U.S. ELECTRICITY TRANSITIONS

Emerging Threats & Opportunities for the Resiliency & Reliability of the U.S. Grid

Prepared by:

DYNAMIC SUSTAINABILITY LAB™
AT SYRACUSE UNIVERSITY

Dr. Jay S. Golden & Aaron Otis

October 2024

In Partnership with: SEVA
Sustainability & Energy Value Advisors

FAST FACTS

*The U.S. power grid is a vast network serving millions of customers, relying on a diverse mix of generators that are constantly changing. **Despite the sheer scale and complexity of the system, there is now no single entity at the local level responsible for overall energy use coordination and optimization**. This fragmented operations and management structure presents significant challenges for ensuring reliable and efficient energy delivery.*

1. NUMBER OF POWER PLANTS IN THE U.S.

As of December 31, 2022, there were **25,378 electric generators at about 12,538 utility-scale electric power plants** in the United States. Utility-scale power plants have a total nameplate electricity generation capacity of at least 1 megawatt (MW).[1]

2. ELECTRICITY GENERATION CAPACITY IN THE U.S.

In 2023, net generation of **electricity from utility-scale generators in the United States was about 4,178 billion kilowatt-hours (kWh) (or about 4.18 trillion kWh).** EIA estimates that in 2023 an additional 73.62 billion kWh (or about 0.07 trillion kWh) were generated with small-scale solar photovoltaic (PV) systems.[2]

3. CAPACITY RETIRED IN THE U.S. IN 2023

22.3 GW of U.S. coal-fired electric generating capacity retired over the past two years, The 2.3 GW of coal-fired capacity scheduled to retire accounts for 1.3% of the that was in operation in 2023. Coal retirements are scheduled to increase again in 2025 when operators expect to retire 10.9 GW.

4. MILES OF TRANSMISSION LINES IN THE U.S.

There are nearly 160,000 miles of high-voltage power lines, and millions of low-voltage power lines and distribution transformers. An NREL 2022 study[3] indicates under a high load growth and high clean electricity futures would **require building 91,000 miles of new high voltage interregional transmission lines by 2035**. As Utility Dive states, "This **appears unattainable** when it takes 10 years on average to move a transmission line from conception to operation, and only 386 miles of high voltage transmission were built in 2021"[4].

---

[1] US EIA (2023).

[2] US EIA (2024).

[3] NREL (2022).

[4] Utility Dive (2023).

5. NUMBER OF U.S. ELECTRICITY CUSTOMERS

160 million customers as of 2022 of which 38% Residential (1.5BkWh), 36% Commercial 1.37BkWh, 27% Industrial1.BkWh and<1% Transportation 7B kWh. This is provided by investor-owned utilities (57%), Public & Federal (16%), Cooperatives (13%) and Others (15%)[5].

6. THE U.S. GRID IS NOT HIGHLY INTEGRATED

The grid is highly fragmented and consists of not one, but three different sections. -the Eastern, Western, and ERCOT (TX) interconnections — which are almost completely isolated from one another. Further, high-voltage lines are largely planned in even greater local isolation – there are 12 different transmission planning regions and only six of them are full Regional Transmission Organizations (RTOs) / Independent System Operators, with the mandate and authority to conduct transmission planning for their region. The remaining five planning regions in the West and Southeast are much more loose associations of dozens of vertically integrated utilities, which tend to plan transmission mostly with just their own local territories (or balancing authorities) in mind.[6]

7. THERE IS NO SINGLE LOCAL ENERGY AUTHORITY FOR RELIABLE ENERGY USE

For any given region of the United States, there is no single local energy authority with comprehensive management responsibility for reliable energy use, similar to the oversight provided by local agencies overseeing clean drinking water. While federal and state agencies regulate and oversee the energy sector, and regional distribution utilities have played a dominant role, the increasing deployment of local energy resources (DERs) is creating new challenges, especially at the local level. The absence of a unified, public serving entity at the local level presents an opportunity for the creation of an Energy Community Optimization agency (ECO-a) to ensure equitable, reliable, and optimized energy use from the federal to the local level

8. NOW IS THE TIME FOR ACTION

The **Bipartisan Infrastructure Law of 2021 allocated $13 billion for modernizing the grid** and the Inflation Reduction Act guarantees up to $250 billion in loans for projects that reduce greenhouse gas emissions from existing energy infrastructure.

---

[5] US EIA (2024)

[6] RMI (2023).

EXECUTIVE SUMMARY

Across the country we are witnessing an unprecedented time of new policies coupled with technology advances and a changing climate. These forces are rapidly impacting the reliability and resiliency of our nation's electricity system which if not addressed can lead to risks that will impact our communities, national security and economy. Unfortunately, the understanding of these risks is not well developed nor communicated which is the driver for this report in hopes to support both public and private decision makers moving forward.

TREND #1: THE GRID IS AGING

The majority of the nation's grid is aging, with some components over a century old — far past their 50-year life expectancy — and others, including 70% of T&D lines, are well into the second half of their lifespans.

The American Society of Civil Engineers in 2021 gave a "C-" grade for the 600,000 miles of transmission lines (240,000 miles of which are considered high-voltage lines or ≥ 230 Kilovolts), and around 5.5 million miles of local distribution lines that operate within federal, state, tribal, and local regulatory jurisdictions.[7]

According to the American Society of Civil Engineers (ASCE), the majority of the nation's grid is aging, with some components over a century old — **far past their 50-year life expectancy** — and others, including 70% of T&D lines, are well into the second half of their lifespans.

TREND #2: UNPRECDENTED DEMAND GROWTH

Federal Energy Regulatory Commission (FERC) filings for 2023[8] reflect **an almost double for 5-year load growth demand** from 2.6% to 4.7% indicating **38 gigawatts (GW) of peak demand growth**. Many experts believe this to be an underestimate and that the nation will witness an even higher growth rate.

As of 2023, the U.S. has about **1.3 million megawatts** of generation capacity. **The largest fuel source is natural gas,** accounting for just under 44% of all generation capacity. **Wind, nuclear, hydro, and solar** together account for more than one-third of capacity.

TREND #3: BATTERY STORAGE

According to the US Energy Information Agency (EIA), U.S. **battery storage capacity has been growing since 2021 and could increase by 89% by the end of 2024**. Developers currently plan to expand U.S. battery capacity to more than 30 gigawatts (GW) by the end of 2024, a capacity that would exceed those of petroleum liquids, geothermal, wood and wood waste, or landfill gas[9].

California's stationary storage capacity has risen 20-fold from 500 megawatts in 2018 to more than 10.3 GW today, with a further 3.8 GW planned to come online by the end of 2024.

Storage is the second-largest technology in the queue for interconnection to the grid in **Texas,** at 37% of the total as of the end of last year, only slightly behind solar. Gas-peaking capacity made up just 1% of the queue, and combined-cycle gas-fired plants just 3%.

---

[7] https://infrastructurereportcard.org/cat-item/energy-infrastructure/

[8] https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

[9] https://www.eia.gov/todayinenergy/detail.php?id=61202

TREND #4: THE GRID IS NOT KEEPING UP

A Lawrence Berkeley National Laboratory 2024 study[10] indicates that **Grid Connection Backlogs in the United States grew 30% in 2023** dominated by requests for solar, wind and energy storage. The demand is growing with 30GW of new offshore wind in addition to battery storage and EVs.

Interconnection requests now typically **take more than 3 years to complete**.

The timeline from the initial connection request to having a fully built and operational plant has increased from <2 years for projects built in 2000-2007 to more than 4 years for those built in 2018-2023.

TREND #5: SUPPLY CHAINS CAN NOT KEEP UP

U.S. manufacturing which has seen atrophy and offshoring in the recent past cannot keep up with the growing demand of critical equipment for the resiliency of the nation's electrical supply.[11], [12]

According to a 2024 DOE report, the **lead times for transformer orders**, particularly distribution transformers, **increased** from three to six months in 2019 **to 12 to 30 months in 2023.**

Transformer cost has also sharply increased to over 200% of the original pricing, surpassing the Consumer Price Index.

TREND #6: PHYSICAL & CYBERTHREATS ARE ON THE RISE

From 2023 to 2022, the National Institute of Science and Technology recorded a jump of about 2,000 system vulnerabilities — a pace of about 60 additional threats per day. According to DOE records, in 2015 there were 42 physical and cyber-attacks or threats against the grid as reported by operating utilities. In 2023, that number jumped to 185 reports an increase of 340%.[13], [14]

A 2015 joint study by Lloyd's and the University of Cambridge studied the impacts of a large-scale cyberattack on the U.S. grid. They found the **damage to the U.S. economy would range between $243 Billion to $ 1 Trillion** with insurance claims up to $71.1 Billion depending on the severity of the attack. The expected costs in 2024 would be far more significant.

> "We have 18 critical infrastructures – food, water, medical care, telecommunications, investments, the works – and all 17 of the others depend heavily on the electric grid,".
> **"The electric grid "is one of our greatest national vulnerabilities,"**
>
> **Former CIA Director, James Woolsey**,
> Before the Cybersecurity and EMP Legislative Working Group
> April 13, 2015

---

[10] https://emp.lbl.gov/news/grid-connection-backlog-grows-30-2023-dominated-requests-solar-wind-and-energy-storage#:~:text=The%20backlog%20of%20new%20power,National%20Laboratory%20(Berkeley%20Lab).

[11] https://www.energy.gov/oe/articles/doe-and-industry-team-keep-lights-america

[12] https://www.wapa.gov/supply-chains/

[13] https://www.eenews.net/articles/tensions-at-home-and-abroad-pose-growing-threat-to-us-grid/

[14] https://www.ciab.com/resources/lloyds-report-cyberattack-on-us-power-grid-could-cost-over-1-trillion-dollars/#:~:text=Lloyd's%20Report%3A%20Cyberattack%20on%20US,Council%20of%20Insurance%20Agents%20%26%20Brokers

TREND #7: CLIMATE CHANGE IMPACTS

Global climate change and expansion of Urban Heat Islands adversely impact the national grid. The nation's electrical grid mostly transmitted and distributed through above-ground transformers, transmission wires, and utility poles are exposed to extreme weather such as high winds, heavy rain, ice, lightning, extreme / prolonged heat events and larger and more frequent forest fires. https://www.climatecentral.org/climate-matters/weather-related-power-outages-rising [15], [16]

The Department of Energy (DOE) found that **power outages are costing the U.S. economy $28 billion to $169 billion annually.**

Of all major **U.S. power outages** reported from 2000 to 2023, **80% (1,755) were due to weather** for which severe weather accounted for 58%. The U.S. experienced about **two times more weather-related outages during the last 10 years** (2014-2023) than during the 10 years between f2000-2009.

TREND #8: NET-ZERO CARBON TRANSITIONS IMPACT THE GRID

The transition to a Net-Zero Carbon Economy including disclosures of greenhouse gas emissions coupled with economic opportunities provided by the 2022 Inflation Reduction Act (IRA) are **driving the demand for clean energ**y. This is further driven by the rapid growth of Electric Vehicles and the resurgence of domestic manufacturing.

Electricity consumption from electric vehicles (EVs) in the United States in the first two months of 2024 **jumped by over 50%** from the same months in 2023 (1.58 million megawatt hours (MWh), compared with 1.04 million MWh).

Total electricity consumption by EVs in 2023 was 7.6 million MWh, up 45% from 2022's total. according to the U.S. Energy Information Administration (EIA).

TREND #9: DISTRIBUTED ENERGY RESOURCES & VIRTUAL POWER PLANTS ARE AN OPPORTUNITY

Distributed energy resources (DERs) such as solar, wind and battery storage are being deployed closer to the demand of electricity users reducing major investments in the gird and distributing risks. Additionally, **Virtual Power Plants (VPPs)** bundle together primarily renewable resources to create a reliable power network which can be dispatched to aid the overall grid during times of peak demand, with far less capital costs and generally lower greenhouse gas emissions.

Deploying 80-160 GW of VPPs—tripling current scale—by 2030 could expand the U.S. grid's capacity to **reliably support rapid electrification** while redirecting grid spending from peaker plants to participants and **reducing overall grid costs by $10 billion per year** *(MIT,2024 How VPPs are shaping tomorrow's energy system. "*

TREND #10: AI CAN BE A GAME CHANGER

Artificial intelligence (AI) is becoming more embedded in our daily lives and our national economy[17]. AI offers the opportunity to better manage the grid and support the development and deployment of Distributed Energy Resources (DERs) and Virtual Power Plants (VPPs).

According to a study by EPRI, the electricity used to operate data centers processing for AI could consume up to 9% of all U.S. electricity generation by 2030. However, **there needs to be studies on how AI can reduce electricity by providing previously unattainable efficiencies**.

---

[15] https://www.climatecentral.org/climate-matters/weather-related-power-outages-rising

[16] https://infrastructurereportcard.org/wp-content/uploads/2020/12/Energy-2021.pdf

[17] https://www.epri.com/about/media-resources/press-release/q5vU86fr8TKxATfX8IHf1U48Vw4r1DZF#:~:text=According%20to%20a%20new%20study,could%20increase%20power%20demands%20substantially.

HOW TO CITE THIS REPORT

J.S. Golden and A. Otis (2024). U.S. Electricity Transitions: Emerging Threats & Opportunities for the Resiliency & Reliability of the U.S. Grid A report by the Dynamic Sustainability Lab. Accessed at: https://www.dynamicslab.org/s-projects-basic

The views and findings contained within this report are solely those of the Dynamic Sustainability Lab and the authors. We appreciate the assistance of Mr. Dana Hoffer of REMCO Group LLC.

ABOUT THE DYNAMIC SUSTAINABILITY LAB

The Dynamic Sustainability Lab (DSL) at Syracuse University is an internationally recognized research center focused on the opportunities, risks and unintended consequences of the transition to a Net-Zero Carbon economy. The DSL focuses in the domains of energy & technology transitions, built environment transitions, biobased transitions and institutional transitions. To learn more visit: www.DynamicsLab.org

ABOUT SEVA

Based in Houston, Texas the energy capital of the world, Sustainability & Energy Value Advisors (SEVA) is a leading energy advisory company that is home to thought leaders, researchers and practionners who provide both industry and governments around the globe the strategies and technical insights to meet the challenges of an ever-changing energy landscape. Our partners take advantage of the impactful insights we provide at the nexus of energy, economics and the environment. To learn more visit: https://sevadvisors.com/home

RESEARCH FELLOWS

Some of the research including all the appendices were undertaken by three student research fellows in the Dynamic Sustainability Lab who we wish to acknowledge and thank.

Haris Khan

Haris Khan was a Graduate Research Fellow at the Dynamic Sustainability Lab. He is also an Ajello Fellow in Energy and Environmental Policy at the Maxwell School of Citizenship and Public Affairs. Haris's research is centered around a number of climate and energy-related topics including energy transitions, carbon reduction technologies, and efficient emission-reduction pathways. He holds a Masters in Public Administration from the Maxwell School at Syracuse University

Anna Iudintseva

Anna Iudintseva was a Graduate Research Fellow at the Dynamic Sustainability Lab. She is also a research assistant at the Syracuse University Soft Materials Lab and has extensive technical experience across numerous engineering and research enterprises. Her research interests also include Aerospace and Deep Space topics. She holds a Master of Science in Mechanical and Aerospace Engineering from the College of Engineering & Computer Science at Syracuse University.

Ryan Hodges

Ryan Hodges was a DSL research fellow majoring in Mechanical Engineering, class of 2024. He is an incoming GDP Engineer at Messer Americas.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF TERMS

Distributed Energy Resources (DERs): Distributed energy resources are small, modular, energy generation and storage technologies that provide electric capacity that typically produce less than 10 megawatts (MW) of power. DER systems may be either connected to the local electric power grid or isolated from the grid in stand-alone applications. DER technologies include wind turbines, photovoltaics (PV), fuel cells, microturbines, reciprocating engines, combustion turbines, cogeneration, and energy storage systems (NREL, 2022).

Generation: Electricity generation is defined as electricity generated from fossil fuels, nuclear power plants, hydro power plants (excluding pumped storage), geothermal systems, solar panels, biofuels, wind, etc. It includes electricity produced in electricity-only plants and in combined heat and power plants (OECD, 2024).

Grid: The grid," refers to the electric grid, a network of transmission lines, substations, transformers and more that deliver electricity from the power plant to your home or business (SmartGrid, 2024).

Grid Interconnection: This ties a network of local grids together at a synchronized frequency. This allows the exchange of energy from local grids with surplus power to those having a demand higher than what they can produce locally. A power outage due to a storm or failures in the local grid can become unlikely if the local network can tap electricity from a regional grid (Clean Energy Finance Center, 2024).

Grid operators (also known as transmission system operators) balance grid operations by ensuring that the amount of electricity put into the grid matches the amount of electricity used by consumers. They work with all of the utilities, generators, and retailers to ensure that the grid is balanced and reliable: too little power can cause blackouts, while too much can cause damage to equipment. In some regions, electric utilities act as grid operators. In other areas, the grid is operated by regional transmission organizations (RTOs) or independent system operators (ISOs), which are different types of organizations that operate the grid but do not own the resources and infrastructure within it (power plants and power lines) (RFF, 2024).

Hardening the grid refers to measures that fortify the system against damage. This can include tree trimming along power lines, replacing wooden electrical poles with steel or concrete, and burying overhead transmission lines (Climate Central, 2024).

Microgrids are self-sufficient energy systems with a smaller, distinct geographic footprint, such as a college campus, hospital complex, or neighborhood. Their relatively small scale also makes microgrids more easily powered by renewable energy sources like solar and wind power, which has the added benefit of reducing emissions from power generation (Climate Central, 2024). The DOE defines the microgrid as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.’

Resiliency: Energy resilience is the ability of the grid, buildings, and communities to withstand and rapidly recover from power outages and continue operating with electricity, heating, cooling, ventilation, and other energy-dependent services. A resilient power system reduces the likelihood of long-duration outages over large service areas, limits the scope and impact of outages when they do occur, and rapidly restores power after an outage (US DOE, 2024).

Smart grid technologies include sensors that allow operators to assess grid stability and provide consumers with better information about outages (Climate Central, 2024).

Transmission & Distribution: Power plants generate the electricity that is delivered to customers through transmission and distribution power lines. High-voltage transmission lines, such as those that hang between tall metal towers, carry electricity over long distances. Higher voltage electricity is more efficient and less expensive for long-distance electricity transmission. Lower voltage (distribution power) electricity is safer for use in homes and businesses. Transformers at substations increase (step up) or reduce (step down) voltages to adjust to the different stages of the journey from the power plant on long-distance transmission lines to distribution lines that carry electricity to homes and businesses (EIA, 2024).

Vertically integrated utilities: Electric utilities that own not only transmission and distribution infrastructure, but also the power plants responsible for electricity generation. They control every stage of the electricity production process in the areas they serve.

Virtual power plants (VPPs), i.e. networks of decentralized power generating units, storage systems, and flexible demand, can optimize the aggregation of distributed resources across large areas by using advanced data analytics such as machine learning. Policy and regulatory issues, including values tacking rules, are the main barriers to wider VPP deployment.

Section 1

ELECTRICITY GENERATION

Image courtesy of National Renewable Energy Laboratory (NREL). Accessed from: https://www.nrel.gov/news/program/2020/nuclear-renewable-synergies-for-clean-energy-solutions.html

1.0 ELECTRICITY DEMAND

In 2023, the U.S. Energy Information Administration (EIA) announced that their National Energy Modeling System (NEMS), which they use to produce their Annual Energy Outlook (AEO), "*requires substantial updates to better model hydrogen, carbon capture, and other emerging technologies. To facilitate these model enhancements, we* ***will not publish*** *an AEO in 2024.*"[18] However, various other government and non-governmental organizations have undertaken to explore electricity generation and demand trends.

As presented in Figure #1.1, total U.S. electricity consumption in 2022 was about 4.07 trillion kWh, the **highest amount recorded and 14 times greater than electricity use in 1950.**[19]

Projections looking forward are mixed as to the severity of the increase of U.S. electricity demand. As presented in table #1.1, the U.S. EIA in their July 2024 projections indicate a 6.41% increase in 2025 from 2021 base numbers. Additional views of the significant electricity demand growth come through documents obtained from Federal Energy Regulatory Commission (FERC) filings for 2023. A report from Grid Strategies in December 2023[20] found that **future demand is anticipated to rapidly increase -almost double for 5-year load growth demand from original forecasts of 2.6% all the way up to 4.7%** indicating 38 gigawatts (GW) of peak demand growth through 2028. The drivers for these unprecedented growth projections are detailed in section 3 of this report.

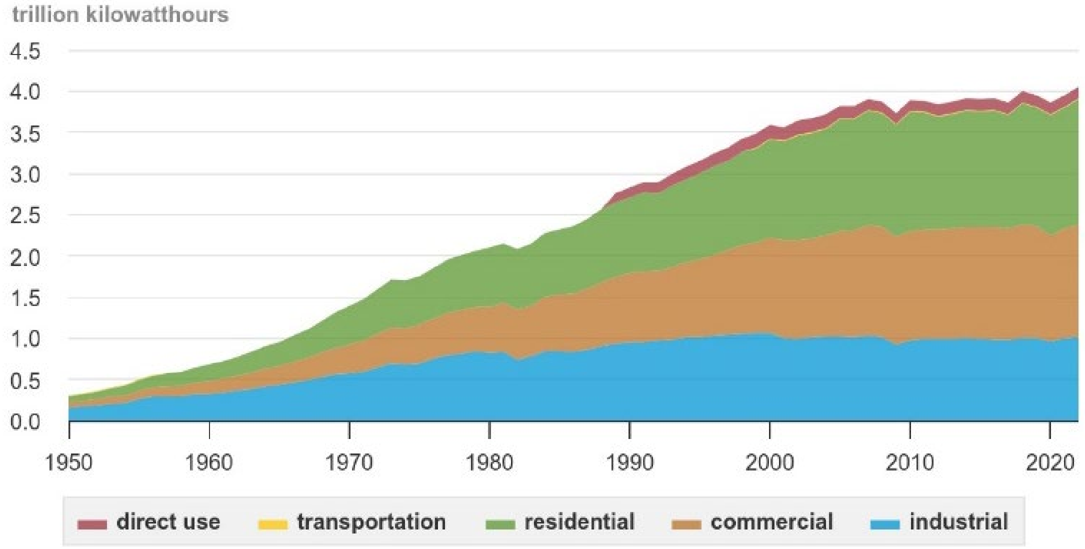


Figure #1.1 U.S. electricity retail sales to major end-use sectors and electricity direct use by all sectors, 1950 to 2022. Source: US EIA (2023).

---

[18] US EIA (2023). Statement on the Annual Energy Outlook and EIA's plan to enhance long-term modeling capabilities. https://www.eia.gov/pressroom/releases/press537.php

[19] US EIA (2024). Use of electricity. Accessed from: https://www.eia.gov/energyexplained/electricity/use-of-electricity.php

[20] https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

	Consumption (billion kilowatthours)					Consumption Growth (billion kWh)			
	2021	2022	2023	2024	2025	2022	2023	2024	2025
Residential sales	1,470	1,509	1,455	1,504	1,527	39	-55	49	24
Industrial sales	1,001	1,020	1,025	1,052	1,090	20	4	27	38
Commercial and transportation	1,335	1,397	1,382	1,425	1,438	63	-16	43	13
Direct use of electricity	139	140	139	143	142	1	-1	4	0
Total consumption	3,945	4,067	4,000	4,123	4,198	122	-67	123	75

Data source: U.S. Energy Information Administration, Short-Term Energy Outlook, July 2024

Table #1.1: U.S. total electricity consumption projections

As of 2024, the United States has nearly 1.3 million megawatts of generation capacity with the largest fuel source of this capacity being natural gas (~44%).

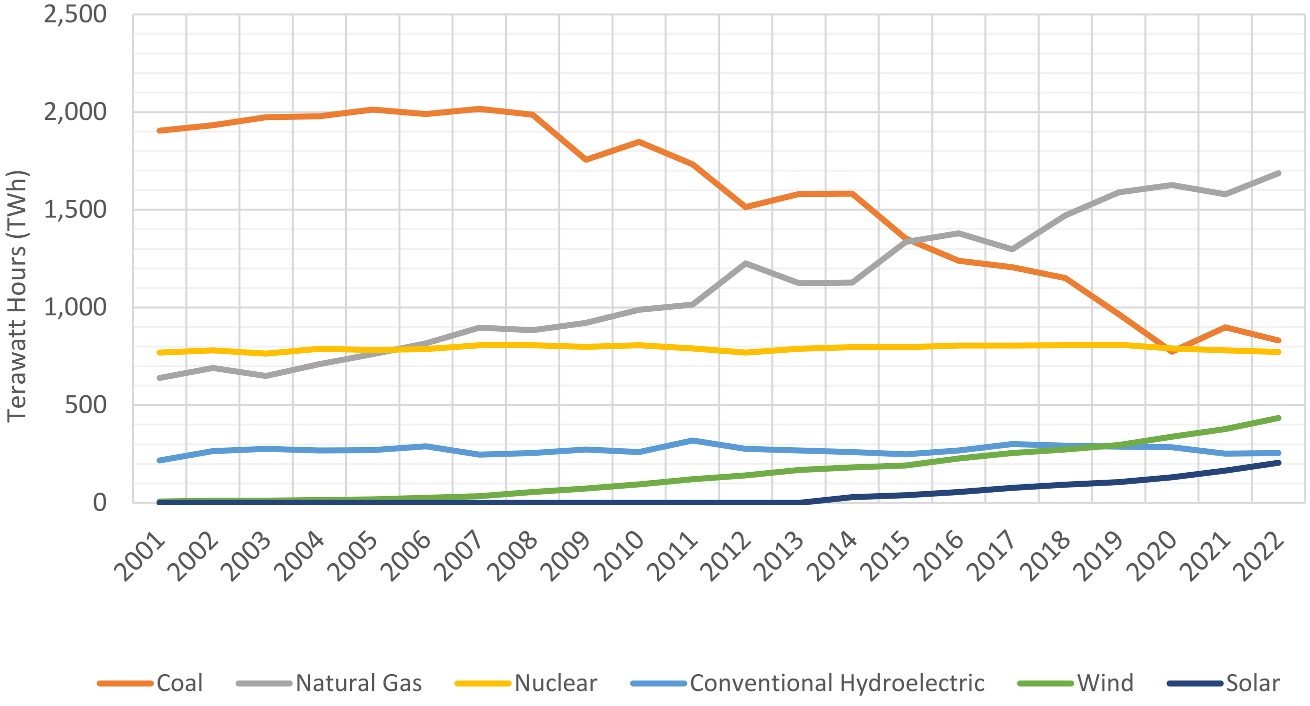


Figure #1.2: National Electricity Generation in Terawatt Hours by Fuel Type, 2001 to 2022. Adapted from EIA Data.

