LWVNM Nuclear Issues Study
Task 3 Report

Nuclear Power in the US

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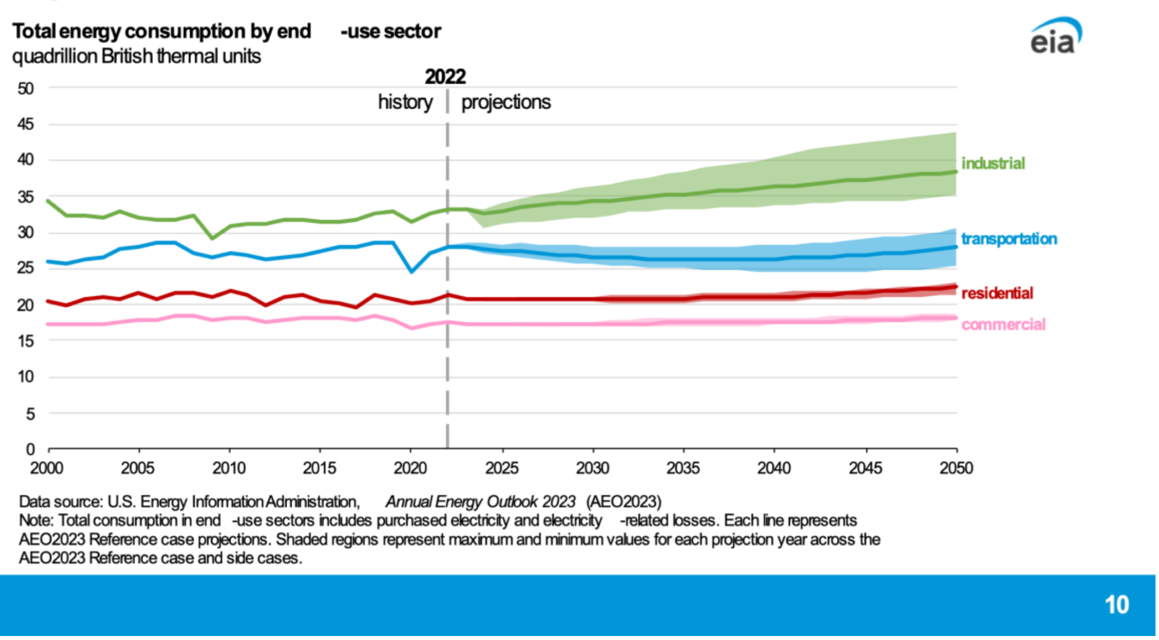
Task 3. Consider the current U.S. energy situation and domestic nuclear plant status including closures with related impacts on states.

Electricity Supply and Demand Estimates to 2050

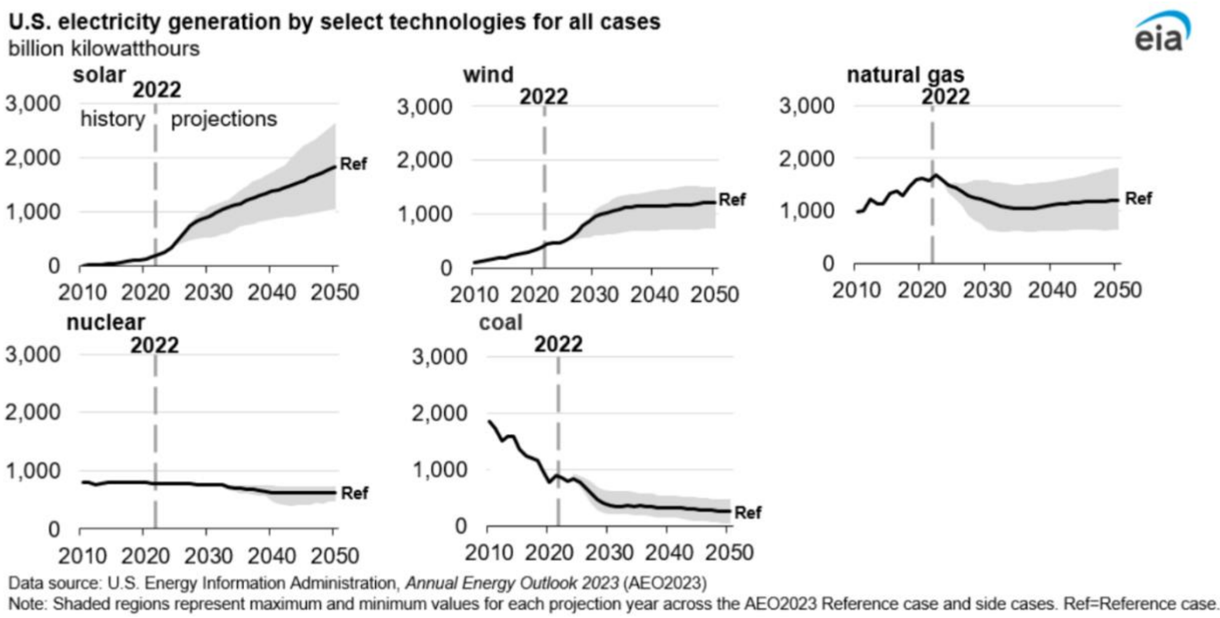
In order to meet climate goals of reducing reliance on fossil fuels for electricity generation by 2050, we need to analyze whether and how US electricity requirements can be met by other energy sources. A first step is to investigate the current and estimated demand for electricity and then identify various ways that this demand can be met. This brief report will focus on the energy mix of fossil fuels (coal and natural gas), nuclear energy, and renewable energy sources (solar and wind) in the US between now and 2050. Note that a number of assumptions must be made in all estimates of energy demand and supply, such as economic growth rates, technological advances, costs and prices, public policies, etc. Likewise, estimates of which investments in non-fossil fuel sources should be selected also depend upon a number of assumptions, which should be made transparent.

