POLICY BRIEF

AFFORDABLE, RELIABLE, AND CLEAN

AN OBJECTIVE SCORECARD TO ASSESS COMPETING ENERGY SOURCES

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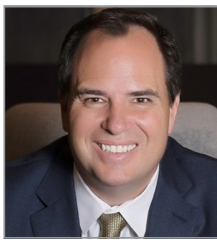

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Overview

America needs affordable and reliable energy sources to power our economy, provide prosperous personal living standards, and compete with global competitors. We also want to produce and use energy sources in a way that ensures a clean and ecologically healthy environment.

Affordable, reliable, and clean. This is the foundational tripod of sound energy policy. Affordability is necessary to ensure consumers can afford the electricity we need for our day-to-day lives. Reliability is necessary to guarantee electricity is available whenever we need it. Environmental impact is important because we all want to be good stewards of our environment.

In this paper, we analyze and assign an objective numerical score for competing energy sources regarding each of the three factors. Adding the three scores for each energy source, we arrive at an overall full-spectrum score for affordable, reliable, and clean energy.

For the purposes of this paper, we will confine our inquiry to energy for electrical power generation. The potential exists for a future paper, applying the same factors, regarding transportation fuels.

In this paper, we will score seven electrical generation sources. They are, in alphabetical order, biomass, coal, hydropower, natural gas, nuclear power, solar power, and wind power.

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Affordable

Pricing data for competing power sources is more complicated than most people assume. For example, a utility may be quoted at a low price for a given quantity of wind power on a day when a brisk wind is blowing. However, there are several hidden factors that make the cost of wind power higher than the quoted price. Among them:

Pricing data for competing power sources is more complicated than most people assume. For example, a utility may be quoted at a low price for a given quantity of wind power on a day when a brisk wind is blowing. However, there are several hidden factors that make the cost of wind power higher than the quoted price.

- Taxpayer subsidies hide a higher overall price for that wind power than what is quoted to the utility. According to the U.S. Energy Information Administration, wind power receives more source-specific federal subsidies than all conventional energy sources combined (Federal Financial Interventions and Subsidies in Energy in Fiscal Years 2016–2022).
- The utilization of power sources that are intermittent and unpredictable, such as wind and solar power, imposes hidden costs on other energy sources and on the overall electric grid. This is because intermittent energy sources require baseload power facilities like natural gas plants to be cycling and available – racking up costs but selling no power – in the background in case they are needed at a moment's notice when wind or solar power ramp down. It costs baseload facilities money to be cycling in the background, which adds to the cost of operating natural gas power plants, even though wind and solar power are gaining the sales and imposing those additional operating costs on natural gas power (Researchers Have Been Underestimating the Cost of Wind and Solar | Energy Central).
- Coal, natural gas, and nuclear power plants can be built almost anywhere. On the other hand, wind and solar power generation is often impractical near population centers and requires the construction of expensive new transmission lines to deliver power to distant cities (National Grid launches $4 billion upgrade of transmission lines to help renewable power flow - syracuse.com). The costs for those additional transmission lines typically soak up additional taxpayer dollars and/or get buried in overall utility bills, even though they are imposed specifically by wind and solar power.

Some "levelized cost" analyses of competing power sources do not include some or all of these factors. As such, they are of little use for real-world side-by-side analysis. The Energy Information Administration, for example, publishes the most well-known "levelized costs" of various power sources but explicitly states that those numbers are not apples-to-apples and should not be used for comparative purposes (Levelized Costs of New Generation Resources in the Annual Energy Outlook 2023).

To address those shortcomings, energy economists have developed a Levelized Full System Costs of Electricity (LFCOE) to account for all the upfront and hidden costs of competing power generation sources. This allows for an apples-to-apples comparison of affordability. The step-by-step factors and processes for determining LFCOE is explained in a paper in the peer-reviewed science journal *Energy*.

