Research

What it Costs to Go 100 Percent Renewable

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Executive Summary

- A "Green New Deal" that includes a proposal to move 100 percent of U.S. electricity production to renewable sources would require at least $5.7 trillion of investment in renewable energy and storage.
- Other studies show that climate policies focused purely on transitioning to *renewable* energy sources (as the Green New Deal proposes) cost far more than policies aimed more broadly at *low-carbon* sources.
- Good climate policy must signal to other countries that greenhouse gas abatement will be reciprocated, and consider the market conditions under which advanced nuclear, carbon capture and sequestration, and energy storage become competitive with incumbent energy sources.

Introduction

The "Green New Deal" (GND) is gaining momentum. Initially championed by Representative Alexandria Ocasio-Cortez and the Sunrise Movement, 45 politicians thus far have signed on to the GND, and one poll found that 81 percent of Americans support at least some of the policies of a GND. As outlined by the Sunrise Movement, the primary goal of a GND is for 100 percent of U.S. electricity to come from renewable sources.

While the GND stretches beyond environmental policy, this analysis is limited to the GND's 100 percent renewable energy target. It finds that such a target is impractical and, even using extremely favorable assumptions, would cost $423.9 billion annually—more than the entire retail cost of electricity in the United States in 2016. This finding is broadly in line with other estimates. The analysis further explains that such a policy is not the most efficient way to abate greenhouse gas emissions.