A particularly relevant, unbiased, and up-to-date source of data for estimating energy demand and supply is the US Energy Information Administration (EIA). Its *Annual Energy Outlook 2023* (AEO2023) provides estimates, using 2022 as the baseline and ending in 2050. First, regarding demand, the AEO2023 estimates that increases in total demand could be as low as zero by 2050 or as high as 15% above the 2022 level. The shaded "cone of uncertainty" in the figure below (from the EIA report) takes into account various assumptions about economic growth, energy costs and availability, energy efficiency, etc. This finding in itself is a remarkable forecast that US energy demand in the residential, commercial, and transportation sectors will remain virtually unchanged in 2050. Growth is projected to occur in the industrial sector, which also has the greatest range of uncertainty.

Figure 7



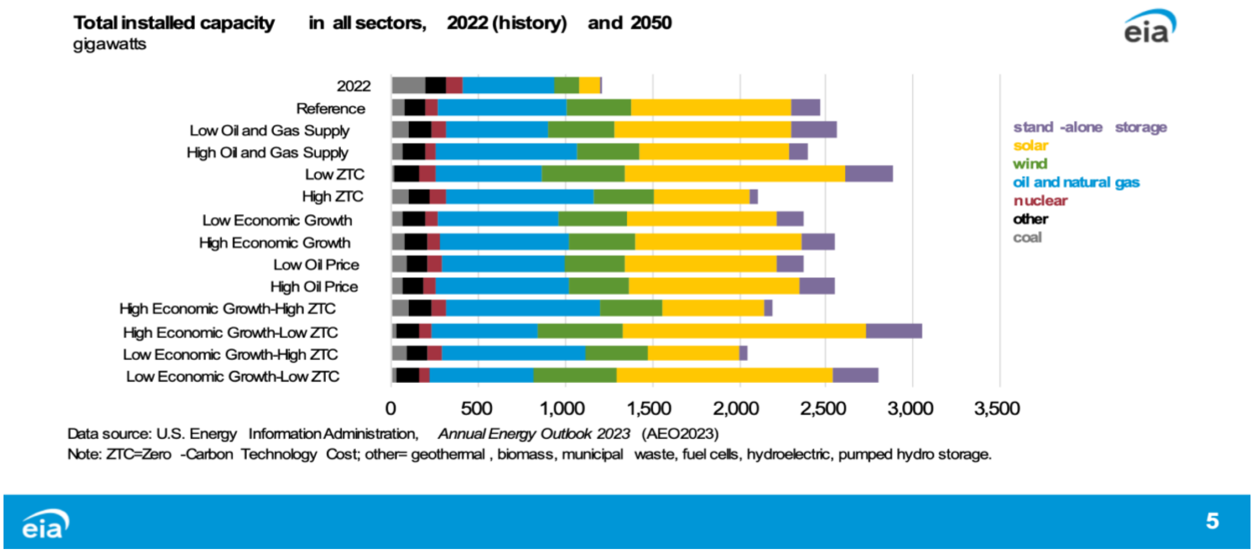
The AEO2023 also provides estimates of where the supply of energy to meet the demand will come from. The figure below tracks estimates for individual energy sources in the context of pre-2020 growth from 2010 to 2050. The reference case (bold line) estimates energy sources under current US laws and regulations (such as the Inflation Reduction Act) as they are expected to be implemented. Note that the use of solar energy is predicted to increase dramatically. Wind energy continues to increase until the mid-2030s and then stabilizes. Natural gas and nuclear energy each exhibit small declines. Coal continues its long-term decline.