1.1 GENERATION PROJECTIONS

As presented in figure #1.3 outlines the EIA projected national electricity generation by fuel source, 2023 to 2050. Based on this and currently available data and policies, there are several key projections that can be derived. While these projections must be carefully balanced with changes that arise from modifications to political policies, administrations, and unforeseen circumstances, these energy trends appear supported by current conditions and net-zero transition goals.

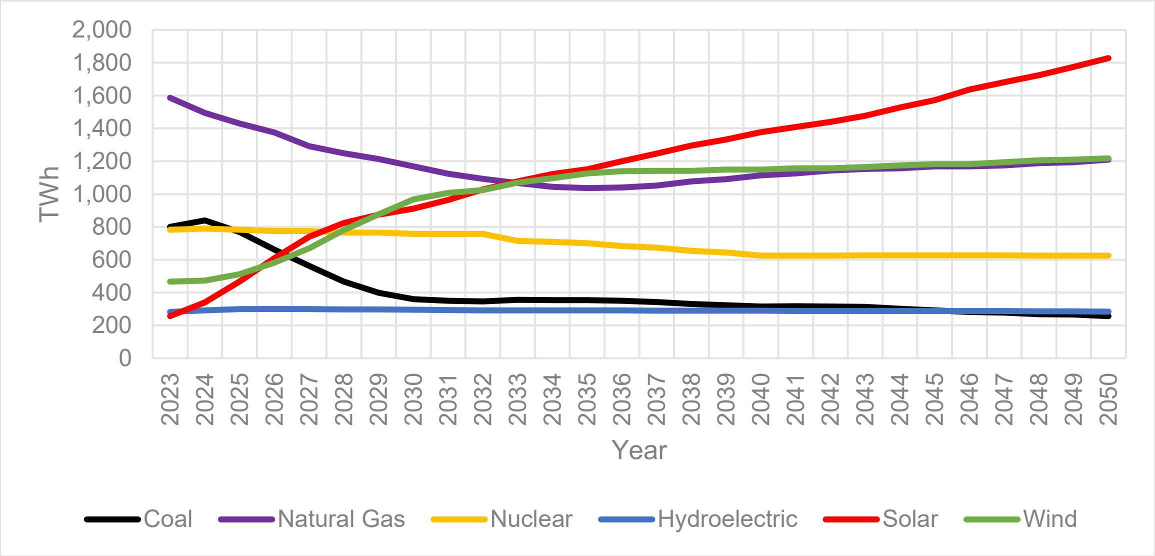


Figure #1.3: Projected National U.S. Electricity Generation by Fuel Source (2023 - 2050). Source: [3]

Fuel/Electricity Generation Source	West South Central	West North Central	South Atlantic	Pacific	New England	Mountain	Mid-Atlantic	East South Central	East North Central
Distillate Fuel Oil	-81.0%	-79.6%	-79.6%	-25.6%	-25.4%	-84.5%	-79.9%	-59.5%	-79.8%
Residual Fuel Oil	N/A	-96.4%	-96.4%	-68.4%	7.3%	0.0%	-58.1%	N/A	0.0%
Petroleum and Other Liquids Subtotal	-81.0%	-80.1%	-80.1%	-51.4%	-12.5%	-35.8%	-77.7%	-59.5%	-61.7%
Natural Gas	-32.4%	-44.4%	-44.4%	-42.4%	-56.3%	-23.7%	-37.4%	-43.1%	-8.8%
Steam Coal	-81.0%	-57.0%	-57.0%	-61.3%	-100.0%	-85.9%	-63.8%	-57.2%	-79.8%
Nuclear / Uranium	-32.6%	-1.0%	-1.0%	-66.0%	0.8%	-33.6%	-6.7%	-30.2%	-19.0%
Renewable Energy	**186.2%**	**711.8%**	**711.8%**	**71.7%**	**256.2%**	**171.6%**	**304.1%**	**413.4%**	**502.3%**
Non-biogenic Municipal Waste	N/A	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	N/A	N/A
Electricity Imports	-5.0%	N/A	N/A	-5.0%	-5.0%	-5.0%	-5.0%	N/A	-5.0%
Total Electric Power in Quadrillion BTU	**16.7%**	**31.6%**	**31.6%**	**27.1%**	**30.4%**	**8.8%**	**6.1%**	**-14.2%**	**16.3%**

Table 1.2: Percent Change in Electricity Generation by Fuel Type/Source/Total Generation, by Region: Change from 2022 to 2050, Projections. Sources: [15-23].

Currently, limited data exists regarding specific state level electricity projections. Despite these limitations and given the reliance of the electricity grid on collective and inter-state electricity transfers, the study of regional electricity forecasts can provide a preliminary look into energy demands and variations. The Federal Energy Regulatory Commissions (FERC) oversees many of the nation's Independent System Operators (ISO), Regional Transmission Operators (RTO) and Balancing Authorities (BA) that share collective multi-state responsibilities. Several key regional trends appear in forecasts.

In all regions but the East South Central, electricity demand is expected to increase by 2050. Renewable and low-carbon electricity planning must therefore include not only current, but future grid demand. Nominal electricity demand and projections should be considered alongside relative portfolio composition when determining state or regional suitability to satisfy industrial electricity demands.

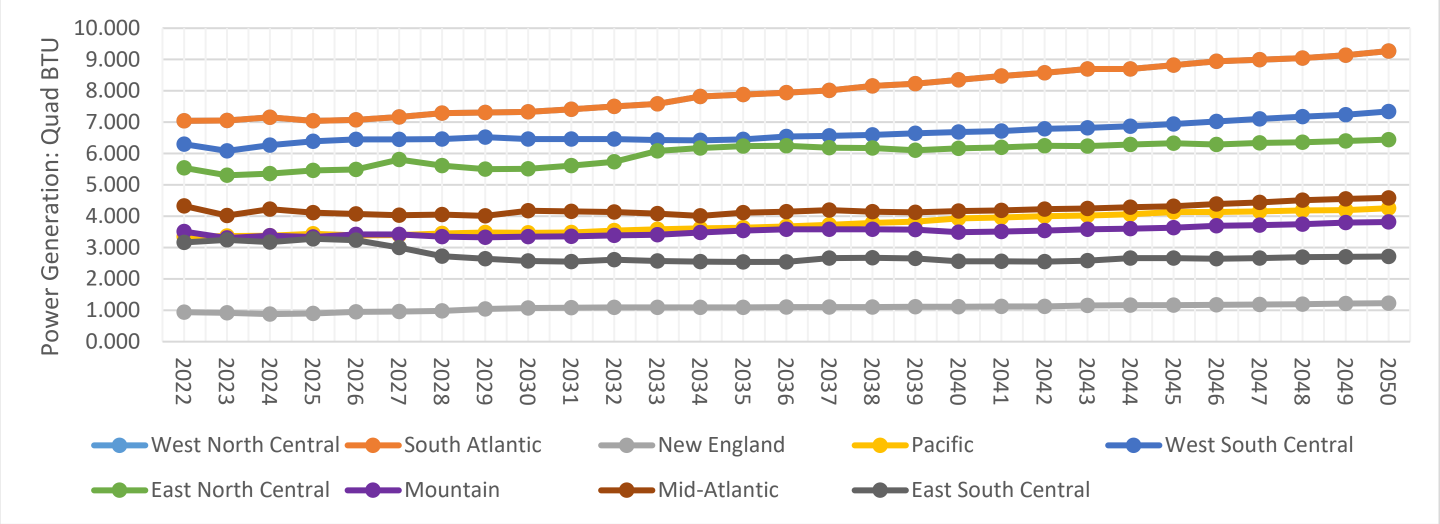


Figure #1.4. Total Power Generation in Quad BTU, 2022 to 2050 Projections by U.S. Census Sub-Region [24]

1.2 GENERATION MIX TRENDS

FOSSIL FUELS GENERATION

Fossil fuels accounted for about 60% of U.S. electricity generation in 2023[21].

Natural Gas

Natural gas was the top source—about 43%—of U.S. utility-scale electricity generation in 2023. Natural gas is used in steam turbines and gas turbines to generate electricity. Natural gas is many times presented as a “transitional” energy source as states move to more renewable sources. Natural gas also benefits from its ability to be used in power plants that can be turned on / off quickly to meet peak electricity demand as compared to coal and nuclear power plants.

Coal-fired power plants are anticipated to witness continued reductions as witnessed by 200 coal plants closed in the last decade, and national coal power generation reduced by 50% of electricity generation in the 1990s to 16.2% in 2023. [4] Additionally, on April 25th, 2024, the EPA issued new regulations that may close the doors of many coal-fired power plants by 2032. [5] Under the plan, existing coal plants that are slated to operate through or beyond 2039 must reduce their greenhouse emissions 90% by 2032. Plants that are scheduled to close by 2039 would have to reduce their emissions 16% by 2030. Plants that retire before 2032 would not be subject to the rules.[6]

NUCLEAR

Nuclear energy provides nearly one-fifth of U.S. electricity. Nuclear energy was the third-highest source—about 18%—of U.S. utility-scale electricity generation in 2023. Nuclear power plants use steam turbines to produce electricity from nuclear fission. Governments participating at COP 2028 (2023) made a **declaration to triple nuclear energy capacity by 2050**, recognizing the key role of nuclear energy in reaching Net Zero transitions [10].

Small Modular Reactors (SMRs)

An emerging opportunity is the potential development of small modular reactors (SMRs) which are advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit and can produce 7.2 million kWh per day, which is about one-third of the generating capacity of traditional nuclear power reactors. SMRs similar to their larger nuclear reactor counterparts both are capable of producing low-carbon electricity. SMRs can be sited on locations not suitable for larger nuclear power plants. Prefabricated units of SMRs can be manufactured and then shipped and installed on site, making them more affordable to build than large power reactors, which are often custom designed for a particular location, sometimes leading to construction delays. SMRs offer savings in cost and construction time, and they can be deployed incrementally to match increasing energy demand. In 2022, the U.S. Nuclear Regulatory Commission (NRC) voted to approve the

---

[21] US EIA (2024). https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php

first SMR submitted by NuScale's in partnership with Utah Associated Municipal Power Systems (UAMPS), a consortium that provides electricity to its members throughout the western United States. The project would have consisted of six 77-MW modules, combined for 462 MW. However, in 2023 the contracted was terminated apparently due to rising costs[22]. More recently, Dow Chemical Company announced a partnership with X-energy announced plans to build four Xe-100 small modular reactors at a Dow industrial site in Seadrift, Texas. The approval process by the U.S. Regulatory Commission is underway.

RENEWABLES GENERATION

Renewables are projected to dominate electricity demand by 2050, though propagation speed and overall nominal output varies significantly by region. By 2050 the majority of U.S. sub-regions are projected to source the majority of their electricity from renewable, non-nuclear energy. Despite the ambitious climate goals of NYS, the Mid-Atlantic region is only projected at 39.8% renewable electricity by 2050, the lowest in the nation besides only East South Central at 39.4%. While the Mid-Atlantic and East South Central have the lowest renewable 2050 renewable projections, they also have the highest nuclear portfolio projections at 27.7% and 23.7% respectively. The Pacific and Mountain regions lead renewable generation projections by 2050, with 84.6% and 70.9% respectively.

51% OF ALL NEW GENERATION CAPACITY UNDER DEVELOPMENT IS SOLAR ENERGY. followed by wind (33%) and natural gas (7%) as of April 2024 (APWA, 2024).

Solar dominates the national renewable portfolio by mid to late 2030s and continues to grow past 2050. Solar is the most rapidly growing energy technology in the US. The Federal Energy Regulatory Commission (FERC) anticipates a "high probability" that between 2023 and 2026, solar will add 85,000 MW of generation, projections over four times higher than those anticipated for wind and 20 times greater than natural gas [7]. With the addition of 85,000 MW, solar would account for 13.1% of national electricity generation, outpacing both wind (12.3%) and hydroelectric (7.5%) [8]. Under an accelerated output scenario, solar additions reach as high as 215,000 MW of generation in the 2023 to 2026 scenario [9].

LAND BASED WIND is projected to play a pivotal role in national renewable energy deployment. Land-based wind turbines generate can range from 100 kilowatts (distributed purposes) to several megawatts (utility-scale purposes). In 2022, turbines grew to just under 140 meters (~460 feet) tall, from ground to blade tip. This can make them more

---

[22] https://spectrum.ieee.org/small-modular-reactors-nuscale

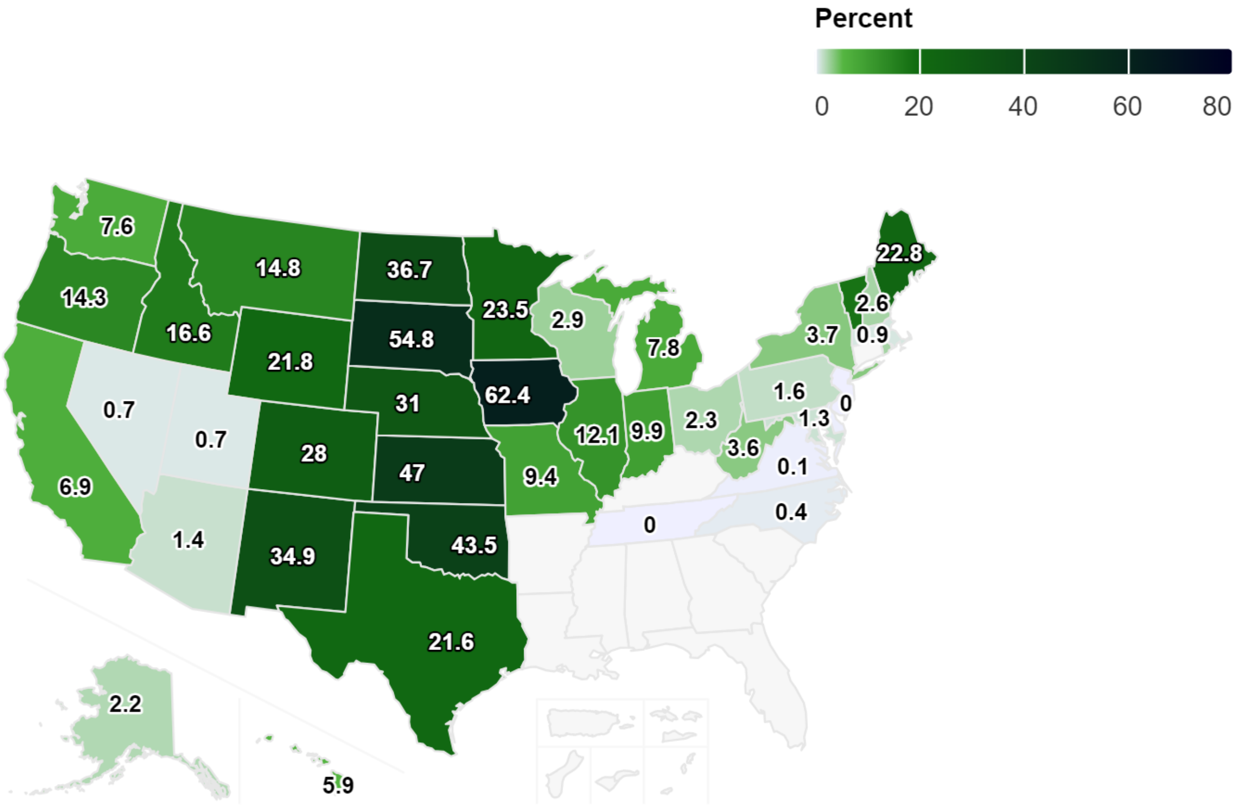


Figure #1.5. 2022 land based wind generation in-state penetration rate. Source: US DOE EERE 2023. Land-Based Wind Market Report: 2023 Edition.

powerful compared to solar by using less land area[23]. The United States boasts abundant land-based, utility-scale wind energy resources. According to a 2022 assessment, the nation has 2.2–15.1 terawatts of land-based resource potential, spanning across all 50 states and U.S. territories, which far exceeds the nation's electricity needs.

In 2022, more than $12 Billion was invested in land based wind while adding 8.5 GIGAWATTS of additional land based wind capacity. In the same year (2022), Iowa generated a nation high of 62.4% of its electricity from land-based wind power, while South Dakota, Kansas, Oklahoma and North Dakota all got over 40% of their electricity from land-based wind power.

OFFSHORE WIND

The Biden Administration has established a goal of 30,000 MW offshore wind development by 2030. Wind power is projected to increase sharply into the 2030s before a relative plateau, but recent setbacks have shown mounting challenges that may reduce the speed of adoption and achievement of state and federal targets (ex. New York State recently suffers three major offshore wind project delays). Supply chain issues, rising production costs, and the availability of qualified labor forces are threatening

---

[23] DOE (2024). Wind Exchange. Accessed from: https://windexchange.energy.gov/markets/land-based

wind power targets both in the US and abroad. Despite challenges, commercial scale projects such as the recently launched South Fork Wind, New York and soon to be operating Vinyard Wind, Massachusetts will add almost 1,000 MW of offshore capacity.

U.S. Census Region	Petroleum & Other Liquids	Natural Gas	Steam Coal	Nuclear/ Uranium	Renewable Energy	Non-biogenic Municipal Waste	Electricity Imports	Total
West North Central (2030)	0.1%	21.7%	11.0%	31.7%	**34.9%**	0.6%	0.0%	7.33
West North Central (2040)	0.1%	17.5%	10.4%	25.1%	**46.5%**	0.5%	0.0%	8.35
West North Central (2050)	0.0%	15.5%	7.7%	22.6%	**53.6%**	0.5%	0.0%	9.27
South Atlantic (2030)	0.1%	21.7%	11.0%	31.7%	**34.9%**	0.6%	0.0%	7.33
South Atlantic (2040)	0.1%	17.5%	10.4%	25.1%	**46.5%**	0.5%	0.0%	8.35
South Atlantic (2050)	0.0%	15.5%	7.7%	22.6%	**53.6%**	0.5%	0.0%	9.27
New England (2030)	0.0%	15.5%	0.0%	26.4%	**49.3%**	2.8%	6.1%	1.07
New England (2040)	0.0%	16.0%	0.0%	25.4%	**50.1%**	2.7%	5.8%	1.11
New England (2050)	0.0%	13.1%	0.0%	23.0%	**56.9%**	2.4%	4.6%	1.23
Pacific (2030)	1.1%	20.1%	0.6%	2.8%	**74.4%**	0.2%	0.9%	3.47
Pacific (2040)	0.9%	13.6%	0.5%	2.4%	**81.7%**	0.1%	0.8%	3.93
Pacific (2050)	0.5%	11.6%	0.4%	2.2%	**84.6%**	0.1%	0.6%	4.26
West South Central (2030)	0.0%	27.8%	5.8%	10.3%	**56.2%**	0.0%	-0.2%	6.46
West South Central (2040)	0.0%	25.2%	3.8%	7.5%	**63.6%**	0.0%	-0.1%	6.68
West South Central (2050)	0.0%	25.5%	2.9%	6.8%	**64.9%**	0.0%	-0.1%	7.35
East North Central (2030)	0.1%	20.6%	11.9%	29.0%	**38.2%**	0.0%	0.2%	5.51
East North Central (2040)	0.1%	19.5%	9.6%	21.4%	**49.3%**	0.0%	0.1%	6.16
East North Central (2050)	0.1%	21.1%	5.8%	20.5%	**52.4%**	0.0%	0.1%	6.45
Mountain (2030)	0.3%	14.5%	12.3%	9.9%	**63.2%**	0.0%	-0.1%	3.35
Mountain (2040)	0.2%	14.7%	5.3%	6.4%	**73.5%**	0.0%	-0.1%	3.50
Mountain (2050)	0.2%	18.7%	4.6%	5.7%	**70.9%**	0.0%	-0.1%	3.82
Mid-Atlantic (2030)	0.1%	33.1%	5.6%	32.9%	**26.0%**	1.0%	1.3%	4.18
Mid-Atlantic (2040)	0.0%	28.1%	5.1%	30.5%	**33.9%**	1.0%	1.3%	4.17
Mid-Atlantic (2050)	0.0%	27.1%	3.3%	27.7%	**39.8%**	0.9%	1.1%	4.59
East South Central (2030)	0.1%	22.4%	24.4%	32.5%	**20.6%**	0.0%	0.0%	2.57
East South Central (2040)	0.1%	20.7%	20.2%	25.1%	**33.9%**	0.0%	0.0%	2.57
East South Central (2050)	0.1%	19.5%	17.3%	23.7%	**39.4%**	0.0%	0.0%	2.72

Table 1.3. 2030, 2040, & 2050 Regional Electricity Generation Portfolio Projections by Fuel Type/Source 2030-2025. Sources: [25-33].