The Levelized Full System Costs of Electricity, using the relatively wind-friendly and solar-friendly geography of Texas as a baseline, is as follows, in dollars per megawatt-hour:

Natural Gas	$40
Coal	$90
Biomass	$117
Nuclear	$122
Wind	$291
Solar	$413

Hydropower was not included in the full system analysis. However, the U.S. Energy Information Administration and energy experts document that hydropower is among the least expensive energy sources (Hydropower Basics | Department of Energy).

With the full-system costs established, an affordability scale of 0 to 10 – with 0 being the least expensive and 10 being the most expensive – yields the following:

Natural Gas	1
Coal	2
Hydro	2
Nuclear	4
Biomass	4
Wind	7
Solar	10

Reliable

Power sources that are available on demand are far more valuable than power sources that are intermittent and unpredictable.

Coal, natural gas, and nuclear are considered baseload power because they can dependably provide reliable, on-demand power whenever they are needed. Biomass can also be available on demand, though biomass fuel stocks are much more limited than abundant coal, natural gas, and uranium. Electrical grid operators can plan well in advance how much power they can generate from these sources in any given hour, day, week, or month. Hydropower is largely on-demand, but drought conditions may affect hydropower generation in certain circumstances.

Wind and solar are more problematic from a reliability perspective. Wind turbines generate, on average, only about 35 percent of the power that would be possible under consistently ideal conditions (Wind was second-largest source of U.S. electricity generation on March 29 - U.S. Energy Information Administration (EIA)). Solar equipment generates, on average, only about 25 percent of the power that would be possible under sunny skies at high noon (Southwestern states have better solar resources and higher solar PV capacity factors - U.S. Energy Information Administration (EIA)).

The limited production of wind and solar power is even more problematic because those limited amounts of power production are unpredictable. Wind speeds can vary greatly on a minute-by-minute basis. The same holds true on an hour-by-hour or day-by-day basis. Solar is similar. Even during daylight hours, cloud coverage can vary on a minute-by-minute or hour-by-hour basis.

Grid operators must always keep electricity generation and supply in balance, but intermittent and unpredictable wind and solar power impose substantial challenges to doing so and inflict greater costs on other power sources that must be dialed up and down to match wind and solar intermittency.

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Dialing up and down backup power generation to accommodate wind and solar is more than merely inconvenient – it is also quite expensive. Just as an automobile will run more efficiently and get better mileage while running at a consistent highway speed than frequently increasing and decreasing speeds in city traffic, forcing backup power to ramp up and down to compensate for the intermittency of wind and solar adds substantial costs to power generation from those backup sources.

Coal, natural gas, and biomass have an advantage in that power providers can store coal, natural gas, and biomass fuel on-site at the power generating facility. They are largely immune from logistical interruptions. Natural gas, on the other hand, holds an advantage in that it is more capable than any other baseload source for quickly ramping up and down power generation to meet supply and demand variations.

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Theoretically, battery storage technology may someday allow wind and solar power to be stored for on-demand use on a grid-scale basis – likely at substantial additional expense. Such battery storage is not possible now, however. At best, battery storage for the large amounts of power necessary to power a community can be attained for only a few hours before the battery power is exhausted. It is highly unlikely that ample battery storage will be technologically or economically possible to provide reliable baseload power during the 20-to-30-year lifespans of wind and solar power facilities being built today or to be built soon.

A scale of 0 to 10, with 0 being the most reliable and 10 being the least reliable, yields the following reliability scores:

Natural Gas	1
Coal	1
Nuclear	1
Biomass	2
Hydro	3
Wind	8
Solar	8

Clean

Americans rightly expect strong environmental stewardship. Clean air, clean water, open spaces, and species protections are important components of power generation and consumption.

Every type of power source has its own unique environmental impact. It is important to focus on each power source's full environmental impact rather than just a single component of environmental impact, such as solely air pollution, land destruction, species impacts, or water and soil pollution.