The chief reason why renewable energy sources are becoming dominant is because of declining costs relative to other sources. Between 2009 and 2021, the cost of solar dropped 90% and wind 72%. Nuclear energy is the only energy source that increased in cost, by 36%, during this period. (See Appendix A for data on declining costs of renewables compared to traditional energy sources.)

Figure 3 below from the AEO2023 consolidates the individual estimates for each energy source into a single chart. It shows the 2022 sources of electricity in the top line and the "reference case" in the second line. The following twelve lines are the estimates of 2050 energy sources based upon various assumptions, such as low vs high oil and gas supply, low vs high renewable energy cost, low vs high economic growth, etc. In all cases, renewable sources, that is, solar and wind energy taken together, are the largest sources of energy, and coal is the lowest source by 2050. The percentage of oil and natural gas may increase or decline depending upon relative costs. Nuclear energy is declining over the period.

Figure 3



The EIA summarized its findings as follows: "In AEO2023, we see stable growth in U.S. electric power demand through 2050 in all cases we considered because of increasing electrification and ongoing economic growth. The combination of declining capital costs and government subsidies, including IRA initiatives, drive rising renewable technologies for electricity generation, such as solar and wind. Once built and when the resource is available, wind and solar are the least cost resources to operate to meet electricity demand because they have zero fuel costs. Over time, the combined investment and operating cost advantage increases the share of zero-carbon electricity generation. As a result, in AEO2023, we see renewable generating capacity growing in all regions of the United States in all cases. Across all cases, compared with 2022, solar generating capacity grows by about 325% to 1019% by 2050, and wind generating capacity grows by about 138% to 235%. We see growth in installed battery capacity in all cases to support this growth in renewables."[i] (emphasis added) EIA thus supports the position that a mix of energy sources, including significant growth in renewables, is sufficient to meet the demand for electricity in 2050.

State Variability in Electricity Energy Sources

AEO2023 focuses on national estimates of energy demand and supply for electricity, but it is worthwhile to consider how the energy mix varies widely by state, due to differences in natural resource availability, relative costs and technologies when initial investment decisions were made, public policies, long-term contracts, impacts on communities, etc. Energy transitions are not smooth and automatically responsive to cost differences. Public utility investments in electricity generation are very large and long-term, and may be influenced by noneconomic considerations.

One example of how state variability might influence the pace at which fossil fuels are replaced by non-greenhouse gas energy sources relates to uses of coal. Appendix B lists the top 10 states that are currently using coal to generate electricity. Note that public utilities in West Virginia, Wyoming, and Kentucky are most dependent upon coal to generate electricity. Some state utilities on this list may choose to continue using coal because it is sourced within their state and benefits many state residents. Utilities in other states are more likely to switch to another energy source as long-term contracts expire and coal plants become obsolete if given incentives to do so or if it is otherwise less costly or preferred by citizens.

A somewhat different analysis might face the 28 states that currently have nuclear plants in operation. Appendix C lists the states with one or more reactors in the order of percentage of dependence on nuclear power in 2023. Note that Nuclear Regulatory Commission licenses to operate are initially for 40 years but may be extended in increments of 20 years if the reactor is operating safely and if requested by the state utility commission. Of the 92 US nuclear reactors operating in 2020, 88 have received an extension of 20 years on the initial 40-year license.

Appendix C shows that New Hampshire is most dependent upon nuclear energy. New Hampshire utilities generated a total of 1,520 MW-hr. of electricity, of which 59.1% came from its Seabrook nuclear plant. Seabrook has already received one extension to operate until 2050. The state's public utility commission will have to decide in the 2040's whether to request an additional 20-year license extension to 2070 or shift to another energy source. A possible alternative energy source might be hydroelectric energy that will be transmitted from Quebec by Avangrid's New England Clean Energy Connect (NECEC) line.

In Appendix C Illinois has the second highest dependence on nuclear energy at 55.6%. After 11 reactors were built in the 1970s and 1980s, its legislature passed a very restrictive requirement in 1987 against building any new nuclear facilities, one of twelve states that have such bans or restrictions.[ii] However, conflicts have arisen in recent years in Illinois about whether to continue to rely on nuclear energy by lifting the restrictions. The state legislature passed a bill in 2023 that would have repealed the state's law banning the construction of new nuclear facilities until a permanent site for nuclear waste disposal is selected. However, the governor vetoed the legislation. Meanwhile, its nuclear utility is applying to extend the licenses of two plants to operate into the 2040s.