	California (2021)		New York (2022)		Georgia (2022)	
	MWh	% Total	MWh	% Total	MWh	% Total
Non-Renewables	**116,375,119**	**58.9%**	**89,977,229**	**71.6%**	**111,280,332**	**87.5%**
Coal	294,154	0.1%	0	0.0%	16,778,383	13.2%
Natural gas	97,427,092	49.3%	60,312,012	48.0%	59,848,731	47.1%
Nuclear	16,477,366	8.3%	26,812,164	21.3%	34,073,591	26.8%
Petroleum	76,998	0.0%	1,856,796	1.5%	517,236	0.4%
Other gas	1,368,920	0.7%	0	0.0%	0	0.0%
Other	730,589	0.4%	996,257	0.8%	62,391	0.0%
Renewables	**81,107,420**	**41.1%**	**35,658,839**	**28.4%**	**15,847,349**	**12.5%**
Geothermal	11,127,544	5.6%	0	0.0%	0	0.0%
Hydroelectric	14,677,580	7.4%	27,431,531	21.8%	3,176,979	2.5%
Solar	34,863,922	17.7%	1,785,243	1.4%	6,947,061	5.5%
Wind	15,177,006	7.7%	4,567,508	3.6%	0	0.0%
Wood	2,841,712	1.4%	423,160	0.3%	5,457,192	4.3%
Battery	-154,694	-0.1%	-5,577	0.0%	-4,113	0.0%
Other biomass	2,574,350	1.3%	1,456,974	1.2%	270,230	0.2%
Total Electric Power Industry Generation	**197,482,539**		**125,636,068**		**127,127,681**	

	Massachusetts (2022)		Nebraska (2021)		Texas (2022)	
	MWh	% Total	MWh	% Total	MWh	% Total
Non-Renewables	**17,467,170**	**81.5%**	**27,042,734**	**71.3%**	**386,334,054**	**73.6%**
Coal	0	0.0%	18,933,617	49.9%	85,336,953	16.2%
Natural gas	15,775,967	73.6%	1,173,365	3.1%	256,139,770	48.8%
Nuclear	0	0.0%	6,880,622	18.1%	41,606,955	7.9%
Petroleum	756,062	3.5%	55,130	0.1%	373,506	0.1%
Other gas	0	0.0%	0	0.0%	2,430,175	0.5%
Other	935,141	4.4%	0	0.0%	446,695	0.1%
Renewables	**3,959,403**	**18.5%**	**10,868,163**	**28.7%**	**138,906,968**	**26.4%**
Geothermal	0	0.0%	0	0.0%	0	0.0%
Hydroelectric	877,145	4.1%	1,123,156	3.0%	620,183	0.1%
Solar	1,934,184	9.0%	60,523	0.2%	22,442,378	4.3%
Wind	215,680	1.0%	9,592,039	25.3%	114,786,903	21.9%
Wood	45,086	0.2%	0	0.0%	1,150,952	0.2%
Battery	-4,505	0.0%	-28	0.0%	-93,448	0.0%
Other biomass	891,813	4.2%	92,473	0.2%	321,919	0.1%
Total Electric Power Industry Generation	**21,426,573**		**37,910,897**		**525,241,022**	

Table #1.4. Selected State Electric Power Industry Generation Breakdown by Non-Renewable & Renewable Sources (20221/2022). Sources: [57-62]

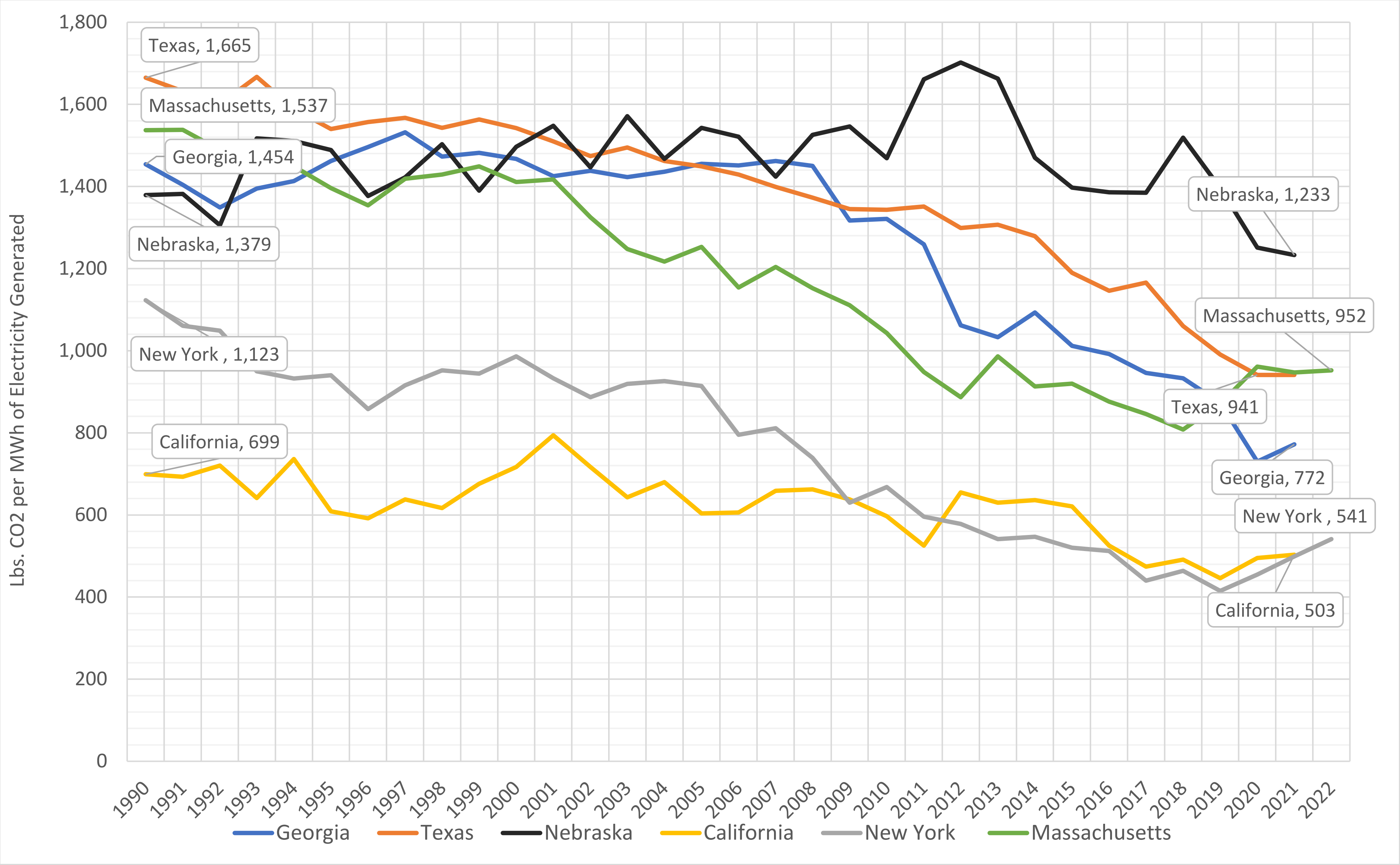


Figure 1.6. Comparison of State GHG Efficiency, Lbs. CO2 per MWh of Electricity Generated: 1990 to 2022. Source: EIA [64-69].

Hawaii	45.19
California	34.26
Connecticut	29.58
Massachusetts	29.50
Rhode Island	27.93
Alaska	24.89
New Hampshire	23.00
New York	22.97
Vermont	21.85
Maine	20.47
Michigan	19.23
New Jersey	18.45
Delaware	18.28
Pennsylvania	17.95
District of Columbia	17.85
Maryland	17.85
Wisconsin	17.31
U.S. Total	16.88
Ohio	16.75
Illinois	16.68
Nevada	16.59
Alabama	15.85
West Virginia	15.56
Indiana	15.33
Arizona	15.24
Minnesota	15.08
Texas	15.02
Virginia	14.99
North Carolina	14.98
South Carolina	14.90
Colorado	14.77
Florida	14.65
Mississippi	14.64
Oregon	14.60
Kansas	14.38
New Mexico	14.29
Georgia	14.10
Iowa	13.10
Kentucky	13.00
South Dakota	12.84
Tennessee	12.76
Arkansas	12.60
Missouri	12.52
Montana	12.52
Oklahoma	12.46
Wyoming	12.20
Louisiana	12.08
Nebraska	11.85
Washington	11.84
Idaho	11.45
North Dakota	11.33
Utah	11.07

Hawaii	40.82
California	22.86
Alaska	21.64
Connecticut	20.82
New England	19.68
Massachusetts	19.76
New Hampshire	19.25
Rhode Island	19.13
Vermont	18.65
Maine	17.61
New York	17.56
District of Columbia	17.01
New Jersey	14.54
Michigan	14.17
Alabama	13.73
Delaware	13.12
Indiana	12.70
U.S. Total	12.66
Maryland	12.57
Mississippi	12.55
Wisconsin	12.36
Arizona	12.16
West Virginia	12.14
Tennessee	12.09
Illinois	11.93
Minnesota	11.92
Montana	11.76
Kentucky	11.71
Colorado	11.65
Oregon	11.60
Pennsylvania	11.49
Florida	11.43
Georgia	11.24
Kansas	11.05
Louisiana	10.79
Ohio	10.69
North Carolina	10.68
Washington	10.57
New Mexico	10.40
Nevada	10.37
South Dakota	10.32
South Carolina	10.31
Arkansas	10.20
Missouri	9.59
Iowa	9.53
Nebraska	9.43
Virginia	9.30
Idaho	9.27
Wyoming	8.98
Texas	8.80
Utah	8.29
Oklahoma	8.14
North Dakota	7.23

Hawaii	36.11
Rhode Island	19.47
Alaska	19.38
California	19.30
Massachusetts	17.78
New England	15.93
Connecticut	15.90
New Hampshire	15.84
Maine	13.00
New Jersey	11.48
Vermont	11.30
District of Columbia	10.92
Maryland	10.08
Colorado	8.97
Minnesota	8.89
Florida	8.85
Illinois	8.81
Virginia	8.58
Delaware	8.54
Michigan	8.20
South Dakota	8.18
Wisconsin	8.09
Indiana	8.03
Kansas	7.85
U.S. Total	7.82
Nevada	7.80
West Virginia	7.66
North Carolina	7.64
New York	7.63
Pennsylvania	7.62
Alabama	7.45
Wyoming	7.39
Missouri	7.36
Nebraska	7.31
Oregon	7.17
Arizona	7.14
North Dakota	7.12
Idaho	6.98
Ohio	6.96
Mississippi	6.84
Montana	6.65
Utah	6.60
South Carolina	6.50
Kentucky	6.47
Washington	6.22
Tennessee	6.17
Iowa	6.11
Louisiana	6.10
Georgia	6.09
Texas	5.88
Arkansas	5.86
New Mexico	5.78
Oklahoma	5.31

Table #1.5 a,b,c. Left to right 2024 cost of electricity per kWh. Far left (a) residential, middle (b) commercial and far right (c) industrial customers. Source: US EIA (2024). Electric Power Monthly.

LEVELIZED COSTS OF ELECTRICITY The levelized cost of electricity (LCOE) can also serve as a proxy for evaluating the trajectory of electricity prices in the future. LCOE captures the cost of generating electricity by specific technology under different scenarios. Changes in domestic electricity prices are theoretically bound to follow similar patterns. LCOE measurements are based on capital costs, operations and management costs, recovery costs, capacity factor, fuel costs, and efficiency. Here is a simplified formula for basic LCOE calculations

sLCOE = {(overnight capital cost * capital recovery factor + fixed O&M cost)/(8760 * capacity factor)} + (fuel cost * heat rate) + variable O&M cost [157].

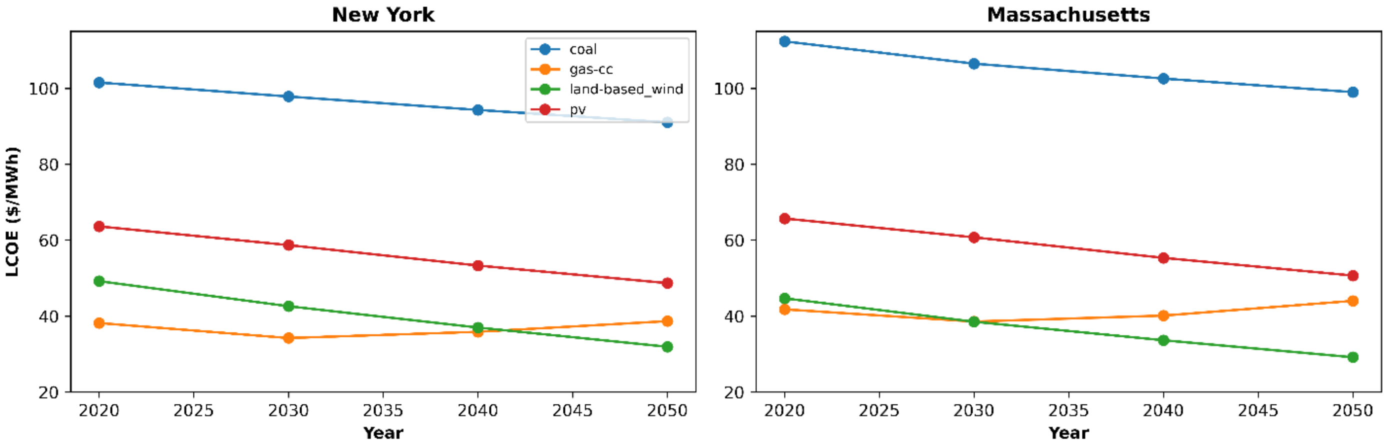


Figure #1.7a. Levelized Cost of Electricity ($/MWh) for four major sources in New York and Massachusetts [158]

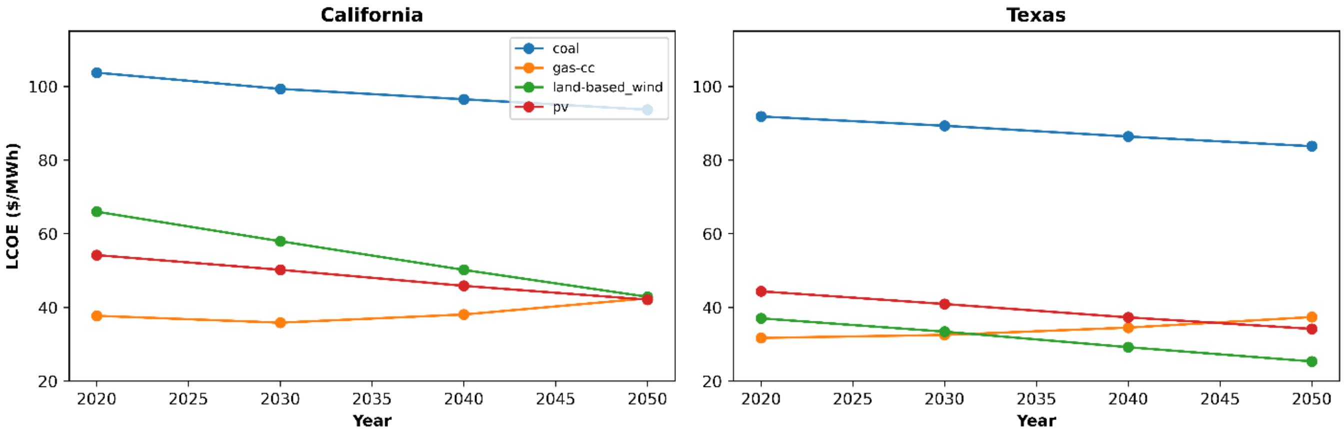


Figure 1.7b. Levelized Cost of Electricity ($/MWh) for four major sources for California and Texas [159

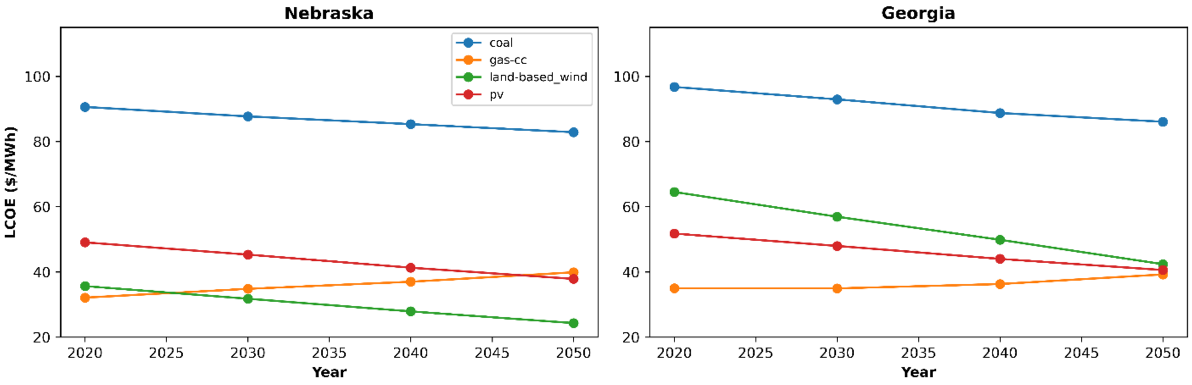


Figure 1.7c . Levelized Cost of Electricity ($/MWh) for four major sources for Nebraska and Georgia

Section 2

TRANSMISSION DEMAND, CONGESTION and the EVOLVING ENERGY MANAGEMENT LANDSCAPE

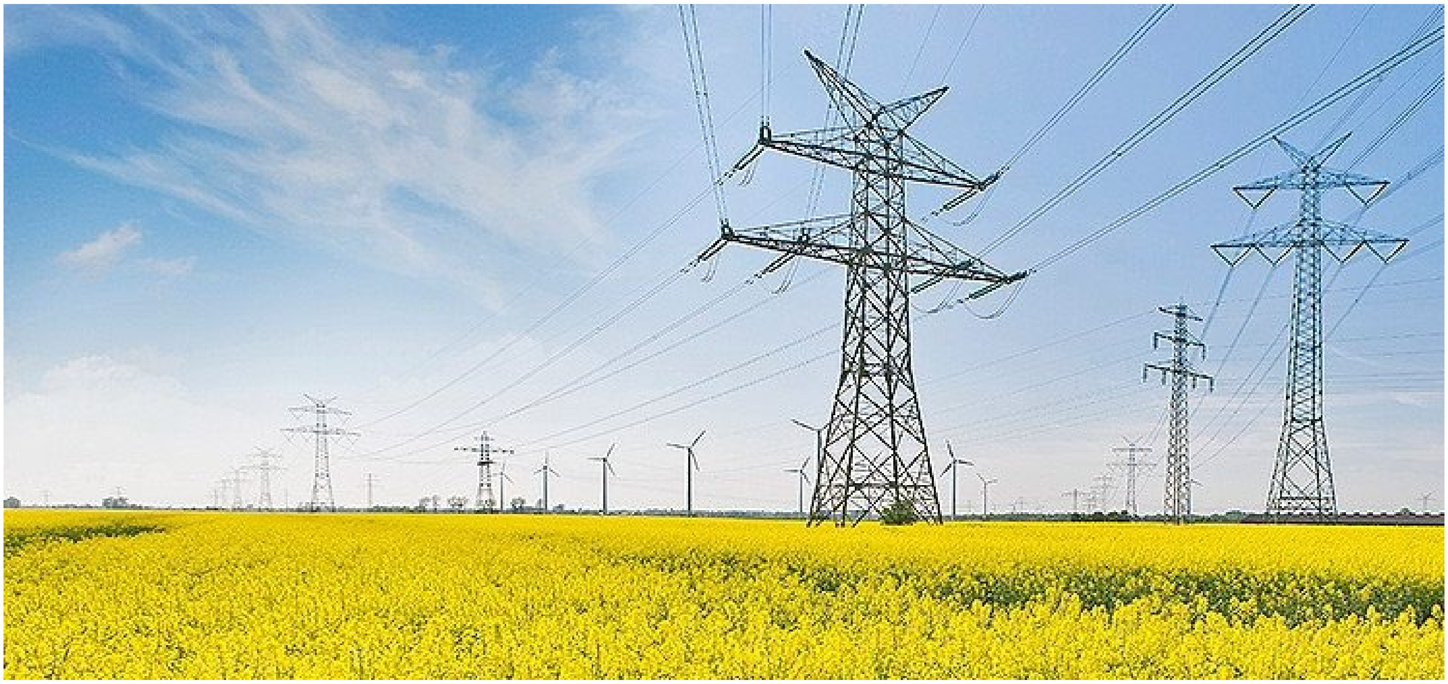


Image Courtesy of the U.S. DOE Office of Policy. Accessed from: https://www.energy.gov/policy/queued-need-transmission

2.1 TRANSMISSION DEMAND & CONGESTION

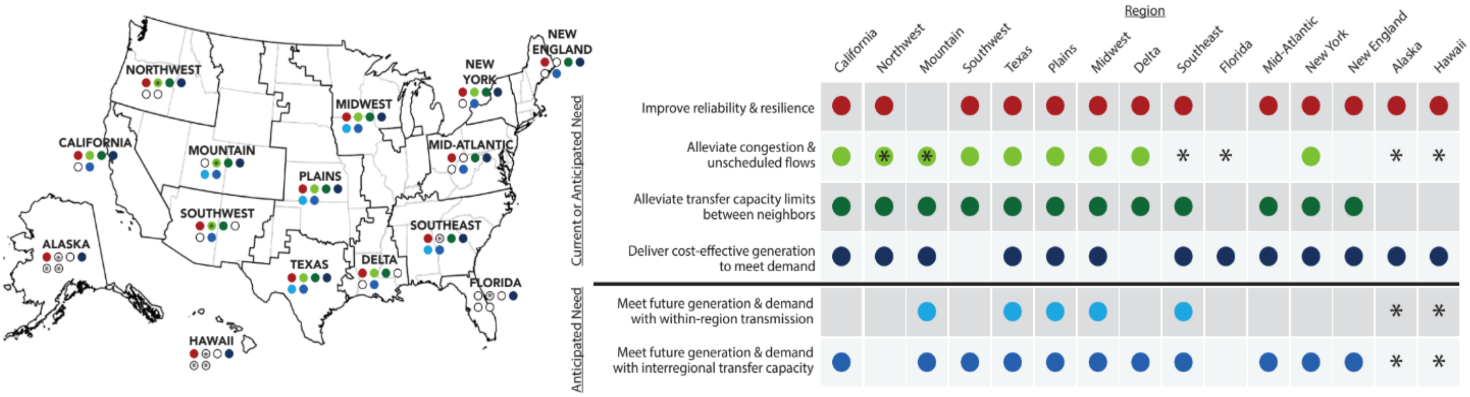
The U.S. installed 1,700 miles of new high-voltage transmission miles per year on average in the first half of the 2010s but dropped to only 645 miles per year on average in the second half of the 2010s.[24]

The 2023 U.S. DOE National Transmission Needs Study[25] highlights the need for expanded regional transmission line development and interregional transfer capacity. The DOE indicates that median capacity expansion requires interregional transfer capacity must grow by 25% to meet future moderate load and clean energy growth, by 114% to meet moderate load and high clean energy growth.

According to the study, there will need to be **capacity expansion by 412% to meet high load growth futures by 2035. The latter two needs represent a doubling and quintupling of the nation's current interregional transfer capacity, respectively.**

Specifically, for the moderate/high scenarios, the median new transmission need is 47,000 gigawatt-miles (GW-mi) of high voltage lines by 2035, a 57% growth from today's system, with 120 GW of cumulative transfer capacity needed between all regions.

According to data from Edison Electric Institute. In 2021, expansion-related transmission capital expenditures were forecast at $9.2 billion but declined to $8.8 billion for 2023.



	California	Northwest	Mountain	Southwest	Texas	Plains	Midwest	Delta	Southeast	Florida	Mid-Atlantic	New York	New England	Alaska	Hawaii
Improve reliability & resilience	●	●		●	●	●	●	●	●		●	●	●	●	●
Alleviate congestion & unscheduled flows	●	●*	●*	●	●	●	●	●	*	*		●		*	*
Alleviate transfer capacity limits between neighbors	●	●	●	●	●	●	●	●	●		●	●	●		
Deliver cost-effective generation to meet demand	●	●	●		●	●	●		●	●	●	●	●	●	●
Meet future generation & demand with within-region transmission			●		●	●	●		●					*	*
Meet future generation & demand with interregional transfer capacity	●		●	●	●	●	●	●	●		●	●	●	*	*

Figure #2.1: U.S. Department of Energy Grid Deployment Office (GDO) 2023 National Transmission Needs Study current and anticipated future capacity constraints and congestion on the Nation's electric transmission grid. Source: US DOE (2023).[26]

---

[24] https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

[25] https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf

[26] https://www.energy.gov/sites/default/files/2023-12/43451_DOE_GDO_Needs_Study_Fact_Sheets_United_States_v6_RELEASE_508_Compliant.pdf

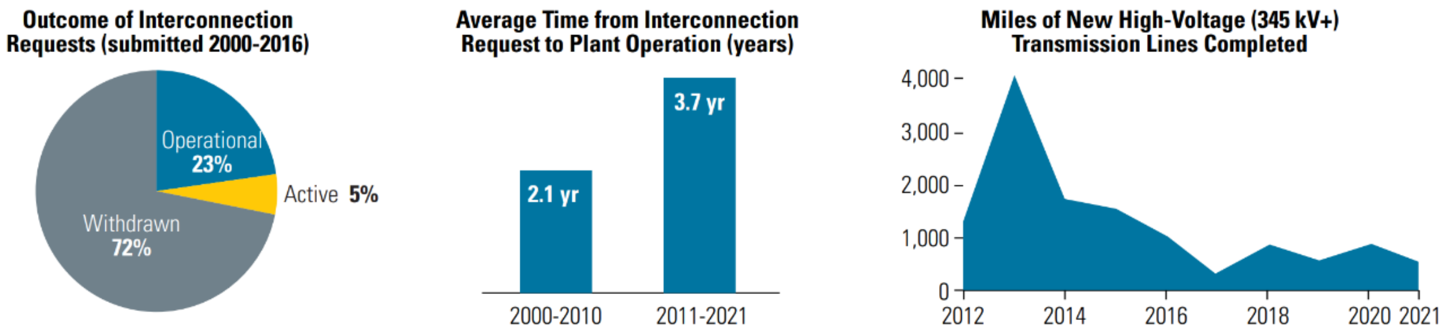


Figure #2.2: Indicators of the Challenges Facing Transmission Interconnection, Planning, and Construction Source: Office of Policy-US DOE (2022)[27].

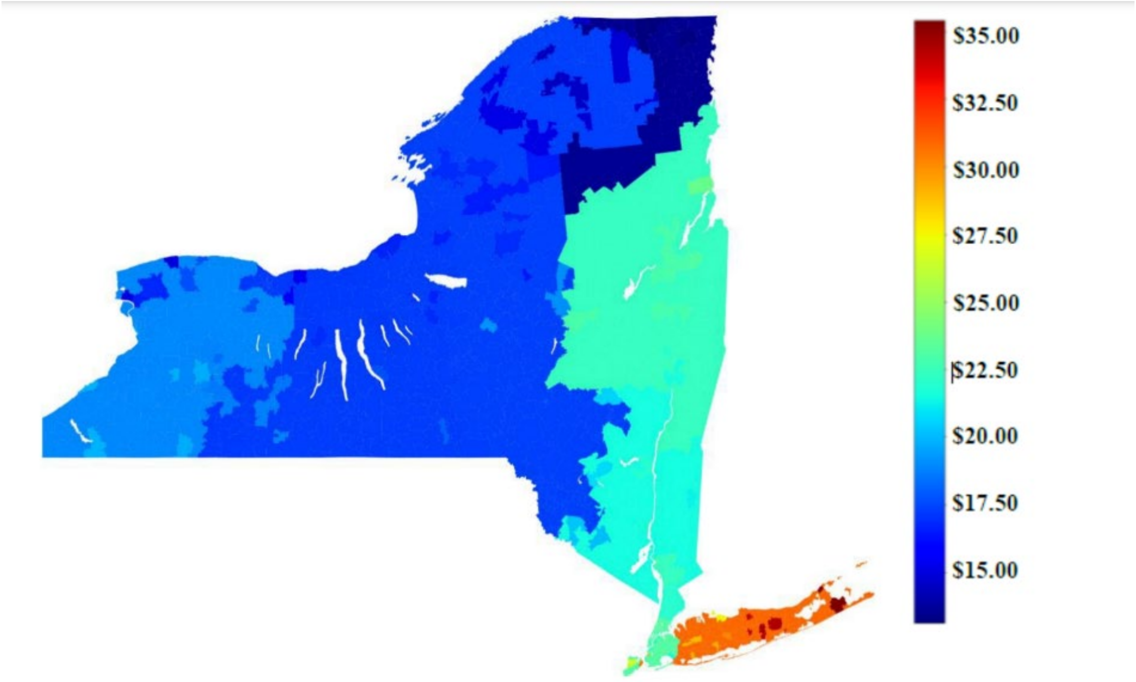


Figure #2.3. Real-time energy and congestion prices ($/MWh) in NYISO in 2020. Source: Patton et al. (2022).[28]

An example of a state's transmission impacts is the 20-year outlook of New York's system resources and transmission constraints which anticipates further congestion issues. To meet the state's Climate Leadership and Community Protection Act's (CLCPA) goals by 2030 and 2040, additional renewable generation is needed. **NYISO has identified that** the local and bulk **transmission systems are inadequate** to achieve these goals, limiting effective delivery of renewable energy to consumers. Long-term planning scenarios with a significant portion of renewable generation would exacerbate existing

---

[27] US DOE (2022). Queued Up But in Need of Transmission. Office of Policy. DOE/OP-0015 • April 2022

[28] Patton, D. VanSchaick, and J. Chen (2022). 2021 State of the Market report for the NY ISO Markets.

transmission congestion with a 23% increase statewide by 2030 (NYISO 022a). The transmission impacts has real time spatially varied economic consequences as presented in figure #2.3.