Emissions/air pollution. Nuclear, hydro, wind, and solar emit no carbon dioxide or traditionally defined pollutants during power generation. Coal and biomass produce significant emissions, though substantially less than in years and decades past. Natural gas produces some emissions but is relatively clean burning. Natural gas emissions are closer to zero than they are to the emissions of coal and biomass.

A scale of 0 to 10, with 0 being no emissions, yields the following emissions/air pollution scores:

Every type of power source has its own unique environmental impact. It is important to focus on each power source's full environmental impact rather than just a single component of environmental impact, such as solely air pollution, land destruction, species impacts, or water and soil pollution.

Nuclear	0
Hydro	0
Wind	0
Solar	0
Natural Gas	2
Coal	7
Biomass	7

Land conservation. Wind and solar power pose unique threats to open spaces and species protection. It requires approximately 60 square miles of solar panels to generate the same amount of power as a conventional power plant. It requires approximately 320 square miles of wind turbines to do the same (The Land Footprint of PV Solar (and Nuclear and Wind Power) | by Alki Delichatsios | Medium). Large-scale power production from wind and solar accordingly requires substantial ecological damage and impact.

To put the land disruption of wind and solar power in perspective, scientists at Harvard University published a peer-reviewed study showing that meeting America's electricity use solely with wind power would require covering fully one-third of America's landmass with wind turbines (Large-scale wind power would require more land and cause more environmental impact than previously thought). That would be catastrophic to open spaces, undeveloped lands, and native ecosystems.

Moreover, wind and solar power generation are often most-efficient far away from urban centers and frequently require extensive networks of transmission wires to deliver wind and solar power to urban areas. Those networks of transmission wires further degrade and destroy open spaces.

The enormous amount of power transmission lines necessary for transporting wind and solar power to far-away population centers create additional direct harms on otherwise undeveloped or minimally developed lands. Faulty or disrupted power lines are frequently the cause of major wildfires. Power transmission lines were the culprit in deadly and massively destructive fires recently in California, the Texas Panhandle, and the Hawaiian island of Maui. The more power transmission lines that are necessary to deliver distant wind and solar power, the greater the likelihood of future catastrophic fires.

Hydro entails transforming river and stream environments into lake and pond environments. That is disruptive to existing ecosystems, though for land conservation purposes the end result is trading a river environment for a lake environment.

Coal mines can be fairly significant in size and disruption. Coal is typically delivered to power plants via existing railroads.

Natural gas is produced on a very small wellhead footprint. Natural gas is typically delivered to power plants via underground pipelines. A small portion of natural gas pipelines are above ground.

Biomass entails cultivating significant amounts of land for biomass fuel. This is somewhat mitigated when the fuel stocks are grown specifically for the purpose of cultivation.

A scale of 0 to 10, with 0 being the least disruptive and 10 being the most disruptive, yields the following land conservation scores:

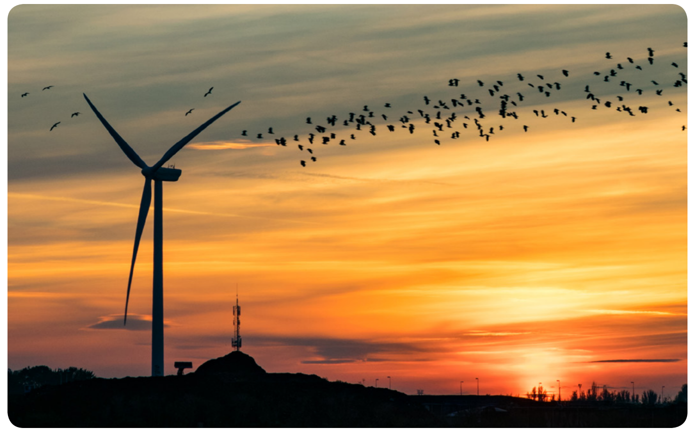
Natural Gas	1
Hydro	2
Nuclear	2
Coal	4
Biomass	4
Solar	6
Wind	10