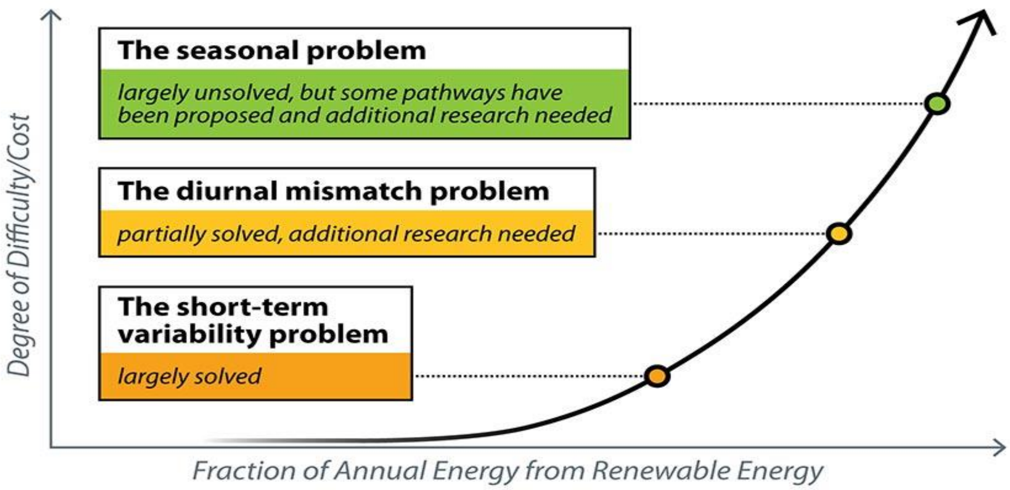
While most states with nuclear facilities have opted to extend their licenses to operate for at least 20 years, ten states chose to permanently close twelve U.S. nuclear reactors between 2013 and 2021, according to a Congressional Research Service (CRS) report in 2021. (See Appendix D for a list of these shutdowns.) Seven other reactor retirements were announced through 2025. However, the CRS report notes that announced retirements have not always occurred as planned because states may take actions to provide more revenues to keep a plant operating. Many other U.S. reactors have been identified by recent studies as being "at risk" of shutdown for economic reasons, although their closures have not been announced.[iii]

It appears that growth in new nuclear power plants is unlikely at the present time. The strategy in most cases is to keep existing nuclear plants in operation when safe to do so.

Renewable Energy Challenges

While some scholars propose that the US can become 100% reliant on renewable energy sources in the foreseeable future (e.g., Jacobson, et al., 2017; Jacobson, 2023), everyone acknowledges that a number of technical and non-technical challenges to renewable energy growth must be addressed. (See Breyer, et al., for a review of scholarly research on 100% renewable energy opportunities and challenges, beginning in the 1970s and growing substantially since 2014. This extensive analysis has 472 references.)

The 2021 study by the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) and DOE's Office of Energy Efficiency and Renewable Energy (EERE) concluded that current technical knowledge was sufficient to achieve up to 80% reliance on renewable energy sources. This study (called the NREL-EERE study below) divided the technical problems in the transition to 100% renewable energy into 3 categories, as shown in NREL-EERE's graphic below.



The short-term variability problem relates to the public utility balancing the supply of renewable energy and demand for electricity on a minute-by-minute basis. This problem is largely solved, according to the NREL-EERE study. Studies of the second problem, called the diurnal mismatch problem, focus on balancing supply and demand over a 24-hour period because peak demand occurs at night but supply of solar and wind energy is mostly generated during the day. Battery storage systems are key to solving this problem. The NREL-EERE study claims that battery technology is currently sufficient to achieve up to 80% of electricity demand using renewable energy sources.