INTER-REGIONAL TRANSMISSION

First, it is important to understand that nationally, there are in essence only three grids in the United States, B — one in the West, the Eastern Interconnection and one in Texas (the Electricity Reliability Council of Texas) — that only connect at a few points and share little power between them. And, those grids are further divided into a patchwork of operators such as California ISO, NYISO, PJM etc who all have competing interests. That makes it hard to build the long-distance power lines needed to transport wind and solar nationwide.

Interregional transmission—lines that connect multiple planning regions—can provide many benefits to electric customers, but market and operating practices were not necessarily designed for this type of interconnected system. A 2024 NREL report[29] A common barrier to interregional transmission among all regions is the lack of clarity on resource adequacy sharing—or how we plan to share electricity generation resources across broad geographic areas to keep the lights on even when demand is high. In addition, transmission owners and operators typically cannot predict when large power transfers are needed and the types of irregular power flows that might occur, such as during extreme weather events. Ensuring internal power networks can handle the large energy flows needed between regions during these events lies outside of current transmission planning and operating practices.

BIG WIRES ACT-A PROPOSED POLICY FIX

In September 2023, Senator John Hickenlooper (D-CO) and Representative Scott Peters (D-CA) reintroduced the Building Integrated Grids with Inter-Regional Energy Supply Act, or the BIG WIRES Act, in both houses of Congress. The proposed legislation authorizes and directs the Federal Energy Regulatory Commission (FERC) to establish minimum requirements for interregional electricity transfer capabilities within the continental United States.

Last year, Congress called for the North American Electric Reliability Corporation (NERC) to conduct an Interregional Transfer Capability Study (ITCS)[7] in the Fiscal Responsibility Act of 2023.[8] The ITCS “will analyze the amount of power that can be moved or transferred reliably from one area to another area of the interconnected transmission systems” and recommend where further additions would realize the most benefits. Yet these far-ranging and comprehensive recommendations are not due to be filed with FERC until December 2, 2024.

The BIG WIRES Act sets out an ambitious timeline for connecting the country. FERC must determine the minimum transfer requirements within 18 months of the bill’s passage. Regions would then have two years to jointly submit a plan for building the infrastructure

---

[29] Simeone & Rose (2024). Barriers and Opportunities To Realize the System Value of Interregional Transmission. NREL NREL/TP-6A40-89363

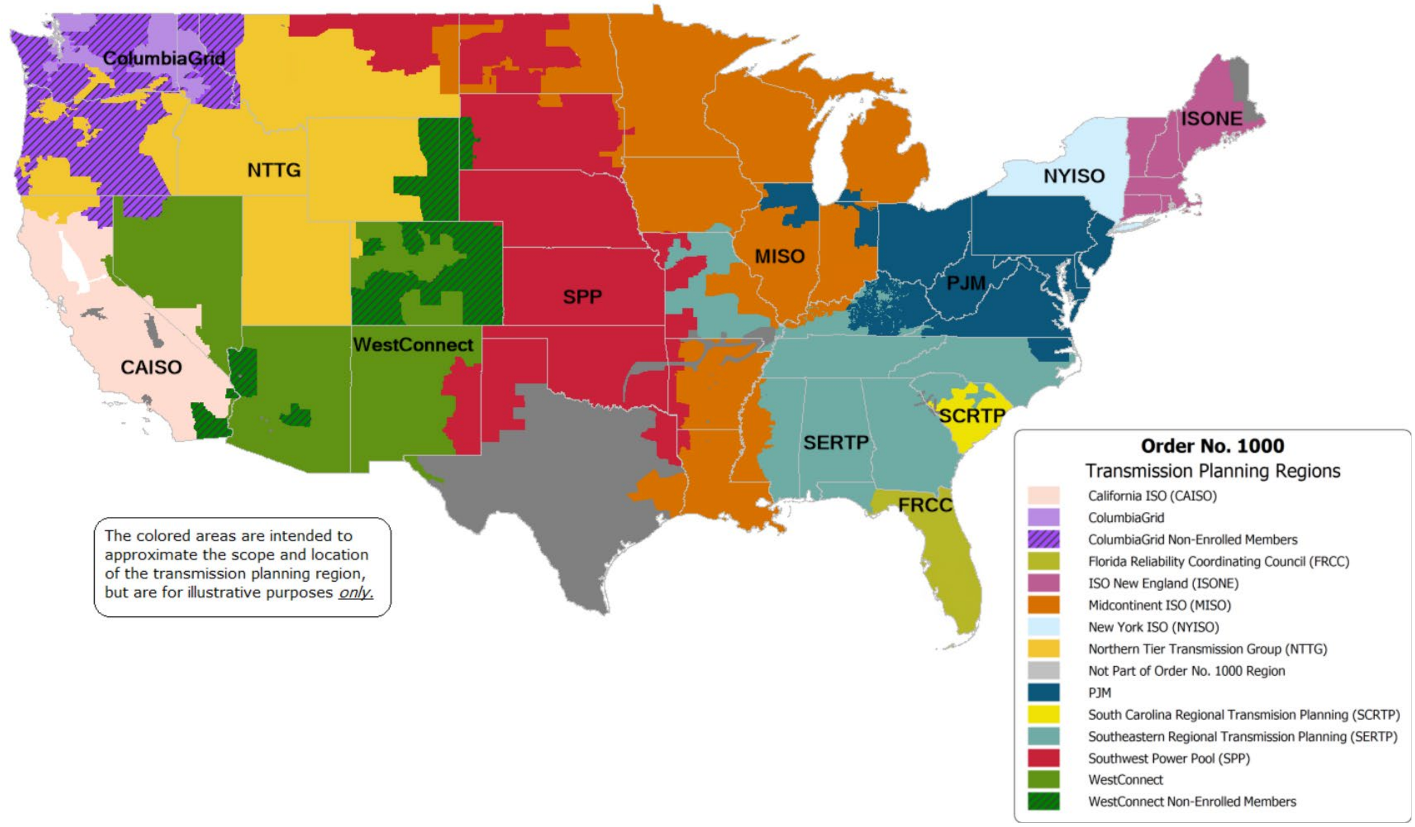


Figure #2.4. Order 1000 Transmission Planning Regions. Source: FERC (2024).

that would satisfy those minimum transfer requirements, and update those plans every five years. More critically, these joint filings would have to incorporate a deadline for the construction of new transmission lines by the end of 2035, including which entity or entities would build the facilities and how costs would be allocated on an interregional basis.

The Act also seeks to uncomplicate long-distance transmission's mosaic of regional grids. The Act directs FERC to divide the country into "Regional Planning Areas" and indirectly suggests that the borders of these areas follow those outlined in FERC Order No. 1000 as presented below.

2.2 EVOLOVING ENERGY MANAGEMENT LANDSCAPE AND OPPORTUNITY

As the United States transitions away from the era of the regulated local monopoly, the need for a more coordinated and efficient energy management approach becomes increasingly evident. While federal and state agencies, as well as regional transmission organizations (RTOs), play crucial roles in overseeing the bulk power system, there is a growing recognition of the need for enhanced coordination at the local level.

An Energy Community Optimization agency (ECO-a) could serve as a local authority to address the challenges of transmission demand, congestion, and the integration of distributed energy resources (DERs). By leveraging advanced technologies and data analytics, an ECO-a can optimize energy flows, manage congestion, and ensure reliable and equitable energy delivery to local communities.

2.3 FUNDING TO ADDRESS THE GRID

BIPARTISAN INFRASTRUCTURE LAW

On November 15, 2021, the bipartisan infrastructure law was passed by Congress. Of the $62 billion provided in the law, Congress provided DOE $27 billion to upgrade and modernize our electrical grid with programs spanning infrastructure to cyber-security and a focus on resiliency of the grid with a specific focus on extreme weather events. Additionally, the funding B will stand up 60 new DOE programs, including 16 demonstration and 32 deployment programs, and expands funding for 12 existing Research, Development, Demonstration, and Deployment (RDD&D) programs.

Transmission facilitation program	$2.5 billion revolving fund for DOE to facilitate the construction of large-scale transmission via Transmission facilitation program capacity reservation contracts, loans, and public-private partnerships
Designation of National Interest Electric Transmission Corridors	Enables FERC to issue a federal permit in a DOE-designated corridor when a state rejects the project; establishes that DOE is to look at future capacity constraints when designating corridors
Preventing outages and enhancing the resilience of the electric grid	$5 billion for DOE grants to states, tribes, and utilities to reduce the likelihood and consequences of disruptive events on the power grid, including hardening transmission
Energy infrastructure federal financial assistance program	$5 billion for DOE grants to demonstrate innovative approaches to transmission, storage, and distribution infrastructure, and new approaches to enhance regional grid resilience
Deployment of technologies to enhance grid flexibility	$3 billion for DOE grants to enhance grid flexibility, including advanced transmission technologies to such as dynamic line rating, flow control devices, advanced conductors, and network topology optimization

Table #2.1: Bipartisan Infrastructure Law: Subset of Transmission-Related Provisions. Source: US DOE (2022). [30]

---

[30] US DOE (2022). Office of Policy. Qued Up but in Need of Transmission. Unleashing the benefits of clean power with grid infrastructure.

GRIP FUNDING

U.S. Department of Energy's (DOE) Grid Resilience and Innovation Partnerships (GRIP) Program. Administered by the Grid Deployment Office was funded by the Bipartisan Infrastructure Law. The GRIP program provides $10.5 billion over five years across three programs to accelerate the deployment of transformative projects that will help to ensure the reliability of the power sector's infrastructure. On October 18, 2023, DOE announced up to $3.46 billion in the first round of GRIP funding, The second round funding opportunity will provide an investment of an additional $3.9 billion for Fiscal Years 2024 and 2025. Successful projects will deploy Federal funding to maximize grid infrastructure deployment at-scale and leverage private sector and non-federal public capital to advance deployment goals. The GRIP Programs are:

Grid Resilience Utility and Industry Grants (FY24/FY25 $918 million) fund comprehensive transmission and distribution technology solutions that will mitigate multiple hazards across a region or within a community. Grid Resilience Grant selections through today's Funding Opportunity Announcement (FOA) will focus on hardening infrastructure with digitization and automation; improving tools to restore power to the grid during outages; and investing in technologies to improve the efficiency of the grid, such as advanced conductoring and reconductoring.

Smart Grid Grants (FY24/FY25 $1.08 billion) increase the flexibility, efficiency, reliability, and resilience of the electric power system, with particular focus on increasing capacity of the transmission system, improving interconnection **Grid Innovation Program** (FY24/FY25 $1.82 billion) provides financial assistance to one or multiple states, Tribes, local governments, and public utility commissions to collaborate with electric grid owners and operators to deploy projects that use innovative approaches to transmission, storage, and distribution infrastructure to enhance grid resilience and reliability. Selections in this program through today's FOA will include transmission projects to support remote clean energy generation, improve interregional interconnection, and that use innovative technologies or execution approaches. The program will also prioritize projects that provide scalability, replicability, and innovation in the distribution space like district electrification, grid and resilience services from distributed energy resources, and battery energy storage systems.

REGIONAL GRID MANAGEMENT ORGANIZATIONS

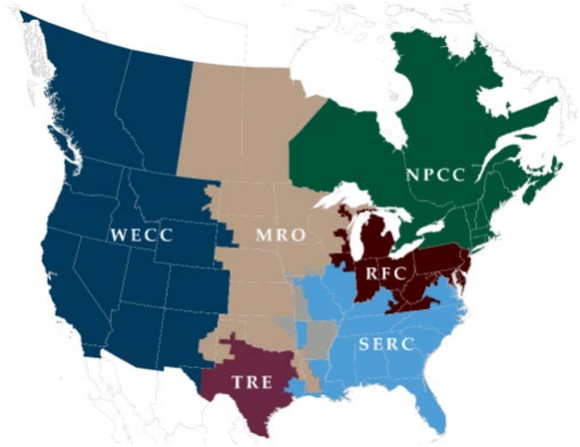


Figure 2.5a. North American Electric Reliability Council (NERC) [113]

- Formed in 1968
- Oversight of 6 regional reliability entities
- Develops standards, monitoring and compliance, resource adequacy, training and procedures

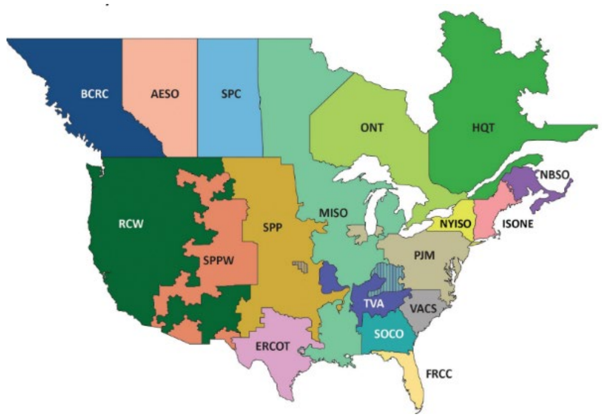


Figure 2.5b. Reliability Coordinators (RC) [114]

- Oversight of “interconnected operations” of electrical grid
- Responsible for electricity delivery to consumers
- Planning and oversight of current and future grid conditions

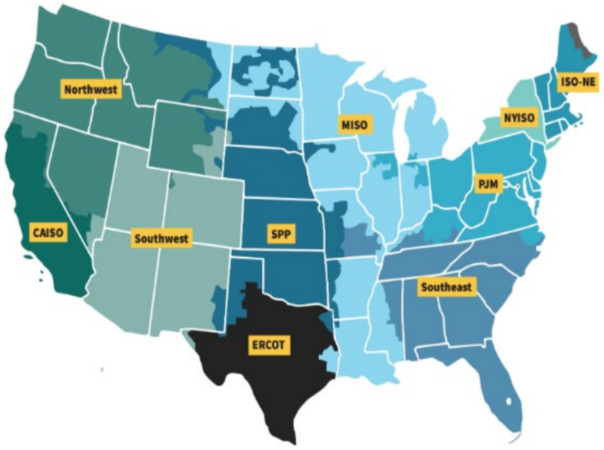


Figure 2.5c. Independent System Operators (ISO) & Regional Transmission Operators (RTO) [115]

- Oversee day-to-day electric grid operation, 190 million people [116]
- Created to ensure competition in wholesale electric markets [117]
- May operate wholesale electricity markets
- Six FERC regulated RTOs/ISOs in the U.S.

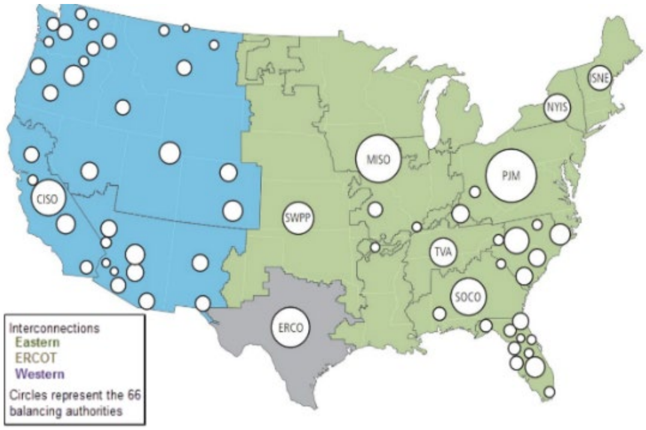


Figure 2.5d. Balancing Authorities (BA) [118]

- Maintain real-time balance between loads and generation with a given area [119]

Section 3

DRIVERS of GROWTH in DEMAND

Photo courtesy US DOE Alternative Fuels Data Center.

3.0 DRIVERS

There are two major drivers for the rapid expansion of electricity generation and transmission/distribution in the United States and around the world. The **first driver is the transition to a net-zero carbon economy** which seeks to replace fossil fuel energy sources with renewable electricity sources as seen with electric vehicles and corporate commitments to net-zero carbon emissions. The **second driver is due to the rapid development of AI, Blockchain and Data Centers** which all require significant amounts of electricity to power and cool.

3.1 NET ZERO CARBON TRANSITIONS

Federal Net-Zero Drivers

In 2021, the United States re-entered the Paris Agreement and has committed to reduce national GHG emissions with four primary actions[31]:

1. Reducing U.S. greenhouse gas emissions 50-52% below 2005 levels in 2030
2. Reaching 100% carbon pollution-free electricity by 2035
3. Achieving a net-zero emissions economy by 2050
4. Delivering 40% of the benefits from federal investments in climate and clean energy to disadvantaged communities

Additionally, the federal government in support of these actions Congress passed the Inflation Reduction Act (IRA), with over $369 billion in climate focused provisions through federal tax credits and incentives. Under the IRA, the federal government has elected to create and expand numerous funding opportunities to aid in the transition [40]. As presented in table 3.1.

The federal government including the US Department of Defense are also electrifying their buildings and fleets further generating demand for renewable electricity across the country.

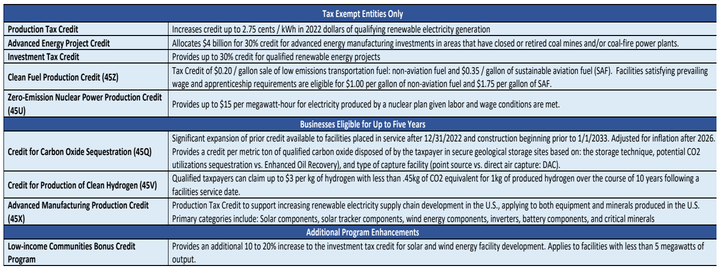
From a regulatory perspective, the US Securities and Exchange Commission (SEC) in 2024 passed rules requiring publicly listed companies to report on their scope 1 & 2 greenhouse gas emissions and document strategies to reduce emissions including those based on transitioning to renewable electricity sources.

The total amount of **new electric generation capacity needed to meet the U.S. government's ambitious 2030 clean energy goals** is already in the early development pipeline. More than 930 gigawatts (GW) of solar, wind, hydropower, geothermal, and nuclear capacity are currently sitting in interconnection queues seeking transmission access, along with over 420 GW of energy storage.[32]

---

[31] The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050. Published by the United States Department of State and the United States Executive Office of the President, Washington DC. November 2021.

[32] US DOE (2022). Office of Policy.



Tax Exempt Entities Only	
Production Tax Credit	Increases credit up to 2.75 cents / kWh in 2022 dollars of qualifying renewable electricity generation
Advanced Energy Project Credit	Allocates $4 billion for 30% credit for advanced energy manufacturing investments in areas that have closed or retired coal mines and/or coal-fire power plants.
Investment Tax Credit	Provides up to 30% credit for qualified renewable energy projects
Clean Fuel Production Credit (45Z)	Tax Credit of $0.20 / gallon sale of low emissions transportation fuel: non-aviation fuel and $0.35 / gallon of sustainable aviation fuel (SAF). Facilities satisfying prevailing wage and apprenticeship requirements are eligible for $1.00 per gallon of non-aviation fuel and $1.75 per gallon of SAF.
Zero-Emission Nuclear Power Production Credit (45U)	Provides up to $15 per megawatt-hour for electricity produced by a nuclear plan given labor and wage conditions are met.
Businesses Eligible for Up to Five Years	
Credit for Carbon Oxide Sequestration (45Q)	Significant expansion of prior credit available to facilities placed in service after 12/31/2022 and construction beginning prior to 1/1/2033. Adjusted for inflation after 2026. Provides a credit per metric ton of qualified carbon oxide disposed of by the taxpayer in secure geological storage sites based on: the storage technique, potential CO2 utilizations sequestration vs. Enhanced Oil Recovery), and type of capture facility (point source vs. direct air capture: DAC).
Credit for Production of Clean Hydrogen (45V)	Qualified taxpayers can claim up to $3 per kg of hydrogen with less than .45kg of CO2 equivalent for 1kg of produced hydrogen over the course of 10 years following a facilities service date.
Advanced Manufacturing Production Credit (45X)	Production Tax Credit to support increasing renewable electricity supply chain development in the U.S., applying to both equipment and minerals produced in the U.S. Primary categories include: Solar components, solar tracker components, wind energy components, inverters, battery components, and critical minerals
Additional Program Enhancements	
Low-income Communities Bonus Credit Program	Provides an additional 10 to 20% increase to the investment tax credit for solar and wind energy facility development. Applies to facilities with less than 5 megawatts of output.

Table 3.1 Maintained and Expanded Federal Programs Supporting the Development of Renewable U.S. Electricity. Sources: [41-49].

State Net-Zero & Clean Energy Drivers

Renewable Portfolio Standards (RPS) and Clean Energy Standards (CES) at the individual state level will be increasingly critical in the siting and development of future data centers. Renewable Portfolio Standards developed by states establish objective dates, electricity portfolios, and emissions standards for which utilities electricity sales are sourced from renewable sources. While the majority of RPS are legally mandated, some states do maintain voluntary programs that provide incentives for renewable adoption. of energy storage.

Renewable Portfolio Standards are attributed to almost 50% of the increased generation of renewable energy within U.S. since the 2000 [55]. Clean Energy Standards are distinguishable from RPS in that some states have recently began to include some low-carbon, but non-renewable, "clean" energy sources in qualifying utility energy provisions, among these, nuclear and biomass serving as examples of non-renewable/traditional sources. Typically, states with a CES policy also maintain an RPS. This allows for the provision of a mandatory percentage of traditional renewable energy, while also enabling the addition of specified non-traditional "low-carbon" energy technologies to satisfy the remaining requirements. Such an arrangement can help to foster innovation in developing new technology and methodologies.

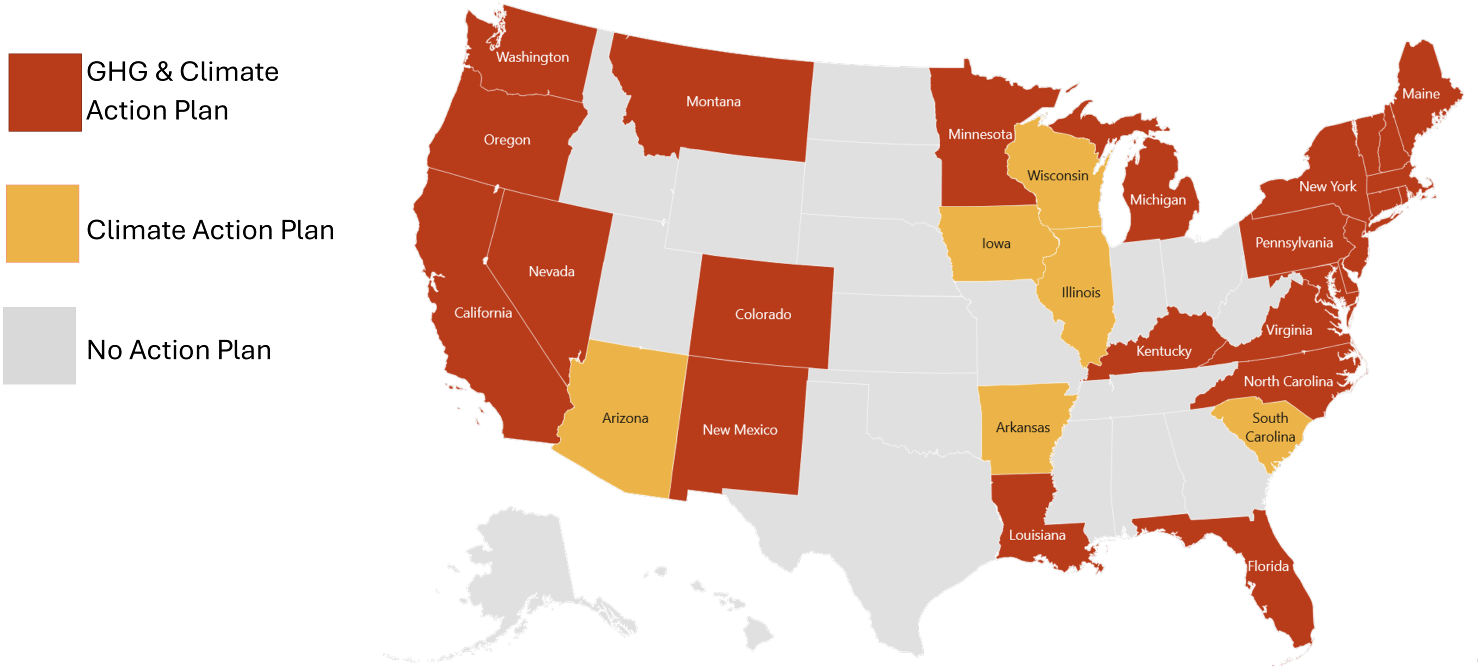


Figure 3.1. State GHG Emissions Standards & Climate Action Plan Status as of June 2024. Source: [56].