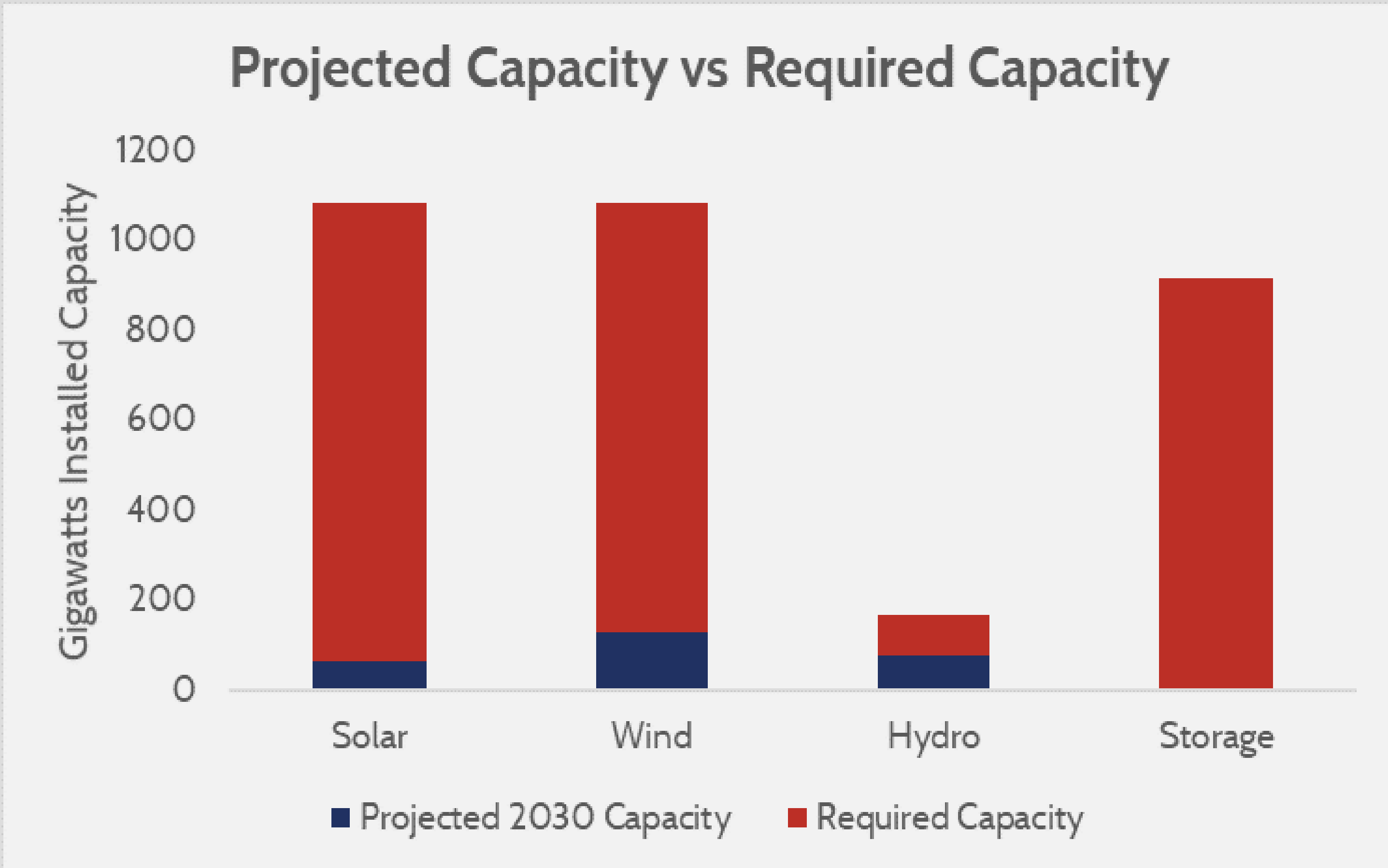
Estimating Costs

An accurate assessment of what a 100 percent renewable target costs is extremely difficult, and presumably only feasible with econometric analyses, like those published by the Energy Information Administration, but such estimates will take time to compile (and hopefully will be forthcoming in the future). A number of variables must be taken into account: seasonal variations in productivity and demand of energy resources, transmission availability and the costs, the required discharge rate of storage capacity, the different costs of peaking units versus baseload units, the costs of stranded assets, the economic effects of higher electricity prices, the economic effects of levying taxes to subsidize renewable electricity sources, the higher capital costs of new electricity sources as a mandate spurs new demand, etc. This analysis is an effort at a simplistic ballpark estimate, not an in-depth and precise projection.

For the sake of estimating the cost of a 100 percent renewable target, this analysis makes a series of substantial assumptions. These are as follows: the United States could entirely use solar power during the day, and wind power during the night; for the hours in the day where neither solar nor wind produce their stated capacity (due to capacity factors of electricity sources), it is assumed that a mixture of hydroelectricity and storage is used; the United States builds the entirety of all potential hydroelectricity resources; storage costs associated with batteries is their average operation and maintenance cost, rather than the (significantly higher) costs of batteries that can discharge a lot of electricity quickly and repeatedly throughout the day; electricity demand is roughly flat (rather than demand spiking during afternoon hours); and there is no increase in the price of wind, solar, hydro, or storage, even though a GND would cause the price of those resources to increase as demand is artificially inflated.

The estimate below is likely to be a significant underestimation, as it reflects the lowest imaginable cost of a Green New Deal.

To imagine what it would cost to implement 100 percent renewable electricity under these unlikely conditions, first note that the United States would need to install enough renewable electricity capacity and storage capacity to be able to meet peak electricity demand in the United States every day, plus a reserve margin. The United States' current electricity generating capacity is 1,085 gigawatts. This provides enough capacity to satisfy peak electricity demands, plus a reserve capacity to provide a safety net in the event of supply disruptions, equipment failures, or other issues that can prevent a power plant from supplying a customer. Now, in thinking about a 100 percent renewable electricity target, most of the power would have to come from wind and solar power. Solar power can only produce power during daylight hours, and wind power is most efficient at nighttime. To maintain an available capacity of 1,085 gigawatts, the United States would need to have 1,085 gigawatts of both solar and wind. Even then, solar power only produces its stated capacity roughly 25.7 percent of the day (its "capacity factor"). Wind power on average only provides power for 34.6 percent of the day. This means that even with these two resources, approximately 40 percent of the time neither would be available, meaning the United States would then require 1,085 gigawatts of an alternative renewable resource—in this analysis it is assumed that this is hydroelectricity, plus storage.



Installing said capacity would be incredibly costly. The table below shows those costs assuming the Energy Information Administration's latest overnight capital costs and operation and maintenance costs from the 2018 Annual Energy Outlook.