In the third zone, however, the seasonal mismatch problem needs research to "evaluate the suite of technologies that can help ensure renewable supply matches demand patterns across all time periods—and that we will need significant engineering and design to transition the grid from one that is dependent on synchronous machines to one that is based on inverters."[iv]

The non-technical problems in transitioning to renewable energy are economic, environmental, social, and political. They include the following issues:

1) Large investments necessary for electrical grid expansion and upgrades. (That is, more transmission lines to connect solar and wind sources to end users and to update existing transmission lines to integrate renewable sources).
2) Local opposition to large solar and wind installations based upon land use and environmental issues, such as impacts on wildlife.
3) Very long permitting times for some renewable energy projects, which relate in part to the local opposition issue above. (For example, Pattern Energy's SunZia transmission line in New Mexico, the largest wind energy project in the Western Hemisphere as of 2023, took 17 years to be approved.)
4) Worker and community exposures to hazardous amounts of lead, lithium, tin, and cadmium used in manufacturing solar and wind equipment.
5) Supply chain issues, including availability of critical but scarce minerals and materials. (See Breyer, et al., 2022, Section VI, Part D for a detailed analysis of this issue.)
6) Opposition by other energy interest groups.

Perhaps one of the easier issues to solve is modernizing the electrical power grid because we have been working on it since at least 2015. The DOE prepared a comprehensive multi-year plan to modernize the electrical power grid nation-wide in November 2015. Much of the early work was on research to identify low-cost technical solutions that could be implemented at state and local levels.

Subsequently, state-level actions to modernize the power grid have been extensive, as reported by the National Council of State Legislatures. Its 2021 report stated: "Legislatures, public utility commissions and energy providers across the nation are discussing grid modernization, assessing needs, policies, costs and return on investment. While needs vary from state to state, the latest report from the American

Society for Civil Engineers found that current grid investment trends will lead to funding gaps of $42 billion for transmission and $94 billion for distribution by 2025… Although many of these upgrades may require significant investment, many can result in operational savings while providing resiliency and other benefits. Technologies that increase knowledge of grid operations, for instance, can allow utilities to better balance fluctuating supply and demand, respond to outages, optimize resource use and increase efficiency."[v] At least $378 billion in federal grants, loans, and tax credits for grid modernization and wind energy projects have been announced by the Department of Energy. Other federal agencies also have clean energy funding available.

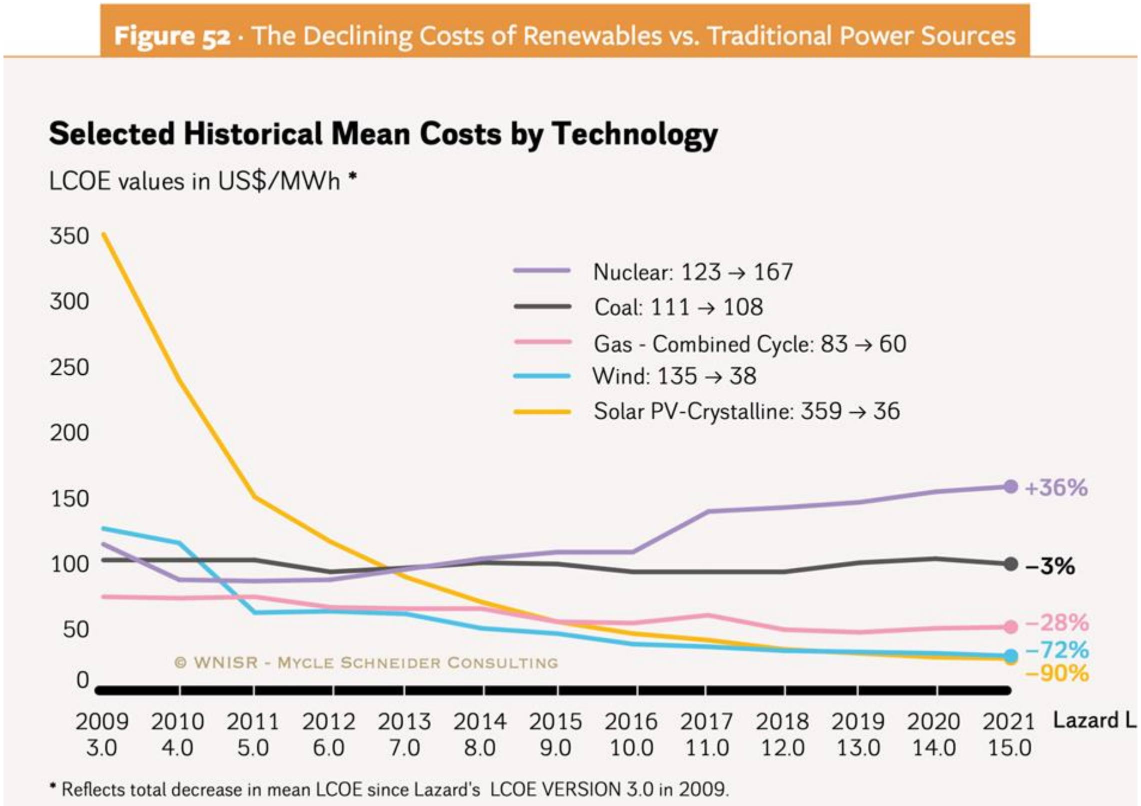
The other issues are challenges to be addressed on a case-by-case basis. Each state has particular circumstances that influence support for or opposition to renewable energy sources. Appendix E shows the percentage of renewable energy generated in each state in November 2023. The contrast between the top 10 states and the bottom 10 is stark. Seven states are already above 50% usage of renewable energy, while six states use 5% or less. The midpoint is only 14%. Clearly, there is much room to increase use of renewable sources, and funding is available to expedite this growth.