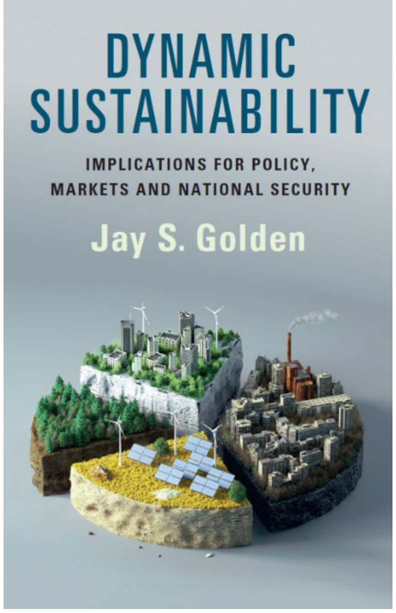
Industry Net-Zero Drivers

In addition to the over 90 countries around the globe that have committed to net-zero carbon emissions the business community is also making commitments. As of late 2023 as reported by Net-Zero Tracker[33], 66% of the annual revenue of the world's largest 2000 companies is now covered by a corporate net zero target. The number of company net zero targets has risen by more than 40% in 16 months — from 702 in June 2022 to 1,003 in October 2023. The aggregate annual revenue covered by net zero targets is $27 trillion.

What is a Net-Zero Carbon commitment? Net-zero emissions, or "net zero," is achieved when all emissions released by human (industrial) activities are counterbalanced by removing carbon from the atmosphere in a process known as carbon removal.

Achieving net zero will require a two-part approach: Part 1 requires all human-/ industrial caused emissions (such as those from fossil-fueled electricity) should be reduced as close to zero as possible. Any remaining emissions should then be balanced with an equivalent amount of carbon removal, which can happen through natural approaches like restoring forests or through technologies like carbon capture and storage (CCS), which mechanically removes carbon and either re-uses the carbon in an industrial process and/or stores/sequesters the carbon in the ground or oceans. Part 2 includes the voluntary carbon credit market.

Companies around the country now quantify and report their corporate (including supply chains) greenhouse gas emissions. To date most of the reporting has been voluntary. The reporting is for scope 1, 2 and 3 greenhouse gas emissions as presented below:



For further information on drivers as well as greenhouse gas emissions requirements read the book Dynamic Sustainability.

Scope 1 covers emissions from sources that an organization owns or controls directly – for example from burning fuel for an organization's facility/operations or company owned vehicles.

---

[33] Net Zero Tracker (2024).

Scope 2 are emissions that a **company causes indirectly and come from where the energy it purchases and uses is produced. For example, the emissions caused when generating the electricity that we use in our buildings would fall into this category.**

Scope 3 encompasses emissions that are not produced by the company itself and are not the result of activities from assets owned or controlled by them, but by those that it's indirectly responsible for up and down its value chain including the organizations supply chain. **So, scope 2 electricity emissions from a supplier are the buyers (processor, manufacturer, brand etc.) Scope 3 emissions.**[34]

3.2 ELECTRIC VEHICLES (EVs)

One of the more significant green technology transitions is the movement towards electric vehicles. This effort has two significant implications to the resiliency of the grid.

Issue #1 is the increased demand for electricity. According to the EIA (2024) electricity consumption in the United States from electric vehicles (EVs) over the first two months of 2024 **jumped by over 50%** from the same months in 2023 as EVs continue to penetrate the U.S. car market and impact electricity flows. As of December 2023, 13 states have a ZEV program (adopting California's program): Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Virginia, Vermont, and Washington state—plus the District of Columbia.

Total electricity use by EVs through February 2024 was 1.58 million megawatt hours (MWh), compared with 1.04 million MWh during the same period in 2023. In 2023 EVs overtook electricity demand by U.S. railways for the first time.

The top state for EV electricity consumption was California, the most populous U.S. state, where EV's consumed 2.58 million MWh of electricity and accounted for just under 34% of total national EV electricity demand.[35] In California, Pacific Gas & Electric has almost 500,000 electric vehicles in its territory and anticipates 3 million by 2030. PG&E expects system demand to increase up to 70% over the next two decades as more EVs are added.[36]

After California, the states of Florida (458,767 MWh), Texas (417,027 MWh), New York (337,367 MWh) and Washington (308,724 MWh) round out the top five states for EV electricity demand in 2023.

---

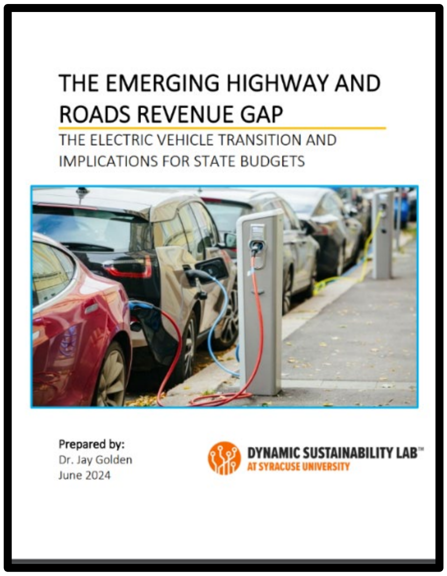
[34] Adapted from National Grid (2024).

[35] Reuters (2024).

[36] Utility Dive (2024).

Issue #2 is the increase demand for Renewable Electricity.

The driver of the EV transition is to address global climate change. This then necessitates a rapid increase in the generation of renewable electricity as presented in Section #1 of this report.



THE EMERGING HIGHWAY AND ROADS REVENUE GAP

THE ELECTRIC VEHICLE TRANSITION AND IMPLICATIONS FOR STATE BUDGETS

Prepared by:
Dr. Jay Golden
June 2024

DYNAMIC SUSTAINABILITY LAB™
AT SYRACUSE UNIVERSITY

To learn more on the EV transition and its implications for the U.S. see the recently issued report sponsored by the Pew Charitable Trusts now available at the **Dynamic Sustainability Lab**.

3.3 AI & DATA CENTERS

Data centers may be critical to our digital economy including social media, they are major consumers of electricity. In fact, McKinsey & Company predicts these operations will double their U.S. electric demands from 17 gigawatts in 2022 to 35 gigawatts by 2030 — enough electricity to power more than 26 million average homes.[37] Similarly, a Electric Power Research Institute (EPRI) 2024 study identified that data centers could consume 9% of the United States' electricity generation by 2030 — double the amount consumed today. Of the 8,000 data centers that exist globally, about a third are in the U.S (see figure 3.2), compared to 16% in Europe and almost 10% in China[38].

Data centers are typically owned and operated either by big companies (such as cloud vendors, banks, or telcos) for their own purposes or by co-location companies. The latter lease out the space and typically provide network capacity and power, as well as the cooling equipment that keeps down server temperatures.

One of the big drivers for the expansion of data centers is the emergence of Artificial Intelligence (AI) which "require approximately ten times the electricity of traditional internet searches and the generation of original music, photos, and videos" as reported in the EPRI study. The same report indicates that a traditional Google search uses about 0.3 Wh while a query using ChatGPT — the chatbot developed by OpenAI — requires about 2.9 Wh,

EPRI's study examines four scenarios of potential data center electricity consumption growth, with varying estimates of public uptake of AI and data center energy efficiency gains. Under the scenarios, U.S. data center power consumption ranges from 4.6% to 9.1% of the country's generation by 2030.

EPRI's analysis also looked at data center load impacts regionally. About 80% of U.S. data center load last year was concentrated in 15 states, led by Virginia and Texas. Virigina is the state which is home to the most data centers in the country. A report by Dominion Energy[39] indicates that Virginia's data centers had a peak load of almost 2.8 gigawatts in 2022. That was 1.5 times the capacity of the company's North Anna nuclear plant, which powers about 450,000 homes.[40]

---

[37] McKinsey and Company (2023). Investing in the rising data center enterprise.

[38] Time (2024). How AI Is Fueling a Boom in Data Centers and Energy Demand.

[39] Dominion Energy (2023). Integrated Resource Plan.

[40] Stateline (2024). States rethink data centers as 'electricity hogs' strain the grid.

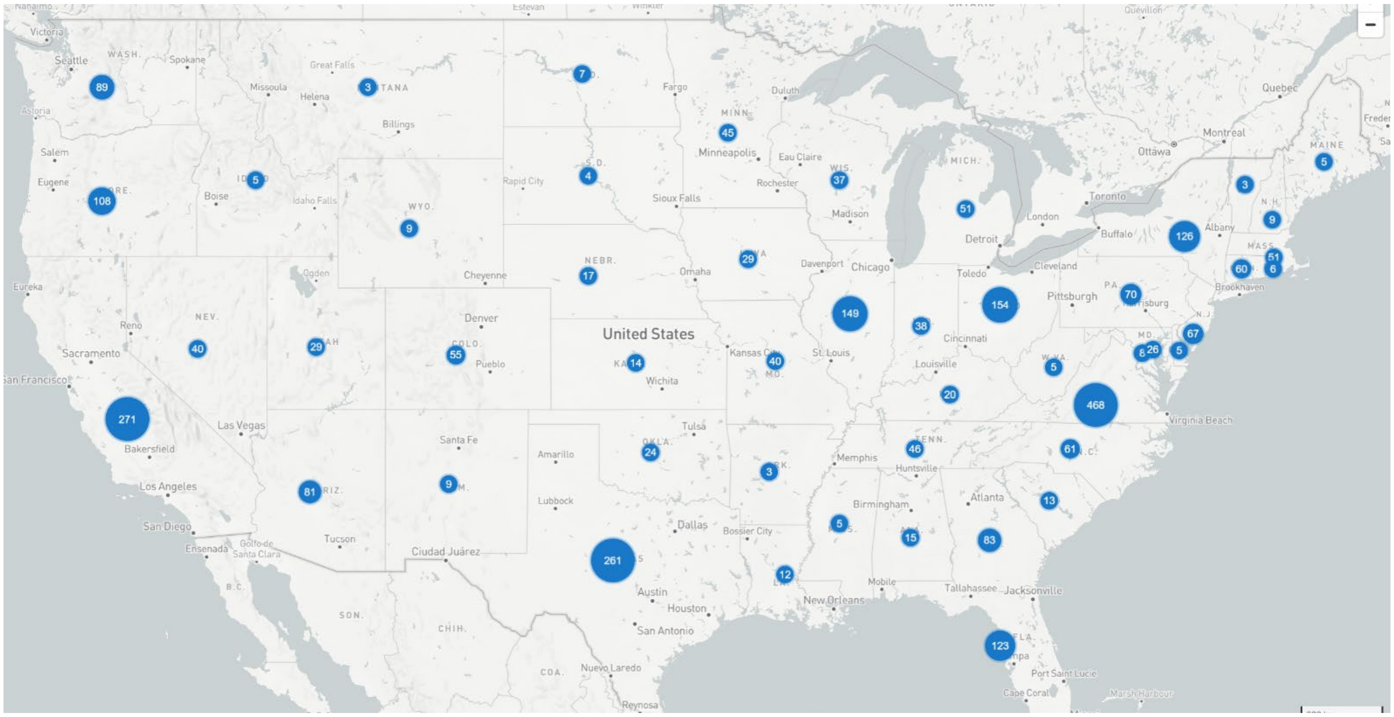


Figure #3.2: Data centers in the United States as of July 2024. Source: Data Center Map.com (2024). Accessed from: https://www.datacentermap.com/usa/

3.4 ELECTRIFYING BUILDINGS

According to US Energy Information Administration (EIA)[41] Commercial Buildings Energy Consumption Survey (CBECS) fewer than one-third of U.S. commercial buildings were all-electric in 2018 (see figure #3.3). As of 2018, 31%, or 1.8 million commercial buildings, were all-electric nationwide. Nearly half of all-electric U.S. buildings were concentrated in a single census region, the South. The South had more commercial buildings than any other region, and those buildings were less likely than those in other regions to use natural gas for space heating. Almost one-quarter of commercial buildings in the Northeast used fuel oil for space heating, which is rare in other regions. Only 8% of U.S. all-electric buildings, 138,000, were in the Northeast.

Buildings can be classified as all-electric in different ways. All-electric buildings are defined here as buildings that consumed only electricity for end uses that electricity can perform, such as space heating, cooling, water heating, and cooking. Other energy sources such as solar, natural gas, and fuel oil may have been consumed for on-site electricity generation.

Despite all-electric buildings accounting for 31% of the commercial U.S. building stock, all-electric buildings totaled only 18% of total U.S. commercial floorspace in 2018.

As a strategy to meet net-zero carbon commitments both the federal government and state governments have sought to revert from fossil fuels to renewable

---

[41] US EIA (2023).

electricity to power building operations (scope 2 greenhouse gas emissions).

Federal Actions

On April 24, 2024, the Department of Energy finalized a rule that will accelerate the electrification of new federal buildings and major renovations and reduce fossil fuel pollution. The Clean Energy for Federal Buildings rule requires a 90% reduction in direct fossil fuel consumption during the next five years and the elimination of burning fossil fuels on-site by 2030[42].

State and Local Actions

The building decarbonization coalition tracks state and local policies for the electrification of buildings. As of July 2024, they indicate that 6 states and 137 local governments address building specific operations fuel types.

Massachusetts has been one of the more aggressive states in respect to electrification of buildings. The Buildings sector is the second largest source of greenhouse gas emissions in Massachusetts, at 35 percent[43]. Natural gas is the heating fuel for 1.4 million, or 51 percent, of Massachusetts households, according to the Census Bureau.[44] State utility regulators on December 6, 2023, issued a ruling that sets a framework for reducing the use of gas for heating as part of a larger strategy to address climate change. The Massachusetts Department of Public Utilities rejected arguments from utilities and the gas industry that had urged the use of "renewable natural gas" and hydrogen as lower-carbon alternatives to natural gas. Instead, the department ruled that the state should encourage a transition to using electricity for heating and other functions gas currently serves. Under the ruling, gas utilities will need to submit climate compliance plans every five years starting in 2025, outlining how they intend to make a transition to clean energy.

The ruling says gas utilities are required to consider non-gas alternatives to gas expansion projects. Companies will no longer be able to make consumers pay for programs that promote the use of natural gas. The alternatives could include electrification, geothermal heat and programs that reduce energy use.[45]

Massachusetts is the **first state to phase out natural gas.** At least 11 other states (California, Colorado, Illinois, Maryland, Minnesota, Nevada, New Jersey, New York, Oregon, Rhode Island and Washington) as well as Washington, D.C., have ongoing regulatory cases that are exploring the future of natural gas.

Similarly, **New York State** adopted in the FY 2024 budget SB 562, the **All Electric Building Act** to address building GHG emissions which account for 32% of all state wide greenhouse gas emissions. Starting in 2026, the all-electric buildings law will require most new buildings in New York to use electric heat and appliances, instead of planet- fossil fuels.[46] Some of the specifics of the law include:

---

[42] RMI (2024).

[43] Mass.gov (2024). Massachusetts Climate Report Card - Buildings Decarbonization\

[44] US Census Bureau (2021).

[45] Inside ClimateNews (2023).

[46] NY Assembly (2024). The All-Electric Building Law

1. Starting in 2026, most new construction of buildings in New York that are seven stories or shorter must be built to use electric heat and appliances. This will also apply to larger commercial buildings with 100,000 square feet or more of conditioned floor area (bigger businesses).
2. Taller residential buildings and smaller commercial buildings will be rolled into the program in 2029.
3. Several exemptions were written into the law to address concerns that were raised as this new law was being written:
    a. Some industries, like restaurants, hospitals and doctors' officers, factories, and agricultural buildings will be automatically exempt from these requirements.
    b. Existing buildings will not be impacted by these new requirements, even if they're being repaired or renovated. If you build an addition on your house, you can still use gas if you want!
    c. Existing gas appliances can also be replaced with new gas appliances.
    d. Waivers will be available for new construction projects if the local electric corporation or municipality can't provide reliable service within a reasonable timeframe.
    e. People can still use fuel-generated power sources, like emergency generators, as backup and standby power systems.

In the western United States, on April 17, 2023 the 9th Circuit overturned the City of Berkely, California's 2019 ordinance prohibiting natural gas infrastructure in buildings. That decision does not currently affect New York state and it is unclear how it will impact other potential regulations across the country.[47]

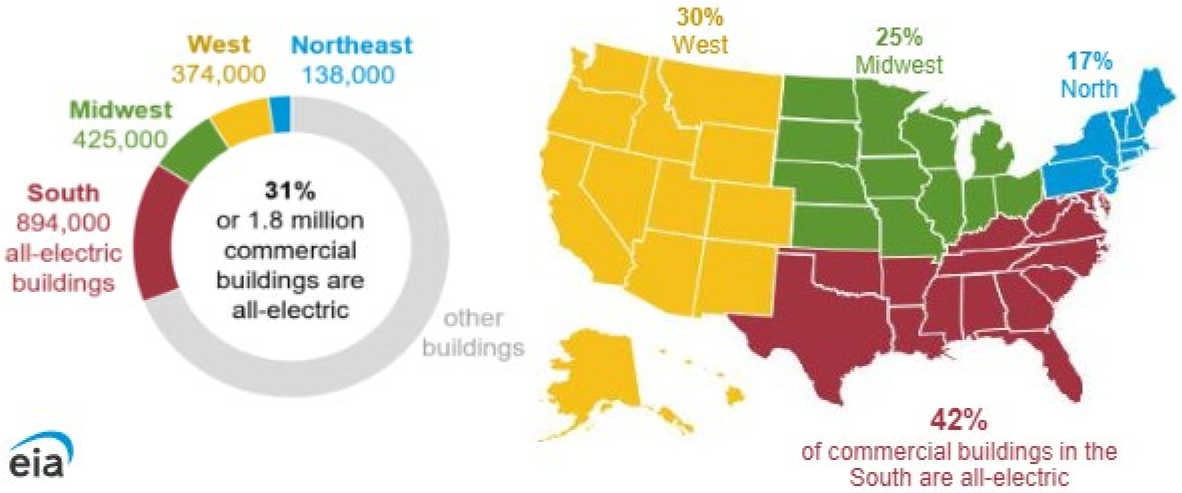


Figure #3.3: U.S. all-electric commercial buildings by census region in 2018. Source: US EIA (2023)[48].

---

[47] Climate Law (2023). Ninth Circuit Holds Berkeley's Gas Ban Preempted by U.S. Energy Policy & Conservation Act
[48] US EIA (2023).

Section 4

RELIABILITY & RESILIENCY IMPACTS

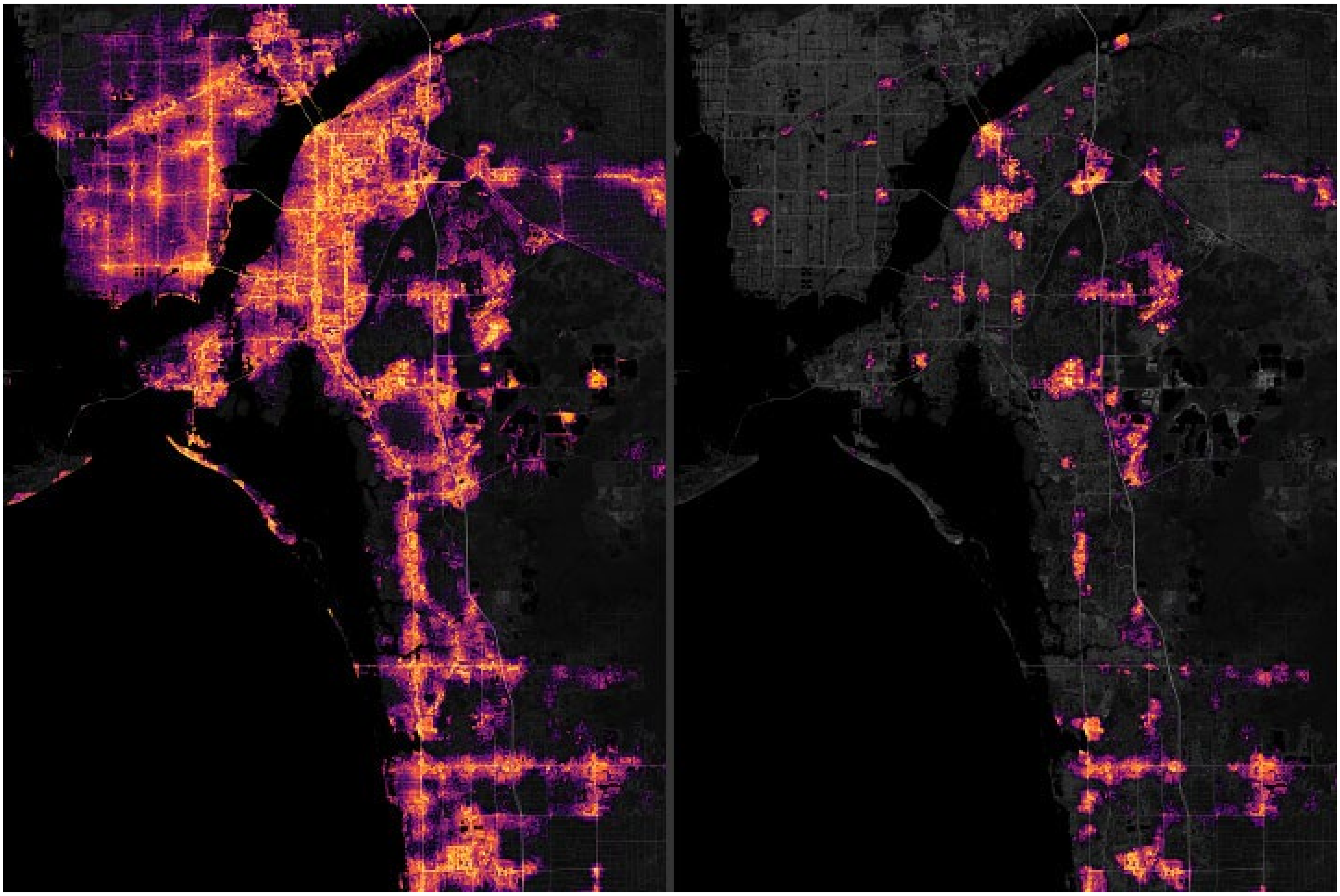


Photo courtesy NASA. Power outages after Hurricane Ian

(2022) in Florida.. Accessed from: https://images.app.goo.gl/tNF2BXeiFQbzK8R57

4.1 WEATHER RELATED RISKS

Non-Heat Related Impacts

Of all major U.S. power outages reported from 2000 to 2023, 80% (1,755) were due to weather[49].

According to NOAA (2023) weather related damages from the 2022 totaled $165.1 billion with the costliest 2022 events being Hurricane Ian ($112.9 billion) and the Western and Central Drought / Heat Wave ($22.1 billion). Adding the 2022 events to the record that began in 1980 as presented in figure #4.1, the U.S. has sustained 341 weather and climate disasters with the overall damage costs reaching or exceeding $1 billion. The cumulative cost for these 341 events exceeds $2.475 trillion. It is important to keep in mind that these estimates do not reflect the total cost of U.S. weather and climate disasters, only those associated with events more than $1 billion in damages. That means they are a conservative estimate of how much extreme weather costs the United States each year. Climate change is enhancing damages due to increased severity of weather-related events. Related, on average, **U.S. electricity customers experienced approximately five and one-half hours of electricity interruptions in 2022.**[50]

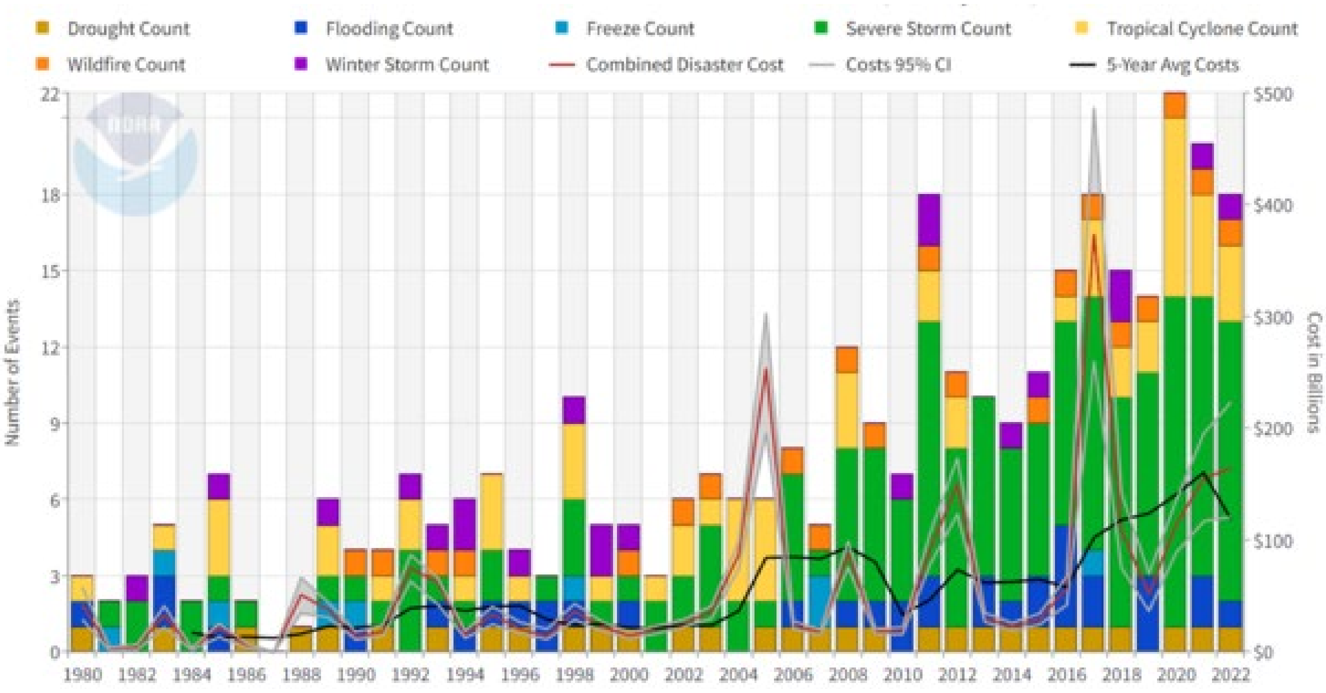


Figure #4.1 Billion Dollar Disaster Events 1980-2022 in the United States (CPI Adjusted). Source: NOAA (2023).