All costs millions USD	Required New Capacity (GW)	Capital Expenditures	Annual O&M	Annual Costs (20-year recovery)
Solar	1022	$1,891,500	$23,892	$118,467
Wind	954	$1,579,966	$51,505	$130,503
Hydro	91	$262,765	$7,666	$20,805
Storage	912	$1,978,498	$55,225	$154,150
Total		**$5,712,729**	**$138,288**	**$423,925**

Merely installing the required renewable capacity above projected renewable growth would cost $5.7 trillion. A business-as-usual approach would have 36.7 gigawatts of new (non-renewable) electricity generating capacity being built by 2030, which would have a capital requirement of approximately $48 billion, meaning the net difference in capital investment required between the 100 percent renewable target and a business-as-usual approach is approximately $5.66 trillion. [1]

To put the above in perspective, *global* clean energy investment in 2017 was $333 billion, a mere 3 percent above 2016's level. Assuming a 20-year recovery, the GND would require about $285 billion of clean energy investment as an annualized capital cost, meaning the United States would have to invest nearly as much money in clean energy as the rest of the world combined.

Combining the $285 billion of capital costs with the operation and maintenance costs results in an average annual expenditure of about $423.9 billion each year. For perspective, total revenue raised in the United States from electricity sales in 2017 was $390 billion. Even under the optimistic conditions of the above assessment, which assume very low electricity storage and discharge costs, and no increased transmission costs, merely building and operating the required number of renewable electric power plants would cost more than what Americans pay for electricity today.

It should also be noted that the above estimate likely seriously underestimates the costs of electricity storage. Storage becomes more expensive if it must discharge quickly, and multiple times throughout the day. The above simply assumes that the type of battery storage being installed at a utility scale today would be sufficient for all purposes, but more nuanced analyses like those from Lazard show an enormous cost difference between storing electricity and generating it. Lazard's analysis estimates that the cost of wholesale, levelized cost of lithium-ion storage (the total lifetime cost relative to energy saved) would be between $204-298 per megawatt hour. For perspective, the levelized cost of a natural gas power plant is $48 per megawatt hour, meaning using battery storage rather than a dispatchable natural gas power plant could cost consumers 4-6 times as much.

The above estimates show that a 100 percent renewable target would require an extraordinary amount of investment, but determining exactly how much a typical consumer would be affected is not easy, since electricity costs encompass more than merely the capital and operating costs. An analysis from Jesse Jenkins produced for the Massachusetts Institute of Technology, however, estimated that a decarbonized 100 percent renewable electricity system would result in an average electricity cost of $150 – 300 per megawatt hour (2017's average electricity cost is $104.8 dollars per megawatt hour). Simply, a 100 percent renewable electricity grid would require Americans to pay between 43 and 286 percent more on their electric bills. In 2017, the average monthly electric bill was $111, so a 43-286 percent increase would translate to an average of between $576 and $3,882 more spent on electricity per year per residence.

Other Estimates Show Similar Expense

This estimated annual cost figure is roughly in line with other estimates. For example, a Risky Business study, which estimated the costs of transitioning to a clean energy economy, concluded that an average annual investment of $320 billion would be required through 2050, and the model for this estimate assumed more resources than just renewables available. A National Bureau of Economic Research study estimated the net cost of reducing total greenhouse gas emissions by 80 percent would be $1.3 – 4.0 trillion (with $3.3 – 6.0 trillion of required investment). Although a $5.7 trillion estimate should not be taken as an accurate assessment, it does provide a ballpark figure that is consistent with what more thorough research on the topic has produced.

More Positive Studies Are Flawed

Despite the apparent popularity of a "100 percent renewable electricity" goal, there is surprisingly little academic research on what it would cost. This dearth is because renewable electricity is not the same as clean or low-carbon electricity. As explained by Jenkins in the MIT study, restricting low-carbon electricity objectives to renewable electricity creates much higher policy costs—10 to 62 percent higher. This expense results from a phenomenon known as the "duck curve," which is that the more non-dispatchable (i.e. renewable) resources you have supplying electricity, the greater the demands are upon your dispatchable (i.e. fossil) resources.