Conclusions

The US Energy Information Administration's AEO2023 states that it is technically feasible to rely on a mix of energy sources to meet both the predicted demand for electricity in 2050 and also net-zero climate goals. Solar and wind energy sources will provide over 50% of supply with substantial funding at the federal and state levels. Existing nuclear energy will continue to provide electricity with plants in operation today whose useful lives have been extended 20 to 40 years beyond initial licenses. The balance of supply will come from natural gas to a large extent and from coal at a much lower extent than in the past.

Achieving the goal of 100% renewable energy requires overcoming a number of challenges. Leading states are showing the way in how to overcome these challenges. The general public is strongly in favor of developing solar and wind energy projects. (See Appendix F for a 2022 Pew survey question comparing public opinions about renewable vs. nuclear energy projects.) Many states are well on the way to investing in infrastructure to support solar and wind energy projects. In our view, the energy transition to renewables is moving ahead quickly enough that no new nuclear plants are needed to meet 2050 goals.

Appendix A



Source: World Nuclear Industry Status Report 2022, page 280
https://www.worldnuclearreport.org/IMG/pdf/wnisr2022-figure52_lazard_lcoe_2021.pdf

Appendix B

Top 10 states using coal to generate electricity in 2023*:

West Virginia	83.9%	Nebraska	50.7%
Wyoming	75.1%	Utah	44.7%
Kentucky	69.0%	Indiana	43.8%
Missouri	64.7%	Montana	39.8%
North Dakota	60.0%	Iowa	37.4%

*Data are extracted from https://www.chooseenergy.com/data-center/electricity-sources-by-state/. The website provides state-by-state data of energy sources as well as lists of the top 10 states using 5 energy sources.

Appendix C

Nuclear Energy Dependence by State, Generation, No. of Reactors, and Potential Lifespan*

State	Total Elec. Generation (MW-hr)	%Nuclear	#Reactors	Grid 1st Connect Dates	Mandatory Retirement Dates*
New Hampshire	1,520	59.1	1	1990	2070
Illinois	15,108	55.6	11	1970-1988	2050-2068
South Carolina	8,693	54.3	7	1970-1986	2050-2066
Tennessee	6,691	48.4	4	1980-1996	2060-2076
New Jersey	5,544	45.5	3	1976-1986	2056-2066
Maryland	2,806	45.4	2	1975-1976	2055-2056
North Carolina	10,920	34.2	5	1975-1987	2055-2067
Pennsylvania	19,532	33.2	8	1974-1989	2054-2069
Alabama	12,259	30.8	5	1973-1977	2053-2057
Virginia	8,061	28.7	4	1972-1980	2052-2060
Arizona	9,550	28.6	3	1985-1987	2065-2067
Georgia	11,782	25.3	4	1974-1989	2054-2069
Michigan	9,908	24.2	4	1975-1986	2055-2066
Arkansas	5,604	23	2	1974-1978	2054-2058
New York	10,462	22.6	3	1969-1987	2049-2067
Minnesota	5,086	20.2	3	1971-1974	2051-2054
Kansas	4,668	18.4	1	1985	2065
Nebraska	3,121	18	1	1974	2054
Wisconsin	5,648	15.2	2	1970-1972	2050-2052
Ohio	10,428	14.9	2	1977-1986	2057-2066
Mississippi	6,713	14.5	1	1984	2064
Missouri	5,993	14.5	1	1984	2064
Louisiana	9,154	12.1	2	1985	2065
Florida	24,467	10.9	4	1972-1983	2052-2063
California	17,257	9.4	2	1986-1987	2066-2067
Texas	50,622	6.8	4	1988-1993	2068-2073
Washington	7,986	3.3	1	1984	2064
Connecticut	2,629	1	2	1975-1986	2055-2066