---

[49] Climate Central (2024). Weather-related Power Outages Rising.

[50] US EIA (2024). U.S. electricity customers averaged five and one-half hours of power interruptions in 2022.

U.S. Climate Region	Weather-related outages (2000-2023)
Southeast	360
South	352
Northeast	350
Ohio Valley	301
Upper Midwest	205
West	151
Northwest	73
Southwest	28
Northern Rockies and Plains	24

Table #4.1. Weather related outages 2000-2023. Source: Climate Central (2024).

State	Weather-related outages (2000-2023)
Texas	210
Michigan	157
California	145
North Carolina	111
Ohio	88
Louisiana	85
Virginia	83
Georgia	83
Pennsylvania	82
Florida	77
Alabama	76

Table #4.2. Weather related outages by state 2000-2023. Source: Climate Central (2024).

HEAT RELATED IMPACTS

Extreme heat was responsible for 48 outages (about 3% of weather-related outages). Heat waves bring increased electricity demand including "peak demand" for cooling, which can overload the system.

In May 2024, the United States faced record power demand in Texas due to an intense heatwave, with the Electric Reliability Council of Texas (ERCOT) seeing peak demand of 77 GW, 13% higher than the May 2023 peak.

In addition, the formation and expansion of urban heat islands (UHIs) is also adding to demands and potential interruptions of electricity. Additional operational and resiliency impacts from heat includes the vulnerability to transmission and distribution systems, as the average power output decreases 0.7% to 1% per 1◦C increase in air temperature, above a reference temperature (usually taken to be 20◦C)" [94].

Air cooled and wet-recirculating systems are the most vulnerable to heat related efficiency losses. As thermal electricity generation is "proportional to the temperature difference between the steam inlet and condenser temperatures" [92]. Higher ambient air temperatures also result in more inefficient combustion due to lower mass density of intake air. Losses to efficiency can also occur in photovoltaic systems. In certain power generation systems, facilities must cease operations when the cooling air or water temperatures reach a certain high, increasing the risk of outages nationally as temperatures increase. Additional concern centers around the temperature of the discharge water.

WILDFIRES

Climate change enhances the drying of organic matter in forests (the material that burns and spreads wildfire), and has doubled the number of large fires between 1984 and 2015 in the western United States[51].

---

[51] Center for Climate & Energy Solutions (2024).

Wildfires accounted for 39 outages (about 2% of weather-related outages)[52]. More than half of these outages were concentrated in the last five years. About one-third were public safety power shutoffs by utilities due to wildfires or to reduce risk of equipment-related ignitions during extreme fire weather days. Wildfire seasons are lengthening and intensifying across the U.S.

VEGETATION

Tree contact with transmission lines is a leading cause of electric power outages and a common cause of past regional blackouts, including the August 2003 blackout that affected 50 million people in the Northeast United States and Canada.

Following the 2003 blackout and subsequent federal legislation, the Commission designated the North American Electric Reliability Corporation (NERC) as the Electric Reliability Organization (ERO), with the responsibility to develop and enforce standards to ensure the reliability of the Bulk Power System, including the Reliability Standard that addresses vegetation management covering tree trimming on rights-of-way. [53]

Electric Reliability Standard FAC-003-4 requires that trees and other vegetation growing in or adjacent to the power line right-of-way be trimmed to prevent power outages caused by tree contact with a transmission line. Any power line contact with a tree can cause a short circuit which may lead to a blackout or threaten public safety.

Sometimes, vegetation in proximity to transmission lines can cause wildfires or at the least, power outages. The Dixie Fire, the **second-largest wildfire in California's history, was sparked when power lines owned by Pacific Gas and Electric (PG&E) came into contact with a tree**. The Dixie Fire started July 13, 2021 and went on to burn 963,309 acres across five counties in Northern California before being contained on October 25, according to Cal Fire. The wildfire destroyed 1,329 structures, including much of the small community of Greenville, about 170 miles north of Sacramento.

PG&E, in a statement, said the tree was one of more than 8 million within strike distance of its power lines. "Taking a bold step forward, PG&E has committed to burying 10,000 miles of lines in addition to the mitigations included in PG&E's 2021 Wildfire Mitigation Plan," the utility said. [54]

DROUGHT & WATER AVAILABILITY

Drought and water availability are another large and looming concern. "Thermoelectric generation accounts for approximately 40% of freshwater withdrawals across all water use sectors" [96]. Once-through cooling systems are at greater risk than plants with recirculating systems. Once through

---

[52] Climate Central (2024). Weather-related Power Outages Rising

[53] FERC (2024). Transmission Line Vegetation Management

[54] CNN (2022). California's second-largest wildfire was sparked when power lines came in contact with a tree, Cal Fire says.

cooling systems use between (10,000-60,000 gallons/MWh), while recirculating systems are much more efficient at (250-1,800 gallons/MWh).

If water levels physically drop below intake valves, this can reduce or halt power generation altogether. 43% of thermodynamic electric plants were found to have less than 10 feet of clearance between the average water level of their cooling water source.

Hydropower facilities may also experience losses due to low water supply, with a roughly linear relationship between annual runoff and generation in many scenarios. For some specific plants and regions, there are documented impact functions. The Hover Dam experiences a 5-6 MW reduced output for every foot decline in lake Mead, while the Colorado River Basin experiences 3% decrease in generation per 1% decrease in river flow [97].

4.2 CYBER & PHYSICAL THREATS

As reported in Reuters (2024)[55] officials at the North American Electric Reliability Corporation (NERC) stated that U.S. power grids are increasingly vulnerable to cyberattacks, with the number of susceptible points in electrical networks increasing by about 60 per day. The grids' virtual and physical weak spots, or points in software or hardware that are susceptible to cyber criminals, grew to a range of 23,000 to 24,000 last year from 21,000 to 22,000 by the end of 2022.

Additionally, physical attacks continue to be a risk to the grid. According to the Department of Energy, 2022 saw an increase of 77% in physical attacks on the grid and 2023 remained high with about 2,800 reports of gunfire, vandalism and other strikes on electrical networks in 2023 (Security Intelligence, 2023)[56].

Examples of recent physical threats to the grid (there are many more identified than listed below) include[57], [58]:

- December 2022: Rifle fire damages two electrical substations in Moore County, North Carolina, cutting power to more than 40,000 customers. Neither the attackers nor their motive is identified.

- December 2022: Two men attacked substations in Washington state, leaving thousands without power on Christmas Day and causing at least $3 million in damage.

---

[55] Reuters (2024). US Electric grid growing more vulnerable to cyberattacks, regular says. April 4, 2024

[56] Security Intelligence (2023). Today's biggest threats against the energy grid.

[57] Security Management (2024).

[58] Axios (2023). Attacks on power grid raise alarm among top officials.

- January 2023: A suspect latered arrested and charged in San Jose, CA bombed a transformer following a similar bombing in the city on December 8, 2022-both explosions left thousands without power.

- February 2023: A man and a woman—one an avowed neo-Nazi—are charged with conspiracy to take down Baltimore's power grid through attacks on electrical substations, in an attempt to cause chaos in that Maryland city.

- June 2023: An attacker fires a rifle at two hydroelectric power stations in Idaho, which interrupts the regional power supply and damages both facilities. Two months later, the suspect is arrested and charged with two counts of destruction of an energy facility.

Component	Hazard	Potential Impacts
Electricity Generation: Thermoelectric	High ambient air temperatures	Reduction in plant efficiency and available generation capacity
	High water temperatures	Reduction in plant efficiency and available generation capacity; increased risk of exceeding thermal discharge limits
	Drought and water availability issues	Reduction in available generation capacity; impacts on coal, natural gas, and nuclear fuel supply chains
	Storms, sea level rise, and storm surge	Increased risk of physical damage and disruption to coastal facilities
	Flooding	Increased risk of physical damage and disruption to inland facilities
Electricity Generation: Hydropower	High ambient air temperatures and evaporative losses	Reduction in available generation capacity and changes in operations
	Changes in precipitation and decreasing snowpack	Reduction in available generation capacity and changes in operations
	Flooding	Increased risk of physical damage and changes in operations
Electricity Generation: Wind Energy	Variations in wind patterns	Variations in wind patterns
Electricity Generation: Solar Energy	High ambient air temperatures	Reduction in potential capacity
	Extreme weather	
Transmission and Distribution: Transformers	High ambient air temperatures	De-rating, decreased capacity, accelerated aging, loss of life
Transmission and Distribution: Power Lines	High ambient air temperatures	Reduction in transmission efficiency and available transmission capacity
	Wildfires	Increased risk of physical damage and decreased transmission capacity
	Storm events, including ice storms	Increased risk of physical damage
Transmission and Distribution: Poles	High Winds	Line damage, failure
	Wildfires	
End Use: Demand	High ambient air temperatures	Increased electricity demand for cooling, increased adoption of air conditioning
	Extreme heat events	Reserve margin vulnerability
Electromagnetic Pulse (EMP)	Natural or Artificial	Can take out equipment

Table #4.3. Potential Impacts of Climate and Weather Hazards on Electrical Sector. Adapted from [89]

Section 5

DISTRIBUTED ENERGY RESOURCES (DERs)

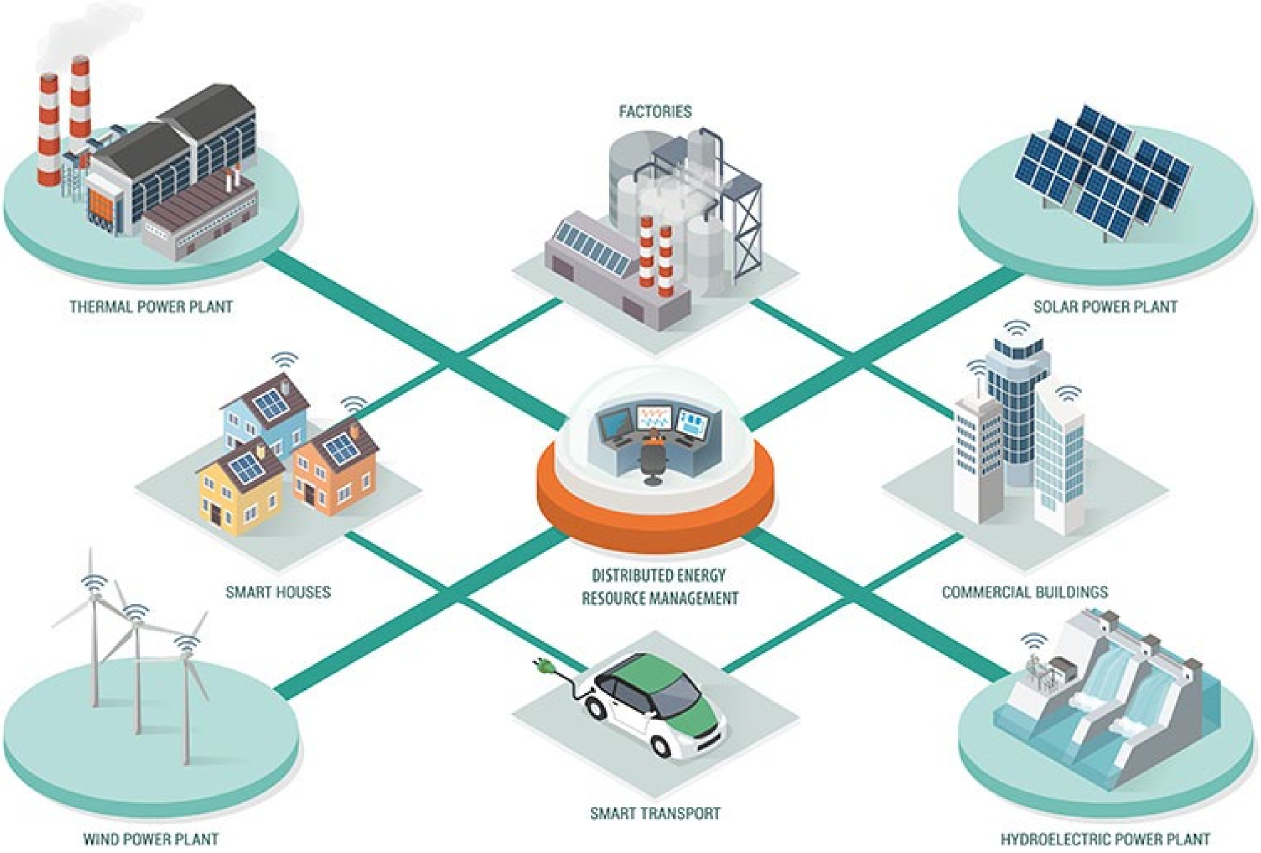


Image courtesy of the National Renewable Energy Lab (NREL): Distributed Energy Resource Management Systems (2024).

5.0 DISTRIBUTED ENERGY RESOURCES (DERs)

5.1 WHAT ARE DERS?

Distributed energy resources are small, modular, energy generation and storage technologies that provide electric capacity or energy where you need it. Typically producing less than 10 megawatts (MW) of power. DER systems may be either connected to the local electric power grid or isolated from the grid in stand-alone applications. DER technologies include wind turbines, photovoltaics (PV), fuel cells, microturbines, reciprocating engines, combustion turbines, cogeneration, and importantly and becoming more common place, energy storage systems such as industrial batteries.

5.2 CAN DER'S STABILIZE THE GRID?

A joint study by GridWorks and GridLab (2018)[59] identified a number of ways that Distributed Energy Resources can help stabilize the grid.

1. DG's greatest capability is the ability to **generate and/or store energy locally, closer to end users** compared to traditional generators. This can reduce demand for costly, large-scale utility infrastructure, such as high voltage transmission lines. DG can also reduce line losses experienced due to the transmission of power across large distances.
2. Energy storage can provide additional capabilities above and beyond distributed generation. First, **batteries can provide dispatchable generation**. This capability allows batteries to shift energy generation by discharging at times of high demand or peak load.
3. When energy prices vary temporally, **batteries can be programmed to respond to price signals** in order to both meet grid needs and reduce customer bills. For example, batteries can be programmed to charge when excess power is available and discharge at times of peak demand. Batteries can also respond instantaneously to changing load.
4. **Batteries can also provide important voltage regulation and frequency regulation services** to improve power quality on existing grid infrastructure. In contrast to traditional utility infrastructure (e.g., transformers, regulators, etc.), storage systems can be paired with smart inverters, described in further detail below, to control the battery's energy output

---

[59] GrrdWorks and GridLab (2018). The role of distributed energy resources in today's grid transition.

autonomously in response to changing conditions on the grid.

5.3 THE MARKET'S VIEW

The US Distributed Energy Resource (DER) market is expected to nearly double in capacity from 2022 to 2027, with capital expenditure reaching US $68 billion per year, according to Wood Mackenzie's '2023 US Distributed Energy Resource Outlook[60] **Their analysis shows that 262 gigawatts (GW) of new DER and demand flexibility capacity will be installed from 2023 to 2027, close to matching the 272GW of utility-scale resource installations also expected during that period.**

Battery energy storage systems (BESS) are one of the key catalysts for current and future growth of distributed energy systems. They can be connected to renewable energy sources such as PV and be used to meet peak electricity demand closer to the user(s). McKinsey and Company (2023) reports[61] that more than $5 billion was invested in BESS in 2022—almost a threefold increase from 2021. The expect the global **BESS market to reach between $120 billion and $150 billion by 2030, more than double its size today.**

5.4 DRIVERS

Financial via the Inflation Reduction Act (IRA)

The Inflation Reduction Act (IRA) of 2022 provides $391 Billion for clean energy through grants, incentives, tax credits and rebates. The Greenhouse Gas Reduction Fund (GHGRF) can provide $27 billion financing for distributed energy resources (DERs) benefiting low-income communities through green banks and community development financial institutions (CDFIs).

Figure # 5.1. Long Duration Battery Energy Storage. Source: US DOE (2023)[1].

The IRA's 48C Qualifying Advanced Energy Project Credit Program gives companies a tax credit worth 30 percent of any money they spend on green energy projects, decreasing the financial risk of investing in nascent technology such as battery manufacturing.

The IRA also provides both additional production and investments for DER technologies including:

1. Providing numerous federal tax credits and incentives to produce and purchase an expanded range of energy technologies at a lower cost for the next ten years.
2. Expanding financing and monetization options for investors and non-tax-paying

---

[60] Wood Mackenzie (2023). US Distributed Energy Resource market to almost double by 2027

[61] McKinsey and Company (2023)

entities such states and tribal governments, as well as municipal, university, school, and hospitals.

Key Energy Investment Elements of the IRA

1. First-Ever Tax Credits for Microgrid Components Will Cut Costs by 10%-50%.
2. Expands Investment Tax Credit (ITC) by 30% for microgrid controllers, stand-alone energy storage, biogas property, dynamic gas, and linear generators constructed before January 1, 2025.
3. Bonus credits available for projects that meet domestic manufacturing and/or siting criteria.
4. Incentives for Clean Energy Production and Technologies Through 2032.
5. Extension of Renewable Electricity Production Tax Credit (PTC) through 2024.
6. Establishes a new, technology-neutral Clean Energy Production Tax Credit (PTC) through 2032.
7. $27B clean energy technology accelerator for investments in technologies and energy efficiency improvements.
8. Easier and More Attractive Finance Opportunities.
9. Direct pay for states, localities, tribes, rural cooperatives, and nonprofits for the renewable ITC and PTC.
10. Tax credit transferability (ability for investors to sell tax credits to third parties).
11. $30B in targeted grant programs for states and electric utilities to accelerate the transition to clean electricity.

Policy

The U.S. Federal Energy Regulatory Commission (FERC) in 2020 issued FERC Order No. 2222 [62] which ultimately went into effect in February of 2022. It represents a significant move towards integrating DERs within the broader energy market, ensuring DERs can compete fairly by supplying all the services they are technically capable of providing through aggregation.

Order No. 2222 allows groups of DERs, such as residential solar arrays, battery storage units and electric vehicles, to provide power and grid services in exchange for financial compensation. This regulatory shift creates a new value stream for DER users and entities, fostering a more resilient and sustainable energy grid.

The rule opens U.S. organized wholesale markets to new sources of energy and grid services. It is anticipated the rule help provide a variety of benefits including: lower costs for consumers

---

[62] https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet

through enhanced competition, more grid flexibility and resilience, and more innovation within the electric power industry.

In April of 2024, **New York State through the New York ISO launched the nation's first program to integrate aggregations of distributed energy resources into wholesale markets.**

The new market rules require participating DER to be at least 10 kW in size.

The **10-kW minimum size was a controversial issue and will significantly limit the number of resources that can participate**, at least initially.

In a concurring statement, FERC Chairman Willie Phillips and Commissioner Allison Clements acknowledged "valid concerns about the potential limiting effect" of the threshold, but said the "**lack of such a requirement would substantially delay rollout of the participation model.**"

How Order 2222 impacts utilities.

Regional grid operators must revise their tariffs to establish DERs as a category of market participant. These tariffs will allow the aggregators to register their resources under one or more participation models that accommodate(s) the physical and operational characteristics of those resources. Each tariff must set a size requirement for resource aggregations that do not exceed 100 kW.

The tariffs also must address technical considerations such as:

- locational requirements for DER aggregations;
- distribution factors and bidding parameters;
- information and data requirements;
- metering and telemetry requirements; and
- coordination among the regional grid operator, the DER aggregator, the distribution utility and the relevant retail regulatory authority.

The rule also directs the grid operators to allow DERs that participate in one or more retail programs to participate in its wholesale markets and to provide multiple wholesale services, but to include any appropriate, narrowly designed restrictions necessary to avoid double counting.

5.5 DER TECHNOLOGIES

The following definitions excluding renewables are from the U.S. Department of Energy by the National Renewable Energy Laboratory, a DOE national laboratory DOE/GO-102002-1520 May 2002:

Diesel Engine generator sets (gensets)

consist of a diesel-cycle (compression ignition) reciprocating engine prime mover coupled to an electric generator. The diesel engine operates at a relatively high compression ratio and relatively low rpm. Diesel engine gensets are a proven, cost-effective, extremely reliable and widely used technology. They are manufactured in a wide range of sizes, from about 1 kilowatt (kW) up to about 10 MW. They can be cycled frequently to operate as peak-load power plants or as load-following plants; they can also be run in baseload mode in off-grid systems. Major drawbacks include very high levels of emissions (particularly nitrogen oxides, a major component of smog), and the need for sound attenuation to muffle the loud engine noise. Diesel engines are thus probably not suitable for most Federal facilities, and should be considered only if other technologies are not practical. One of the least expensive DER technologies, they cost about $810/kW, installed.

Dual-Fuel Engine gensets consist of a diesel-cycle engine modified to use a mixture of natural gas and diesel fuel (typically, 5% to 10% diesel by volume) connected to an electric generator. The small amount of diesel fuel allows the use of compression ignition, and the high percentage of natural gas in the mix results in much lower emissions (and somewhat lower power output) than those of a diesel engine. In most other cost and operational respects, dual-fuel engines are comparable to diesels; they are available in sizes from a few kilowatts to about 10 MW at an installed cost of about $875/kW.

Natural Gas Engine gensets are made up of a reciprocating (piston-driven) natural gas-fueled engine using a spark-ignition system (Otto fuel cycle) coupled to an electric generator. In most other respects, natural gas engines perform similarly to diesels and dual-fuel engines, but have the potential for the lowest emissions of all types of reciprocating engines. They are available in sizes from a few kilowatts to about 5 MW, and they cost about the same as diesel and dual-fuel engines—around $825/kW.

Combustion Turbines (also called gas turbines) burn gas or liquid fuel; hot gases expand against the blades of a rotating shaft, producing a high-speed rotary motion that drives an electric generator. While they may take a few more minutes to get up to speed in comparison to reciprocating engines, gas turbines are well suited for peaking and load-following applications and for baseload operation in larger sizes. Installed costs are somewhat higher than those of reciprocating engines, and maintenance costs are slightly lower. Turbines are efficient and relatively clean. They can easily be fitted with pollution controls to run even cleaner. They are available in sizes ranging from about 300 kW to several hundred megawatts, and costs range from $910/kW to $1,400/kW, installed.

Microturbines are smaller, somewhat less efficient versions of combustion turbines, in the range of about 30 to 250 kW. They run on natural gas at high speeds (typically around 90,000 rpm). The electrical output of the generator is typically passed through an inverter (an electronics-based apower converter, also called a power conditioning unit or PCU) to provide 60 Hz AC power. Microturbines targeted to the small industrial and commercial market are designed to be compact, affordable, reliable, modular and simple to install. The newest versions meet very low emissions requirements. Microturbines are commercially available and currently cost around $1,000/kW.

Electric Vehicles (V2G, V2X, V2H, V2B)

Vehicle-to-grid (V2G), vehicle-to-home (V2H), vehicle-to-building (V2B), vehicle-to-load (V2L), vehicle-to-everything (V2X)

EVs can function as grid supply—serving the same functions as power generators—as well as being grid loads. EVs could pump electricity back onto the grid at times of high demand and participate in the ancillary services markets, providing services like frequency and voltage regulation, reactive power for power factor correction, and reserve capacity. The auto industry needs to build V2G features into its vehicles. Currently, most manufacturers are not including onboard V2G capability in their vehicles (except for a few pilot programs and the newer Nissan Leaf models), and even where it is built-in, using it for V2G would void the vehicle warranty. It's a classic chicken-and-egg problem: Manufacturers aren't including V2G features because there isn't a market, and there isn't a market because there aren't enough vehicles with those features.

V2G technology powers bi-directional charging, which makes it possible to charge the EV battery and take the energy stored in the car's battery and push it back to the power grid. While bi-directional charging and V2G are often used synonymously, there is a slight difference between the two. While bi-directional charging means two-way charging (charging and discharging), V2G technology only enables the flow of the energy from the car's battery back to the grid.