There are two commonly cited analyses, though, which are used to claim that a 100 percent renewable electricity target is affordable. The first, and most notable, is by Dr. Mark Jacobson of Stanford University. In his 2015 analysis, Jacobson et al. assert that it is net beneficial to switch to 100 percent renewable electricity, and that the reason it has not happened yet is because people are "unaware" of the benefits or ease of transition. This study has since been widely debunked, as it assumes far more hydroelectric usage than is even remotely technically achievable in the United States.

Another major assessment comes from the Lappeenranta University of Technology and Energy Watch Group. The research notes that widespread adoption of storage technology, particularly lithium-ion batteries, coupled with declining costs of renewable electricity make transitioning to 100 percent renewable electricity a low-cost endeavor. This study is flawed in that it assumes a massive, nearly 90 percent, decrease in lithium-ion battery cost by 2050. This assumption is contrary to the expectation of market analysts, which is that a global shortage of cobalt will make lithium-ion batteries *more* expensive. From 2016 to 2017, cobalt prices increased by 117 percent, and prices are expected to continue to climb. Furthermore, because much of the world's cobalt comes from the Democratic Republic of the Congo, batteries are often likened to "blood diamonds." The ethical and economic problems surrounding lithium-ion batteries is spurring innovation in alternative technologies, but so far an economical solution has not been identified.

Climate Policy, Rightly Understood

Despite the high costs of transitioning to 100 percent renewable electricity, it is not a deterrent to advocates of the policy objective. The Sunrise Movement's proposed draft text explicitly calls for "massive spending." The justification for such a high-cost policy comes from concern about low-probability, high-cost consequences of climate change, known as tail effects. If one believes that the tail effects are existentially threatening, then there is potentially no cost too high to prevent them.

This outlook is a poor approach to policy. Climate change is better understood as a collective action problem; no one country controls enough of global emissions to unilaterally implement a solution. Fundamentally the problem is a "prisoner's dilemma" type of game-theory problem, where each individual participant has high incentives to betray other participants, even though the optimal outcomes require cooperation. Thus, the goal of climate policy is not to reduce emissions *per se*, but rather to induce reciprocity from other nations. The objective of climate policy, then, should be to convince other nations that they need to act, and domestic emissions reductions are useful primarily in being convincing to other major emitters—China, India, Russia, etc.—that actions they take to reduce emissions will be reciprocated.

Thus, an effective climate policy is not a massively expensive “renewable electricity” objective, but rather a policy that reduces the most emissions for the least cost. Such a policy signals to other actors that the United States is seriously addressing an international problem, yet does so at the lowest cost.

Have Climate Initiatives Been Efficient?

Past AAF research has demonstrated that broad regulatory mandates are not effective climate policies. When controlling for business cycles, for example, greenhouse gas regulation in the United States has only been about half as effective as claimed on paper. Further research from AAF comparing carbon taxes and regulation found that regulations cost twice as much per ton of greenhouse gas abated as a carbon tax. Similarly, The Breakthrough Institute evaluated major economies that undertook significant climate policies, and found that in almost all cases there was little to no improvement in the carbon intensity (emissions per unit of gross domestic product) of the observed economies—the economies only got smaller in response to the policy change, not cleaner. In short, lots of evidence shows that the GND’s regulate-and-spend approach to climate policy is among the least effective available.

Better climate policy must employ the advantages of dispersed choice and markets. Cleaner energy is more readily adopted when it has a market advantage over incumbents and consumers have an option for choice. Such a situation can only arise in a market that allows for choice, and broad regulatory mandates or subsidies typically reduce choice and market competition. A serious look at U.S. climate policy should not simply be seeking opportunities for regulations or subsidies, but rather consider what are the market conditions under which advanced nuclear, carbon capture and sequestration, and energy storage become competitive with incumbent energy sources.

[1]

	2030 Cumulative Additions (GW)	Capital Cost (millions)
Combined Cycle GW	25.3	$ 24,865
Combustion Turbine/Diesel GW	9.1	$ 10,113
Nuclear GW	2.2	$ 13,081
Other	0.3	$ –
Total	36.7	$ 48,058