Direct animal kills. Land degradation directly harms species and ecosystems. Some forms of power generation additionally harm species and ecosystems through high numbers of direct kills. Peer-reviewed studies find wind turbines and solar power equipment in the United States kill more than one million birds and bats, including many protected and endangered species, each year (Comparing bird and bat fatality-rate estimates among North American wind-energy projects - Smallwood - 2013 - Wildlife Society Bulletin - Wiley Online Library). Also, the construction and operation of offshore wind power projects is directly correlated with increased whale and dolphin high mortality events (Energy Updates | Caesar Rodney). More wind and solar power will drive those direct-kill numbers even higher.

Hydro dams negatively impact ecosystems during construction. Also, hydro dams have significant impacts on salmon and other fish species. This is somewhat mitigated by positive impacts for other species.

Biomass often kills animals as the biomass is gathered.

A scale of 0 to 10, with 0 entailing little or no direct animal kills, yields the following scores:



> **Land degradation directly harms species and ecosystems. Some forms of power generation additionally harm species and ecosystems through high numbers of direct kills.**

Natural Gas	0
Nuclear	1
Coal	2
Hydro	3
Biomass	5
Solar	5
Wind	7

Soil and water pollution and impacts. All power generation sources have impacts that degrade soil and water. Some are far more damaging than others.

Construction of a hydroelectric dam will flood existing land and may impede fish migration. However, those harms may be largely balanced by the benefits to many plants and animals from the creation of a new pond or lake.

The environmental impacts of coal mining are becoming smaller all the time, especially with the requirement that the land affected by a coal mine must be restored to its pre-mining condition after completion of mining. Still, mining itself substantially degrades the land during mining operations and can lead to additional issues of air and water pollution.

Uranium mining faces similar environmental obstacles to coal, though much less uranium than coal is required to power a full-scale power plant.

With recent advances in hydraulic fracturing and directional drilling, natural gas production requires a very small footprint to produce prodigious amounts of natural gas.

All power generation sources have impacts that degrade soil and water. Some are far more damaging than others.

Biomass requires the destruction of forests or the development of previously undeveloped lands to produce the biological material necessary to fuel biomass facilities.

Wind and solar equipment require the mining, refining, and utilization of substantial amounts of toxic metals and rare-earth minerals. Rare-earth mining and the refining of rare-earth minerals are among the most environmentally destructive practices on the planet, typically resulting in widespread and heavily toxic pollution of soil and water (Not So "Green" Technology: The Complicated Legacy of Rare Earth Mining).

A scale of 0 to 10, with 0 being minimally damaging, yields the following soil and water pollution scores:

Natural Gas	1
Hydro	2
Nuclear	2
Coal	4
Biomass	4
Solar	7
Wind	7

Total environmental impact. Adding together the four environmental impact scores above yields the following total environmental impact scores, with lower total scores equating to less environmental harm:

Natural Gas	4
Nuclear	5
Hydro	7
Coal	17
Solar	18
Biomass	20
Wind	24

Converted to a 0 to 10 scale consistent with the "affordable" and "reliable" factors, here are the comparable "clean" scores, with lower scores equating to less environmental harm:

Natural Gas	1
Nuclear	1
Hydro	2
Coal	5
Solar	5
Biomass	6
Wind	7

Cumulative Affordable, Reliable, and Clean Score

Adding together the above numbers yields the following affordable, reliable, and clean total scores, with lower scores being closer to perfect power sources and higher scores being least compatible with the affordable, reliable, and clean ideal:

Natural Gas	3
Nuclear	6
Hydro	7
Coal	8
Biomass	12
Wind	22
Solar	23

Conclusion

Affordable, reliable, and clean are the foundational elements of sound energy policy. An in-depth analysis of seven common electrical power sources reveals that natural gas makes the most sense according to the affordable, reliable, and clean standard, with nuclear, hydro, and coal not far behind. Biomass trails by a moderate margin while wind and solar stand apart as the least desirable power sources.

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