Besides V2G, there is another abbreviation often mentioned in relation to bi-directional charging - V2X. V2X means vehicle-to-everything. It includes many different use cases, such as:

Fuel Cells which produce DC electricity by a thermochemical process in which hydrogen (H2) is passed over an anode and air over a cathode in an electrolyte bath; the DC power is inverted to AC for grid operation. Byproducts are heat, water, and carbon dioxide, making fuel cells one of the cleanest sources of energy. Unless it is transported to the site, the hydrogen comes from reforming a fuel such as natural gas or propane, a process that may produce environmental emissions. Fuel cells using a phosphoric acid electrolyte were the first to become commercially available; solid oxide, molten carbonate, and proton exchange membrane (PEM) technologies are poised to follow. Fuel cells are efficient, quiet, and modular.

They are available in sizes ranging from a few watts to 200 kW—the current commercially available size for stationary power applications. Although costs are expected to go down, fuel cells are now one of the most expensive DER technologies, starting at about $5,500/kW, installed.

Photovoltaic Cells (PV) are thin layers of a semiconductor (usually crystalline silicon) that convert sunlight directly to DC electricity; an inverter converts the DC to standard AC power for connection to utility systems. These “solar cells” are built up into panels with power ratings ranging from a few watts to about 100 W. The panels are modular and can be configured into larger arrays to match almost any load requirement. Noise and emissions are nonexistent, and maintenance is minimal because there are no moving parts. Photovoltaic systems are a proven technology and are available from numerous manufacturers. Depending on the application, PV systems can range from $8,000/kW to $13,000/kW, installed. Grid-connected systems typically fall in the low end of the range, while systems with battery storage constitute the high end.

Wind Turbines, another renewable energy technology, contain propellerlike blades that turn the energy in the wind into rotational motion to drive a generator. Most wind turbines are asynchronous, meaning they turn at variable speeds; the output of the generator must pass through an inverter to achieve 60 Hz AC electricity. Wind turbines range in electrical output from a few watts to more than 1 MW. Applications include remote power systems, small-scale or residential electricity production, and utility-scale power generation. DER scale systems can cost anywhere from $1,000/kW to $3,000/kW installed, depending on the application. Like photovoltaics, wind turbines are a proven technology and are available from several manufacturers.

Storage Devices take energy from the electric grid or another source (such as a renewable DER) and store it, making it available when needed. Storage technologies currently available have a range of characteristics for various applications. Batteries are the most common form of electric energy storage; applications range from low power uses, such as remote telecommunications, to high-power uses, such as utility grid support (requiring an inverter). A UPS is another common storage system, typically consisting of batteries mated to control electronics that convert stored energy to AC electricity and dispatch it as needed (for example, to provide full power during an outage or to smooth out power quality problems). Flywheels convert electric or mechanical energy into rotational energy and invert it for use when needed. Superconducting magnetic energy storage (SMES) uses a magnetic coil cooled to very low temperatures to store electric energy with little loss; like other DC devices, it uses an inverter to convert DC to AC that can be dispatched to a utility grid. These storage technologies are all commercially available and becoming more cost-effective as applications increase. The cost of purchasing and installing energy storage systems can range from $1,100/kW to $1,300/kW.

Renewables include photovoltaics and small-scale wind. Self-standing Solar photovoltaic (PV) power to the grid or to battery storage poses a unique set of benefits and challenges. In distributed solar applications, small PV systems (5–25 kilowatts [kW]) generate electricity for on-site consumption and interconnect with low-voltage transformers on the electric utility system.

Deploying distributed PV can reduce transmission line losses, increase grid resilience, avoid generation costs, and reduce requirements to invest in new utility generation capacity. With proper equipment and calibration, distributed PV systems can also mitigate reliability issues experienced by providing standby capacity during electric utility disturbances or outages.

Hybrid Systems are combinations of these technologies, designed for specific or unusual applications. Renewable energy technologies such as wind and solar systems, for example, depend on energy sources that cannot be dispatched—i.e., we have no control over their availability. For this reason, it can be necessary to combine them in a hybrid system, such as a PV system with battery backup, to collect energy for use when a facility needs it. Nonrenewable hybrid DER systems are also used; one example is a battery system packaged with a microturbine, to ride through short outages with the batteries and use backup power from the microturbine for sustained outages. Depending on your needs, more than one of these technologies and systems might work for you. In that case, you could custom design several technologies and control systems to obtain the greatest benefit.

5.6 DER CONCERNS

DERs may present challenges for electric utilities and power customers. DG resources may introduce operational complexities for transmission, distribution, and generation systems. For example, too much DG can create excess demand at a substation, causing power to flow from the substation to the transmission grid and increasing the likelihood for high voltage swings and other stresses on electric equipment.

Increased DG use may cause financial equity issues as well. Utilities may have to make capital investments to address potential strains on the system caused by DG deployment, and these costs may be borne by both DG-owning and non-DG-owning electric customers. Designing rates for DG customers can also present challenges. For example, subject to applicable state or local laws, most electric utilities compensate DG producers through net metering, under which customers with on-site generation are credited for their kilowatt-hour sales back to the grid and charged for periods when their electricity consumption from the grid exceeds their DG output.

Under many net-metering programs, the customer is both charged and credited at the utility’s full retail rate of electricity, thus potentially over-compensating DGs with a value of generation that is higher than the utility’s avoided cost (since the full retail rate includes expenses other than the cost of the power itself). Some, but not all, regulators have adopted alternative compensation schemes to appropriately value the full costs associated with DG production. These financial equity issues may also arise in the future with the growth of storage and EVs.

5.7 OPTIMIZING DER INTEGRATION

While DERs offer significant benefits, they can also present challenges for electric utilities and power customers. The integration of DG resources can introduce operational complexities for transmission, distribution, and generation systems. For example, excessive DG penetration can lead to substation overloading, causing power to flow back to the transmission grid and potentially causing voltage swings and other equipment stresses.

An Energy Community Optimization agency (ECO-a) can play a pivotal role in addressing these challenges by:

1. Coordinating DER operations: Optimizing the dispatch of DERs to balance supply and demand.
2. Managing local congestion: Identifying and mitigating congestion points.
3. Integrating DERs into the local grid: Developing protocols and standards for seamless integration.
4. Leveraging AI and machine learning: Utilizing advanced analytics to optimize local DER operations and grid management.

Section 6

VIRTUAL POWER PLANTS (VPPs)

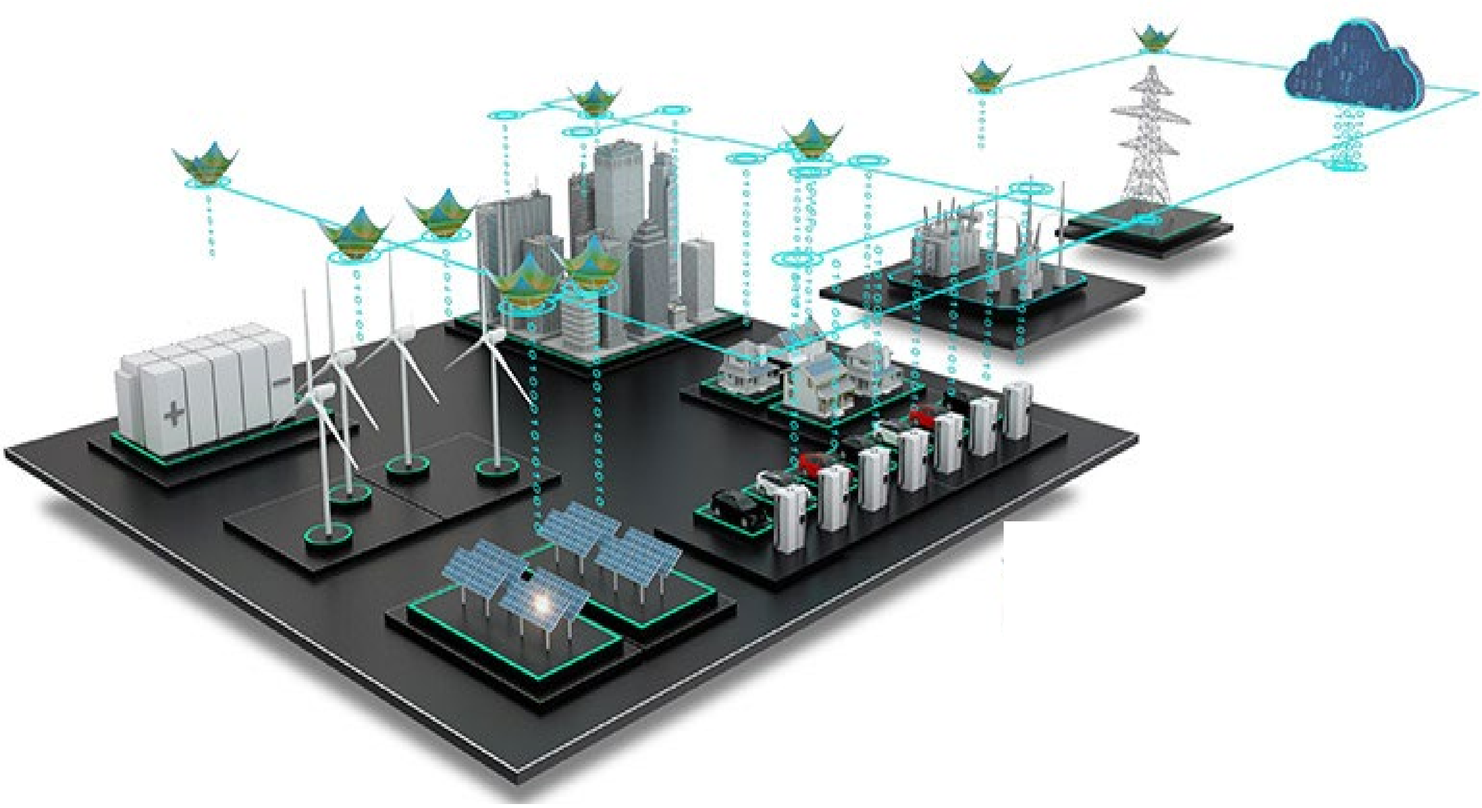


Image courtesy of NREL (2024).[63]

---

[63] https://www.nrel.gov/grid/autonomous-energy.html

6.0 VIRTUAL POWER PLANTS

Virtual Power Plants (VPPs) bundle together resources (primarily renewable resources) to create a reliable power network which can be dispatched to aid the overall grid during times of peak demand, just like a real, centralized power plant could but with far less capital costs and generally lower greenhouse gas emissions.

The "virtual" nature of VPPs comes from its lack of a central physical facility, like a traditional coal or gas plant. By generating electricity and balancing the energy load, the aggregated batteries and solar panels provide many of the functions of conventional power plants[64].

Technology plays a pivotal role with distributed energy sources by connecting them to the grid through technologies like Wi-Fi, Bluetooth, and cellular services. In aggregate, adding VPPs can increase overall system resilience. By coordinating hundreds of thousands of devices, VPPs have a meaningful impact on the grid—they shape demand, supply power, and keep the electricity flowing reliably. Companies working to deliver VPPs via DERs do so by using an intelligent control system and bidirectional technology to aggregate energy from networked resources at a multitude of sites, such as solar-plus-storage systems, EVs and other DERs.

The Department of Energy states, "With peak electricity demand rising and old coal and gas power plants retiring, t**he U.S. grid will need to add enough new capacity to serve over 200 gigawatts (GW) of peak demand by 2030**.

For the U.S. to follow a path toward 100% clean electricity by 2035, new capacity needs could be nearly double this amount. **Deploying 80-160 GW of VPPs—tripling current scale—by 2030 could expand the U.S. grid's capacity to reliably support rapid electrification** while redirecting grid spending from peaker plants to participants and **reducing overall grid costs by $10 billion per year."**[65]

VPPs not only helps stabilizing the power grids. It also **creates the preconditions for integrating renewable energies into the markets**. Individual small plants can in general not provide balancing services or offer their flexibility on the power exchanges. This is because their generation profile varies too strongly or they simply do not meet the minimum bid size of the markets. By aggregating the power of several units, a VPP can deliver the same service and redundancy and subsequently trade on the same markets as large central power plants or industrial consumers[66].

---

[64] MIT (2024). How virtual power plants are shaping tomorrow's energy system.

[65] DOE (2023). DOE Releases New Report on Pathways to Commercial Liftoff for Virtual Power Plants

[66] Next (2024).

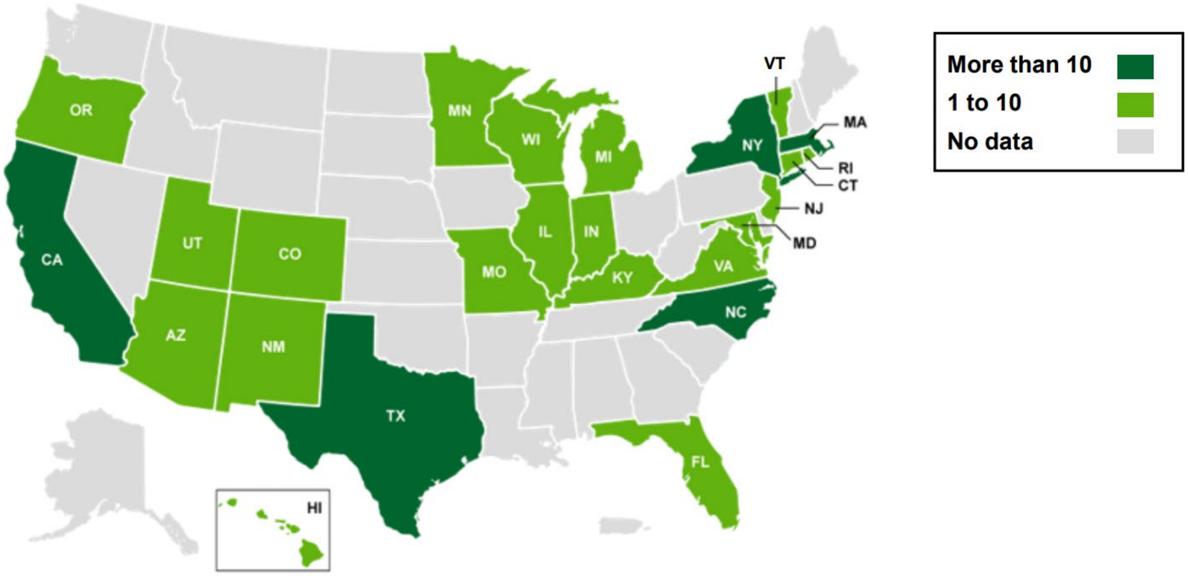


Figure #6.1. Number of 3rd party VPPs procured by utilities in each state (2022). Source: U.S. DOE (2023). Pathways to Commercial Liftoff. Virtual Power Plants.

While virtual power plants (VPPs) offer significant benefits, their current operation by private companies can limit their ability to serve the local community. An Energy Community Optimization agency (ECO-a) could play a crucial role in ensuring that VPPs are utilized to benefit local communities and support local infrastructure reliability and longevity.

By aggregating and managing VPPs, an ECO-VPP using AI can:

1. Coordinate management: Ensure that VPPs operate in a manner that extends, not hastens useful life of distribution wires, transformers, substations, and other infrastructure.
2. Optimize locally: Ensure that VPPs act optimally together to maximize across all local resources the benefits for all stakeholders, resource owners and customers.
3. Enhance local grid stability: Provide flexibility and responsiveness to local grid fluctuations.
4. Reduce local peak demand: Alleviate strain on the local grid during peak load periods.
5. Support local renewable energy integration: Facilitate the integration of distributed renewable energy resources.

REFERENCES

1. U.S. Energy Information Administration. Annual Energy Outlook: AEO 2020. Access from: https://www.eia.gov/outlooks/aeo/pdf/AEO2023_Narrative.pdf

2. U.S. Energy Information Administration. Annual Energy Outlook: AEO 2020. Access from: https://www.eia.gov/outlooks/aeo/pdf/AEO2023_Narrative.pdf

3. Placeholder (EXCEL)

4. Davenport, C., & Friedman, L. Biden's New Power Plant Rules: 5 Things to Know. *The New York Times.* April 25, 2024. Access from: https://www.nytimes.com/2024/04/25/climate/joe-biden-climate-global-warming.html

5. Davenport, C., & Friedman, L. Biden's New Power Plant Rules: 5 Things to Know. *The New York Times.* April 25, 2024. Access from: https://www.nytimes.com/2024/04/25/climate/joe-biden-climate-global-warming.html

6. Davenport, C., & Friedman, L. Biden's New Power Plant Rules: 5 Things to Know. *The New York Times.* April 25, 2024. Access from: https://www.nytimes.com/2024/04/25/climate/joe-biden-climate-global-warming.html

7. Misbrener, K. U.S. Solar Energy Capacity Could Soon Overtake Wind Power. *Solar Power World.* November 28, 2023. Accessed from: U.S. solar energy capacity could soon overtake wind power (solarpowerworldonline.com)

8. Misbrener, K. U.S. Solar Energy Capacity Could Soon Overtake Wind Power. *Solar Power World.* November 28, 2023. Accessed from: U.S. solar energy capacity could soon overtake wind power (solarpowerworldonline.com)

9. Misbrener, K. U.S. Solar Energy Capacity Could Soon Overtake Wind Power. *Solar Power World.* November 28, 2023. Accessed from: U.S. solar energy capacity could soon overtake wind power (solarpowerworldonline.com)

10. U.S. Department of Energy. At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero. December 1, 2023. Accessed from: https://www.energy.gov/articles/cop28-countries-launch-declaration-triple-nuclear-energy-capacity-2050-recognizing-key

11. Snyder, A. A look back at the Shoreham nuclear plant protest, 40 years later. *The Suffolk Times.* June 3, 2019. Accessed from: https://suffolktimes.timesreview.com/2019/06/at-look-back-at-the-shoreham-nuclear-plant-protest-40-years-later/

12. Ritchie, H. How Long Does it Take to Build a Nuclear Reactor?. *Sustainability by Numbers.* April 3, 2023. Accessed from: https://www.sustainabilitybynumbers.com/p/nuclear-construction-time

13. U.S. Energy Information Administration. Annual Energy Outlook: AEO 2020. Access from: https://www.eia.gov/outlooks/aeo/pdf/AEO2023_Narrative.pdf

14. U.S. Energy Information Administration. Annual Energy Outlook: AEO 2020. Access from: https://www.eia.gov/outlooks/aeo/pdf/AEO2023_Narrative.pdf

15. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.1 New England. *suptab_2.1.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

16. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.2 Middle Atlantic. *suptab_2.2.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

17. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.3 East North Central. *suptab_2.3.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

18. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.4 West North Central. *suptab_2.4.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

19. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.5 South Atlantic. *suptab_2.5.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

20. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.6 East South Central. *suptab_2.6.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

21. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.7 West South Central. *suptab_2.7.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

22. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.8 Mountain. *suptab_2.8.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

23. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.9 Pacific. *suptab_2.9.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

24. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2 United States. *aeotab2.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

25. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.1 New England. *suptab_2.1.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

26. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.2 Middle Atlantic. *suptab_2.2.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

27. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.3 East North Central. *suptab_2.3.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

28. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.4 West North Central. *suptab_2.4.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

29. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.5 South Atlantic. *suptab_2.5.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

30. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.6 East South Central. *suptab_2.6.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

31. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.7 West South Central. *suptab_2.7.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

32. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.8 Mountain. *suptab_2.8.* Accessed from: https://www.eia.gov/outlooks/aeo/tables_ref.php

33. U.S. Energy Information Administration. Annual Energy Outlook 2023: Reference Case Projections Tables: Excel Sheet: Table 2.9 Pacific. *suptab_2.9.* Accessed from: Placeholder (EXCEL)

34. IEA 50. Data Centers and Data Transmissions Networks. Accessed from: https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks

35. OSTP (2022). Climate and Energy Implications of Crypto-Assets in the United States. White House Office of Science and Technology Policy. Washington, D.C. September 8, 2022. Accessed from: https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf

36. OSTP (2022). Climate and Energy Implications of Crypto-Assets in the United States. White House Office of Science and Technology Policy. Washington, D.C. September 8, 2022. Accessed from: https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf

37. Parsons, E., Hall, K., Waite, A., & Swank, W. What's Next for the Data Center: 2024 Trends to Watch. *Commscope.* 2023. Accessed from: 2024 Data Center Trends eBook by DCD Magazine- Issuu

38. Blood, M. R. California Insurance Market Rattled by Withdrawal of Major Companies. *Associated Press.* June 5, 2023. Accessed from: https://apnews.com/article/california-wildfire-insurance-e31bef0ed7eeddcde096a5b8f2c1768f

39. Center for Climate and Energy Solutions (C2ES). Drought and Climate Change: U.S. Drought Monitor. 2024. Accessed from: https://www.c2es.org/content/drought-and-climate-change/

40. U.S. Department of Energy. Inflation Reduction Act Keeps Momentum Building for Nuclear Power. September 8, 2022. Accessed from: https://www.energy.gov/ne/articles/inflation-reduction-act-keeps-momentum-building-nuclear-power

41. U.S. Department of the Treasury. Fact Sheet: How the Inflation Reduction Act's Tax Incentives are Ensuring All Americans Benefit from the Growth of the Clean Energy Economy. October 20, 2023. Accessed from: https://home.treasury.gov/news/press-releases/jy1830#:~:text=The%20Inflation%20Reduction%20Act%20modifies,proportion%20of%20qualified%20apprentices%20from

42. U.S. Department of the Treasury. Fact Sheet: How the Inflation Reduction Act's Tax Incentives are Ensuring All Americans Benefit from the Growth of the Clean Energy Economy. October 20, 2023. Accessed from: https://home.treasury.gov/news/press-releases/jy1830#:~:text=The%20Inflation%20Reduction%20Act%20modifies,proportion%20of%20qualified%20apprentices%20from

43. U.S. Department of the Treasury. Fact Sheet: How the Inflation Reduction Act's Tax Incentives are Ensuring All Americans Benefit from the Growth of the Clean Energy Economy. October 20, 2023. Accessed from: https://home.treasury.gov/news/press-releases/jy1830#:~:text=The%20Inflation%20Reduction%20Act%20modifies,proportion%20of%20qualified%20apprentices%20from

44. U.S. Department of Energy. Alternative Fuels Data Center: Clean Fuel Production Credit. Accessed from: Alternative Fuels Data Center: Clean Fuel Production Credit (energy.gov)

45. U.S. Department of Energy. Inflation Reduction Act Keeps Momentum Building for Nuclear Power. September 8, 2022. Accessed from: Inflation Reduction Act Keeps Momentum Building for Nuclear Power | Department of Energy

46. Congressional Research Service. The Section 45Q Tax Credit for Carbon Sequestration. August 25, 2023. Accessed from: IF11455 (congress.gov)

47. Ding, Y., Baldino, C., & Zhou, Y. Understanding the Proposed Guidance for the Inflation Reduction Act's Section 45V Clean Hydrogen Production Tax Credit. *The International Council on Clean Transportation*. Accessed from: Understanding the proposed guidance for the Inflation Reduction Act's Section 45V Clean Hydrogen Production Tax Credit- International Council on Clean Transportation (theicct.org)

48. Bricker Graydon. Inflation Reduction Act (IRA): Advanced Manufacturing Production Credit – A Cheat Sheet. May 3, 2023. Accessed from: Inflation Reduction Act (IRA): Advanced Manufacturing Product Credit – A cheat sheet (brickergraydon.com)

49. U.S. Department of Energy. Low-Income Communities Bonus Credit Program. Accessed from: Low-Income Communities Bonus Credit Program | Department of Energy

50. The White House. Executive Order of Ensuring Responsible Development of Digital Assets. March 9, 2022. Accessed from: Executive Order on Ensuring Responsible Development of Digital Assets | The White House

51. OSTP (2022). Climate and Energy Implications of Crypto-Assets in the United States. White House Office of Science and Technology Policy. Washington, D.C. September 8, 2022. Accessed from: https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf

52. OSTP (2022). Climate and Energy Implications of Crypto-Assets in the United States. White House Office of Science and Technology Policy. Washington, D.C. September 8, 2022. Accessed from: https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf

53. OSTP (2022). Climate and Energy Implications of Crypto-Assets in the United States. White House Office of Science and Technology Policy. Washington, D.C. September 8, 2022. Accessed from: https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf

54. Placement

55. National Conference of State Legislators. State Renewable Portfolio Standards and Goals. August 13, 2021. Accessed from: State Renewable Portfolio Standards and Goals (ncsl.org)

56. National Conference of State Legislators. State Renewable Portfolio Standards and Goals. August 13, 2021. Accessed from: State Renewable Portfolio Standards and Goals (ncsl.org)

57. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ny.* Accessed from: https://www.eia.gov/electricity/state/newyork/xls/ny.xlsx

58. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ma.* Accessed from: https://www.eia.gov/electricity/state/massachusetts/xls/ma.xlsx

59. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ca.* Accessed from: https://www.eia.gov/electricity/state/california/xls/ca.xlsx

60. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *tx.* Accessed from: https://www.eia.gov/electricity/state/texas/xls/tx.xlsx

61. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ne.* Accessed from: https://www.eia.gov/electricity/state/nebraska/xls/ne.xlsx

62. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ga.* Accessed from: https://www.eia.gov/electricity/state/georgia/xls/ga.xlsx