*Sources: Choose Energy, https://www.chooseenergy.com/data-center/electricity-sources-by-state/; US Energy Information Administration, https://www.eia.gov; Nuclear Regulatory Commission https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html; Office of Nuclear Energy, https://www.energy.gov/ne/office-nuclear-energy

Appendix D

U.S. Nuclear Reactor Shutdowns, 2013-2021*

State	Reactor	Start-up Year	Shutdown Date	Generating Capacity (Megawatts)	Major Factor(s) Contributing to Shutdown
Florida	Crystal River 3	1977	Feb. 2013	860	Cost of major repairs to reactor containment
Wisconsin	Kewaunee	1974	May 2013	566	Operating losses
California	San Onofre 2	1983	June 2013	1,070	Cost of replacing defective steam generators
California	San Onofre 3	1984	June 2013	1,080	Cost of replacing defective steam generators
Vermont	Vermont Yankee	1972	Dec. 2014	620	Operating losses
Nebraska	Fort Calhoun	1973	Oct. 2016	479	Operating losses
New Jersey	Oyster Creek	1969	Sept. 2018	614	Agreement with state to avoid building cooling towers
Massachusetts	Pilgrim	1972	May 2019	685	Operating losses; rising capital expenditures
Pennsylvania	Three Mile Island I	1974	Oct. 2019	803	Operating losses
New York	Indian Point 2	1974	Apr. 2020	1,020	Low electricity prices; settlement with state
Iowa	Duane Arnold	1975	Aug. 2020	601	Lower-cost alternative power purchases
New York	Indian Point 3	1976	Apr. 2021	1,038	Low electricity prices; settlement with state

*Source: Adapted from Table 1, Congressional Research Service. U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns. June 10, 2021. https://crsreports.congress.gov R46820.

