 1226 = 2278 MWh/year.
There are several other factors that can significantly impact the implied CO₂ abatement costs for renewables. Although the example shown above focuses on capacity factor and tax credits, the same framework can be used to demonstrate sensitivity to other cost drivers, including capital costs, financing costs, system integration costs, and economic life.

5. Conclusion

The electric power industry is transforming rapidly due to technological changes, dramatic cost reductions in renewable generation, and increasingly ambitious climate and environmental policy goals and consumer preferences. Meanwhile, there is significant uncertainty about how regulatory policies will evolve to create proper incentives for transitioning into a future with lower CO₂ emissions. Understanding the implied costs of CO₂ abatement for various alternative clean energy technologies and their sensitivities with respect to the type of resources they displace will be a critical component for more cost-effectively setting regulatory policies and making resource planning decisions to meet emissions reduction targets.

Absent a nationally coordinated effort, it is likely that more states and regional entities will address climate protection locally, and if so it will be helpful for them to consider benchmarking implied CO₂ abatement costs of new clean energy development. As we discussed in this article, implied CO₂ abatement costs can vary substantially depending on the clean energy technology, as well as the type of resources displaced, which could vary over time and by location. Of course, it is essential to recognize that clean investment itself can impact the displaced resources over time. For example, at high solar penetrations, the marginal resources displaced by solar can shift towards less peaking generation as their coincidence with net peak load declines. In some regions with intentions for very high renewable penetration, it could turn out that renewables displace each other during some operating hours, resulting in no net emissions savings in those hours.

The graphical framework described in this article provides a visual representation of the implied CO₂ abatement costs for clean energy investments, while preserving the underlying cost and emissions information for both the clean energy resource and the potential resources that can be displaced. This framework can be used by policymakers and resource planners to evaluate abatement costs in a way that recognizes the dynamic nature of the CO₂ reductions from the mix of generation resources that might be displaced. Using this framework, we show that the implied CO₂ abatement costs of renewables can increase in the near term if the mix of displaced resources shifts towards less coal and more gas generation, because the avoided CO₂ emissions would be much lower. This increase in abatement costs, however, can be at least partially reversed over a longer horizon if the clean energy development displaces some of the new generation resources that would be otherwise needed for resource adequacy. Also, when comparing alternative clean energy investments, it is important to recognize that the mix of displaced resources can vary for each type of clean technology due to differences in their generation profiles. This means that the lowest-cost clean technology does not necessarily lead to the lowest implied CO₂ abatement cost, if there is a slightly more expensive investment opportunity that can displace higher-emitting or higher-cost resources.

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