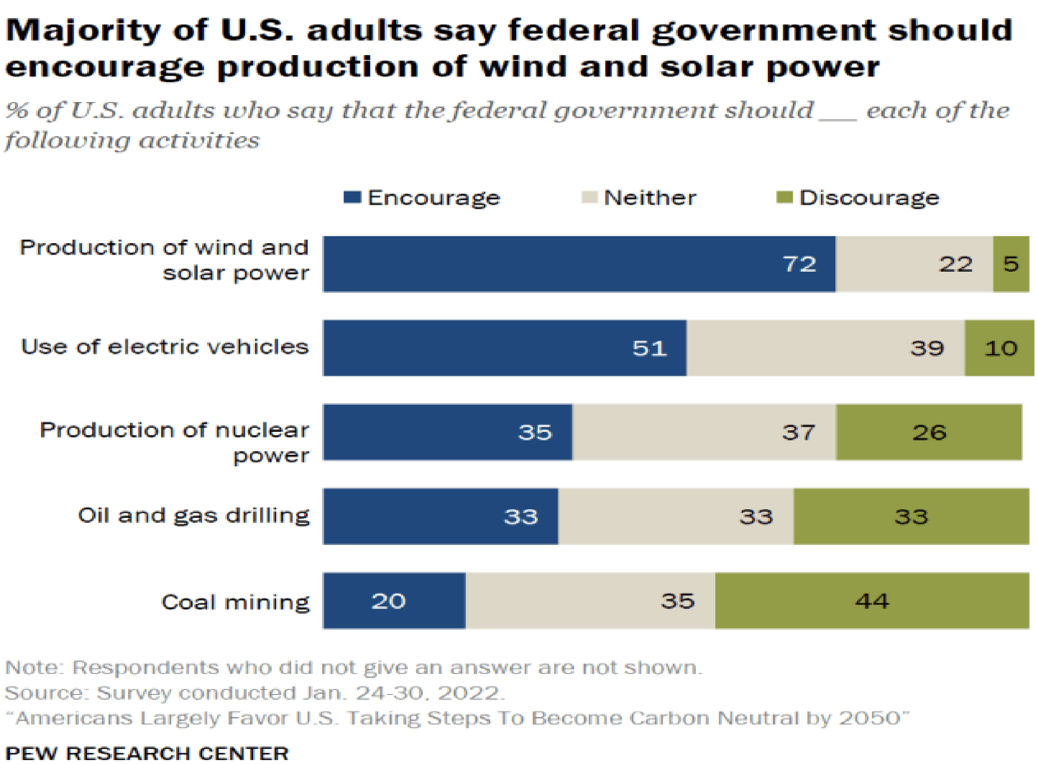
Appendix E

Renewable Energy Use by State, November 2023*

State	% Renewable Sources (11/23)		% Solar	% Wind	Hydroelectric
1. Vermont	95.3		25.0	16.0	54.3
2. Washington	65.8		1.2	5.7	58.9
3. South Dakota	64.1		0	44.6	19.5
4. Idaho	59.9		9.1	10.5	40.3
5. Maine	57.0		13.3	16.4	27.3
6. Oregon	55.3		5.3	14.6	35.4
7. California	50.5		31.4	5.0	14.1
8. Montana	46.3		2.3	13.4	30.6
9. Iowa	40.9		1.7	38.2	1.0
10. New Mexico	38.9		10.2	28.7	0
11. Massachusetts	38.1		33.1	0.8	4.2
12. Colorado	35.1		11.1	22.0	2.0
13. Hawaii	32.4		24.8	7.6	0
14. North Dakota	31.8		0	28.1	3.7
15. Kansas	30.7		0.4	30.3	0
16. Nevada	30.3		27.3	0.5	2.5
17. New York	28.9		5.9	2.9	20.1
18. Oklahoma	28.4		0.3	26.5	1.6
19. Minnesota	22.7		4.6	17.0	1.1
20. Nebraska	22.7		0.4	20.4	1.9
21. Texas	21.4		6.3	15.0	0.1
22. Alaska	18.6		0	0	18.6
23. Wyoming	14.7		0.5	13.0	1.2
24. Utah	14.2		13.1	1.1	0
25. Rhode Island	14.0		12.7	1.3	0
26. North Carolina	12.4		9.2	0.2	3.0
27. Tennessee	11.9		1.5	0	10.4
28. Maryland	11.2		6.9	0.7	3.6
29. Illinois	9.5		2.3	7.1	0.1
30. New Hampshire	9.4		0	2.1	7.3
31. Indiana	9.0		3.3	5.3	0.4
32. Missouri	8.6		1.4	5.5	1.7
33. New Jersey	8.1		8.1	0	0
34. Kentucky	7.7		0.5	0	7.2
35. Virginia	7.5		6.4	0	1.1
36. Michigan	7.0		1.6	4.6	0.8
37. Arkansas	6.3		1.8	0	4.5
38. Delaware	6.2		6.2	0	0
39. Alabama	6.1		0	0	6.1
40. Arizona	6.1		0	1.4	4.7
41. Florida	6.1		6.1	0	0
42. Georgia	5.9		5.9	0	0
43. Wisconsin	5.9		2.6	1.4	1.9
44. South Carolina	5.6		3.6	0	2.0
45. Connecticut	5.0		4.3	0	0.7
46. West Virginia	5.0		0.1	2.2	2.7
47. Ohio	3.1		1.7	1.1	0.3
48. Pennsylvania	2.5		0.7	0.8	1.0
49. Louisiana	1.3		0.5	0	0.8
50. Mississippi	0.9		0.9	0	0

*Source: Adapted from https://www.chooseenergy.com/data-center/electricity-sources-by-state/, November 2023.

Appendix F



Endnotes

[i] Quote from US Energy Information Administration (EIA), "Annual Energy Outlook 2023," March 2023. https://www.eia.gov/outlooks/aeo/narrative/index.php#ExecutiveSummary

[iiii] According to the National Conference of State Legislatures website, the 12 states with bans or strong restrictions on new nuclear power plants are: California, Connecticut, Hawaii, Illinois, Maine, Massachusetts, Minnesota, New Jersey, New York, Oregon, Rhode Island, and Vermont. https://www.ncsl.org/environment-and-natural-resources/states-restrictions-on-new-nuclear-power-f

[iii] Quote from Congressional Research Service (CRS), "U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns," June 10, 2021. https://crsreports.congress.gov R46820.

[iv] The "inverter problem" is described in the NREL-EERE study. An inverter converts direct current (DC) electricity, which is what a solar panel generates and battery systems produce, to alternating current (AC) electricity, which the electrical grid uses. With DC, electricity is maintained at constant voltage in one direction. With AC, electricity cycles in both directions in the circuit. See EERE's website for a fairly non-technical description of inverters. https://www.energy.gov/eere/solar/solar-integration-inverters-and-grid-services-basics#:~:text=Traditional%20%E2%80%9Cgrid%2Dfollowing%E2%80%9D%20inverters,the%20inverter%20tries%20to%20match

[v] Source for quote: National Council of State Legislatures, "Modernizing the Electric Grid: State Role and Policy Options." Updated September 22, 2021. Glen Andersen, Megan Cleveland, and Daniel Shea. https://www.ncsl.org/energy/modernizing-the-electric-grid