63. U.S. Energy Information Administration. State Profile and Energy Estimates: Texas. Accessed from: https://www.eia.gov/state/?sid=TX

64. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ny.* Accessed from: https://www.eia.gov/electricity/state/newyork/xls/ny.xlsx

65. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ma.* Accessed from: https://www.eia.gov/electricity/state/massachusetts/xls/ma.xlsx

66. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ca.* Accessed from: https://www.eia.gov/electricity/state/california/xls/ca.xlsx

67. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *tx.* Accessed from: https://www.eia.gov/electricity/state/texas/xls/tx.xlsx

68. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ne.* Accessed from: https://www.eia.gov/electricity/state/nebraska/xls/ne.xlsx

69. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ga.* Accessed from: https://www.eia.gov/electricity/state/georgia/xls/ga.xlsx

70. New York State Climate Action Council. (2022). Scoping Plan: Executive Summary. Accessed from: https://climate.ny.gov/resources/scoping-plan/

71. Massachusetts Executive Office of Energy and Environmental Affairs. (2022). Clean Energy and Climate Plan for 2050. Accessed from: https://www.mass.gov/doc/2050-clean-energy-and-climate-plan/download

72. Massachusetts Department of Energy Resources (DOER). Stretch Energy and Municipal Opt-In Specialized Building Code Frequently Asked Questions. Accessed from: https://www.mass.gov/doc/stretch-energy-and-municipal-opt-in-specialized-building-code-faq/download

73. Governor Gavin Newsom. California Releases World's First Plan to Achieve Net Zero Carbon Pollution. Accessed from: https://www.gov.ca.gov/2022/11/16/california-releases-worlds-first-plan-to-achieve-net-zero-carbon-pollution/

74. Governor Gavin Newsom. California Releases World's First Plan to Achieve Net Zero Carbon Pollution. Accessed from: https://www.gov.ca.gov/2022/11/16/california-releases-worlds-first-plan-to-achieve-net-zero-carbon-pollution/

75. California Legislative Information. SB-253 Climate Corporate Data Accountability Act (2023-2024). Accessed from: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB253

76. NC Clean Energy Technology Center. Database of State Incentives for Renewables & Efficiency: Programs: Texas. Accessed from: https://programs.dsireusa.org/system/program/tx

77. Nebraska Public Power District. NPPD Board Approves Net-Zero Carbon Goal by 2050

78. Nebraska Department of Environment and Energy. Nebraska Climate Pollution Reduction. Accessed from: http://dee.ne.gov/ndeqprog.nsf/onweb/cprg

79. Georgia Environmental Protection Division. Georgia Climate Pollution Reduction Grant. Accessed from: https://epd.georgia.gov/georgia-climate-pollution-reduction-grant

80. U.S. Environmental Protection Agency. Priority Climate Action Plans for States, MSAs, Tribes, and Territories. Accessed from: https://www.epa.gov/inflation-reduction-act/priority-climate-action-plans-states-msas-tribes-and-territories

81. Jones, E., & Mecke, M. (November 14, 2023). New Report: Georgia's Poor and Rural Communities Face Biggest Climate Risks. *WABE.* Accessed from: https://www.wabe.org/georgias-poor-and-rural-communities-face-biggest-climate-risks-new-report/

82. Crypto Altruism. Crypto vs. Climate Change – Tokenizing Carbon Sequestering Assets. Accessed from: Crypto vs. Climate Change – tokenizing carbon sequestering assets — Crypto Altruism

83. Global CCS Institute. CCS Explained: The Basics. Accessed from: CCS Explained: The Basics- Global CCS Institute

84. VERTIV. (2024). Rethinking Modern Data Center Design and Construction Trends. Accessed from: Vertiv-RethinkingModernDataCenterDesign.pdf (datacenterdynamics.com)

85. Falconer, R. NOAA: 2023 Worst Year on Record for Billion-Dollar Disasters. *AXIOS.* September 12, 2023. Accessed from: 2023 worst year on record for billion-dollar disasters, NOAA says (axios.com)

86. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

87. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

88. Uptime Institute. Annual Outage Analysis 2023. Accessed from: Annual Outage Analysis 2023- Uptime Institute

89. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

90. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

91. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

92. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

93. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

94. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

95. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

96. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

97. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

98. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

99. U.S. Department of Homeland Security. FEMA Flood Map Service Center: Hazus. Accessed from: FEMA Flood Map Service Center | Hazus

100. Allen-Dumas, R. M., KC, B., & Cunliff, C. (2019). Oak Ridge National Laboratory. Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods: ORNL/TM-2019/1252. Accessed From: oak-ridge-national-laboratory-response-grid-rfi (energy.gov)

101. Purtill, C. You're Gonna Need a Bigger Number: Scientists Consider a Category 6 for Mega-Hurricane Era. *Los Angeles Times.* April 26, 2024. Accessed from: Scientists debate adding a Category 6 for mega-hurricanes- Los Angeles Times (latimes.com)

102. Clifford, C. CNBC. Why it's so Hard to Build New Electrical Transmission Lines in the U.S.. February 21, 2023. Accessed from: Why it's so hard to add electrical transmission lines in the U.S. (cnbc.com)

103. Lydersen, K. Modernizing the Grid: Who Pays, Who Profits, Who Participates?. *Energy News Network.* April 7, 2017. Accessed from: Modernizing the grid: Who pays, who profits, who participates? | Energy News Network

104. U.S. Federal Energy Regulatory Commission. FERC Takes on Long-Term Planning with Historic Transmission Rule. May 13, 2024. Accessed from: https://www.ferc.gov/news-events/news/ferc-takes-long-term-planning-historic-transmission-rule

105. U.S. Department of Energy. National Transmission Needs Study. October 2023. Accessed from: National Transmission Needs Study (energy.gov)

106. U.S. Department of Energy. National Transmission Needs Study. October 2023. Accessed from: National Transmission Needs Study (energy.gov)

107. U.S. Department of Energy. National Transmission Needs Study. October 2023. Accessed from: National Transmission Needs Study (energy.gov)

108. U.S. Department of Energy. National Transmission Needs Study. October 2023. Accessed from: National Transmission Needs Study (energy.gov)

109. Butler, G. Grid Interconnection Queues Grew 27% in 2023, says DOE Lab. *Data Center Dynamics.* April 24, 2024. Accessed from: Grid interconnection queues grew 27% in 2023, says DOE lab- DCD (datacenterdynamics.com)

110. Rand, J., Manderlink, N., Gorman, W., Wise, R., Seel, J., Kemp, J. M., Jeong, S., & Kahrl, F. (2024). Queued Up: 2024 Edition Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2023. Accessed from: PowerPoint Presentation (lbl.gov)

111. Penrod, E. US Grid Interconnection Backlog Jumps 40%, with Wait Times Expected to Grow as IRA Spurs More Renewables. *Utility Dive.* April 11, 2023. Accessed from: US grid interconnection backlog jumps 40%, with wait times expected to grow as IRA spurs more renewables | Utility Dive

112. Penrod, E. US Grid Interconnection Backlog Jumps 40%, with Wait Times Expected to Grow as IRA Spurs More Renewables. *Utility Dive.* April 11, 2023. Accessed from: US grid interconnection backlog jumps 40%, with wait times expected to grow as IRA spurs more renewables | Utility Dive

113. Western Electricity Coordinating Council (WECC). The Bulk-Power System: Background. Accessed from: The Bulk-Power System (wecc.org)

114. North American Electric Reliability Corporation (NERC). Reliability Coordinators. Accessed from: https://www.nerc.com/pa/rrm/bpsa/Pages/RCs.aspx

115. U.S. Federal Energy Regulatory Commission. RTOs and ISOs. Accessed from: https://www.ferc.gov/power-sales-and-markets/rtos-and-isos

116. U.S. Federal Energy Regulatory Commission. An Introductory Guide to Electricity Markets Regulated by the Federal Energy Regulatory Commission. April 25, 2024. Accessed from: An Introductory Guide to Electricity Markets regulated by the Federal Energy Regulatory Commission | Federal Energy Regulatory Commission (ferc.gov)

117. Energy KnowledgeBase. Independent System Operator (ISO). Accessed from: Independent System Operator (ISO) · Energy KnowledgeBase

118. U.S. Department of Energy. How it Works: The Role of a Balancing Authority. Accessed from: https://www.energy.gov/sites/default/files/2023-08/Balancing%20Authority%20Backgrounder_2022-Formatted_041723_508.pdf

119. SPP Southwest Power Pool. Operating Reliability. Accessed from: Operating Reliability- Southwest Power Pool (spp.org)

120. National Renewable Energy Lab. Renewable Energy System Interconnection Standards. Accessed from: Renewable Energy System Interconnection Standards | State, Local, and Tribal Governments | NREL

121. National Renewable Energy Lab. Renewable Energy System Interconnection Standards. Accessed from: Renewable Energy System Interconnection Standards | State, Local, and Tribal Governments | NREL

122. North American Electric Reliability Corporation. Reliability Guideline: Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018. Accessed from: NERC Reliability Guideline Template

123. McAllister, R., Manning, D., Bird, L., Coddington, M., & Volpi, C. (2019). New Approaches to Distributed PV Interconnection: Implementation Considerations for Addressing Emerging Issues. *National Renewable Energy Lab.* Accessed from: New Approaches to Distributed PV Interconnection: Implementation Considerations for Addressing Emerging Issues (nrel.gov)

124. U.S. Department of Energy. (2015) Wind Vision: A New Era for Wind Power in the United States: DOE/GO-102015-4556. Accessed from: WindVision_Report_final.pdf (energy.gov)

125. French, M. J. Sticker Shock Awaits New Yorkers' Utility Bills to Fund Renewables. *Politico.* March 20, 2023. Accessed from: https://www.politico.com/news/2023/03/20/new-york-utilities-costs-00086572

126. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ny.* Accessed from: https://www.eia.gov/electricity/state/newyork/xls/ny.xlsx

127. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ma.* Accessed from: https://www.eia.gov/electricity/state/massachusetts/xls/ma.xlsx

128. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ca.* Accessed from: https://www.eia.gov/electricity/state/california/xls/ca.xlsx

129. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *tx.* Accessed from: https://www.eia.gov/electricity/state/texas/xls/tx.xlsx

130. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ne.* Accessed from: https://www.eia.gov/electricity/state/nebraska/xls/ne.xlsx

131. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ga.* Accessed from: https://www.eia.gov/electricity/state/georgia/xls/ga.xlsx

132. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ny.* Accessed from: https://www.eia.gov/electricity/state/newyork/xls/ny.xlsx

133. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ma.* Accessed from: https://www.eia.gov/electricity/state/massachusetts/xls/ma.xlsx

134. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ca.* Accessed from: https://www.eia.gov/electricity/state/california/xls/ca.xlsx

135. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *tx.* Accessed from: https://www.eia.gov/electricity/state/texas/xls/tx.xlsx

136. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ne.* Accessed from: https://www.eia.gov/electricity/state/nebraska/xls/ne.xlsx

137. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ga.* Accessed from: https://www.eia.gov/electricity/state/georgia/xls/ga.xlsx

138. Kenward, A., & Raja, U. (2014). Blackout: Extreme Weather, Climate Change and Power Outages. *Climate Central.* Accessed from: https://assets.climatecentral.org/pdfs/PowerOutages.pdf

139. Ware, G. *The Conversation.* Power Outages Linked to Heat and Storms and Rising, and Low-Income Communities are Most at Risk. (May 1, 2024). Accessed from: https://theconversation.com/power-outages-linked-to-heat-and-storms-are-rising-and-low-income-communities-are-most-at-risk-228778#:~:text=Many%20Americans%20think%20of%20power,storms%20as%20the%20planet%20warms.

140. Climate Central. Weather-related Power Outages Rising. (April 24, 2024). Accessed from: Weather-related Power Outages Rising | Climate Central

141. Climate Central. Weather-related Power Outages Rising. (April 24, 2024). Accessed from: Weather-related Power Outages Rising | Climate Central

142. U.S. Department of Energy. National Transmission Needs Study. October 2023. Accessed from: National Transmission Needs Study (energy.gov)

143. Powell, C., & Statler, A. FERC's New Interconnection Rule Modernizes the Process to Bring Clean Energy Online. *Earth Justice.* (August 28, 2023). Accessed from: FERC's New Interconnection Rule Modernizes the Process to Bring Clean Energy Online- Earthjustice

144. U.S. Department of Energy. Data Centers and Servers: Buildings. Accessed from: Data Centers and Servers | Department of Energy

145. Rareshide, M. Power in the Data Center and its Cost Across the U.S. *Site Selection Group.* (October 23, 2017). Accessed from: Power in the Data Center and its Cost Across the U.S. (siteselectiongroup.com)

146. U.S. Energy Information Agency. Electricity Explained: Factors Affecting Electricity Prices. (Last updated: June 29, 2023). Accessed from: Prices and factors affecting prices- U.S. Energy Information Administration (EIA)

147. U.S. Energy Information Agency. Electricity Explained: Factors Affecting Electricity Prices. (Last updated: June 29, 2023). Accessed from: Prices and factors affecting prices- U.S. Energy Information Administration (EIA)

148. Narayanan, R. Why Are New England's Electricity Prices so Expensive?: The Answer Boils down to Our Over-Dependence on Fossil Fuels. *Conservation Law Foundation.* (March 15, 2024). Accessed from: Why Are New England's Electricity Prices So Expensive?- Conservation Law Foundation (clf.org)

149. Schmitt, M. How Much Does it Cost to Power One Rack in a Data Center. *Nlyte Software.* (July 27, 2021). Accessed from: How Much Does it Cost to Power One Rack in a Data Center? | Nlyte

150. Benetton, M., Compiani, G., & Morse, A. (2023). When Cryptomining Comes to Town: High Electricity-use Spillovers to the Local Economy. *Becker Friedman Institute.* Accessed from: BFI_WP_2023-78.pdf (uchicago.edu)

151. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ny.* Accessed from: https://www.eia.gov/electricity/state/newyork/xls/ny.xlsx

152. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ma.* Accessed from: https://www.eia.gov/electricity/state/massachusetts/xls/ma.xlsx

153. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ca.* Accessed from: https://www.eia.gov/electricity/state/california/xls/ca.xlsx

154. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *tx.* Accessed from: https://www.eia.gov/electricity/state/texas/xls/tx.xlsx

155. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ne.* Accessed from: https://www.eia.gov/electricity/state/nebraska/xls/ne.xlsx

156. U.S. Energy Information Administration. (2022). Excel Sheet: State Electricity Profiles: Full Data Tables 1-17: *ga.* Accessed from: https://www.eia.gov/electricity/state/georgia/xls/ga.xlsx

157. National Renewable Energy Lab. Energy Analysis: Simple Levelized Cost of Energy (LCOE) Calculator Documentation. Accessed from: Simple Levelized Cost of Energy (LCOE) Calculator Documentation | Energy Analysis | NREL

158. National Renewable Energy Lab. SLOPE State and Local Planning for Energy. Accessed from: https://maps.nrel.gov/slope/data-viewer?filters=%5B%5D&layer=stdscen23.mid-case&year=2030&res=state

159. National Renewable Energy Lab. SLOPE State and Local Planning for Energy. Accessed from: https://maps.nrel.gov/slope/data-viewer?filters=%5B%5D&layer=stdscen23.mid-case&year=2030&res=state

160. National Renewable Energy Lab. SLOPE State and Local Planning for Energy. Accessed from: https://maps.nrel.gov/slope/data-viewer?filters=%5B%5D&layer=stdscen23.mid-case&year=2030&res=state

161. *Data Center Sales and Marketing Institute.* 20 Data Center Site Selection Best Practices. Accessed from: https://www.dcsmi.com/data-center-sales-and-marketing-blog/20-data-center-site-selection-best-practices

162. Jones, E., & Mecke, M. (November 14, 2023). New Report: Georgia's Poor and Rural Communities Face Biggest Climate Risks. *WABE.* Accessed from: https://www.wabe.org/georgias-poor-and-rural-communities-face-biggest-climate-risks-new-report/

163. Kann, D. (November 14, 2023). Report: Georgia, Southeast among the most at-risk from climate change. *The Atlantic Journal-Constitution.* Accessed from: Report: Georgia, Southeast among the most at-risk from climate change (ajc.com)

164. Nebraska Department of Environment and Energy. Nebraska Climate Pollution Reduction. Accessed from: http://dee.ne.gov/ndeqprog.nsf/onweb/cprg

165. U.S. Energy Information Administration. Electricity Data Browser. Accessed from: Electricity data browser- Net generation for all sectors (eia.gov)

166. National Renewable Energy Lab. Solar Resource Maps and Data. Accessed from: Solar Resource Maps and Data | Geospatial Data Science | NREL

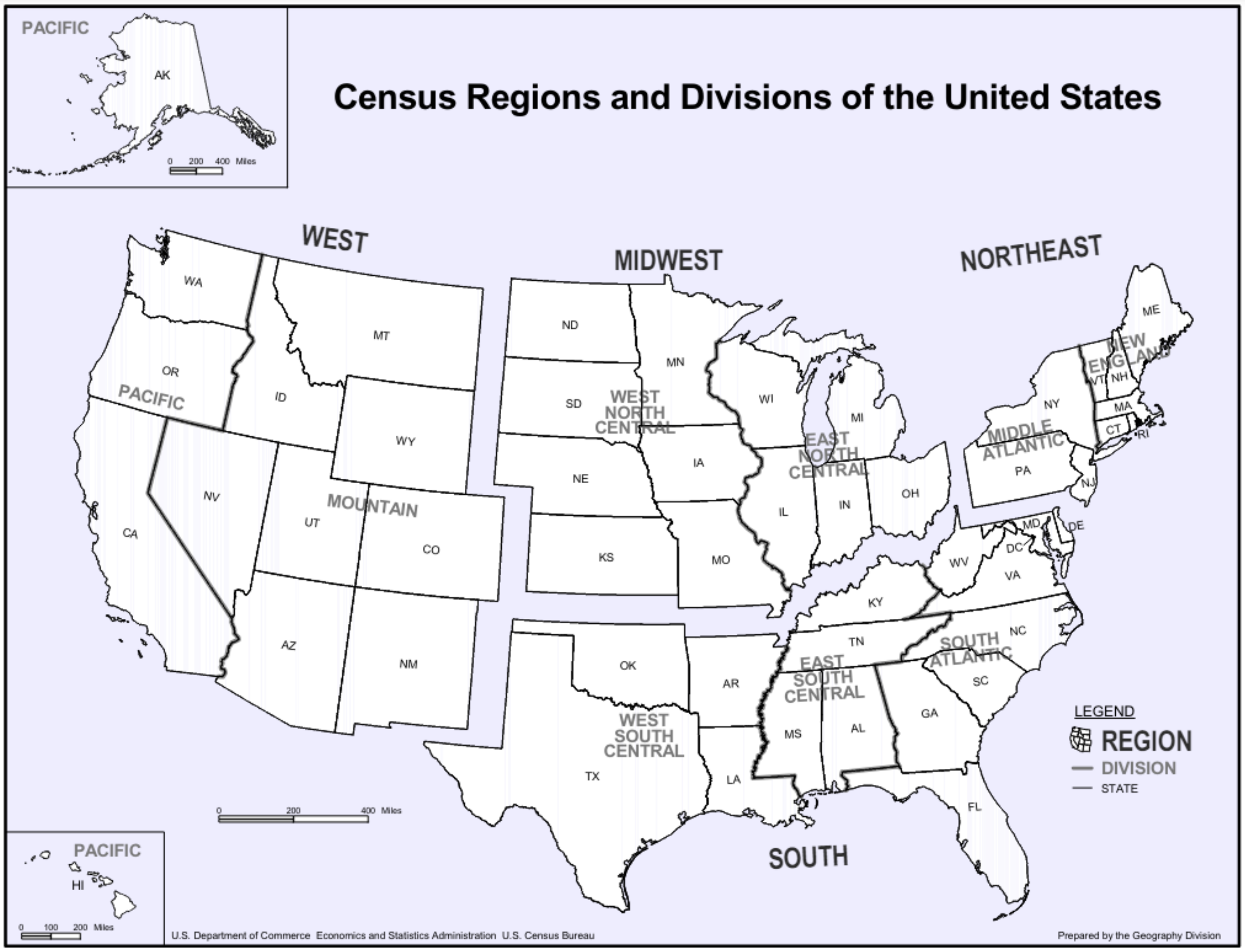
167. Lopez, A., Roberts, B., Heimiller, D., Blair, N., & Porro, G. (2012). U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. *National Renewable Energy Laboratory.* Accessed from: U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis (nrel.gov)

168. National Renewable Energy Lab. SLOPE State and Local Planning for Energy. Accessed from: https://maps.nrel.gov/slope/data-viewer?filters=%5B%5D&layer=stdscen23.mid-case&year=2030&res=state

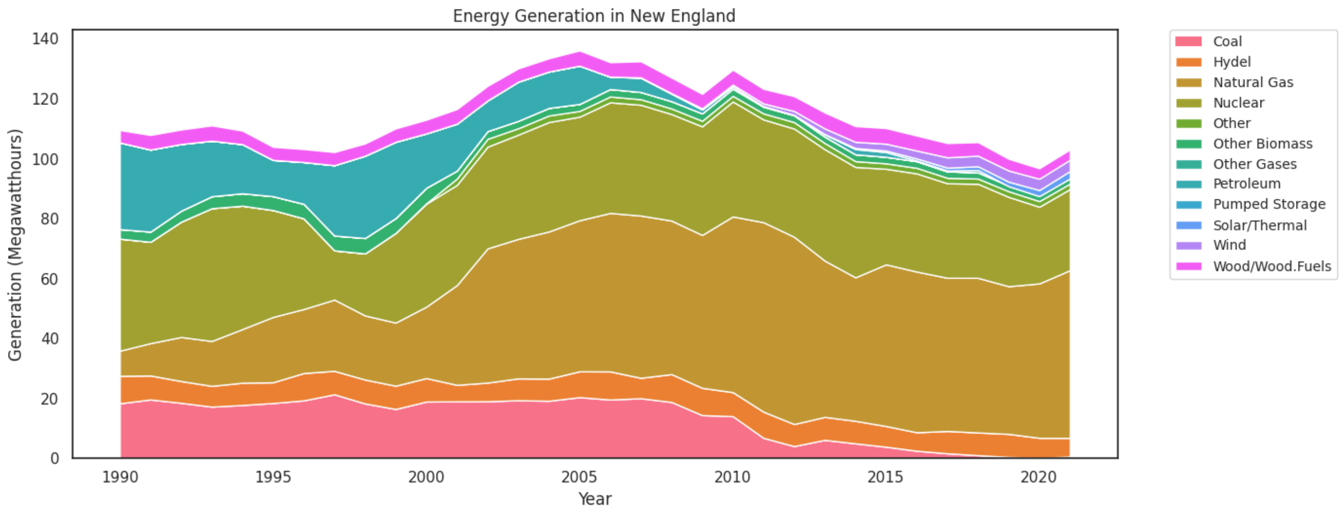
169. Office of Governor Gavin Newsom. (2023). Building the Electricity Grid of the Future: California's Clean Energy Transition Plan. Accessed from: Building the Electricity Grid of the Future: California's Clean Energy Transition Plan

170. U.S. Energy Information Administration. US Electricity Profile 2022. Accessed from: US Electricity Profile 2022- U.S. Energy Information Administration (EIA)

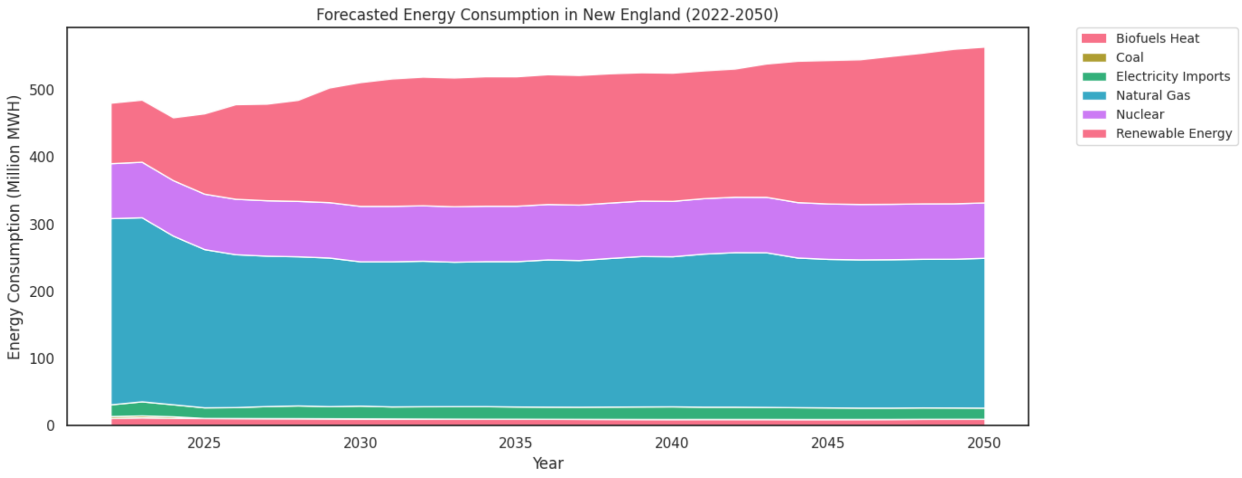
APPENDICES



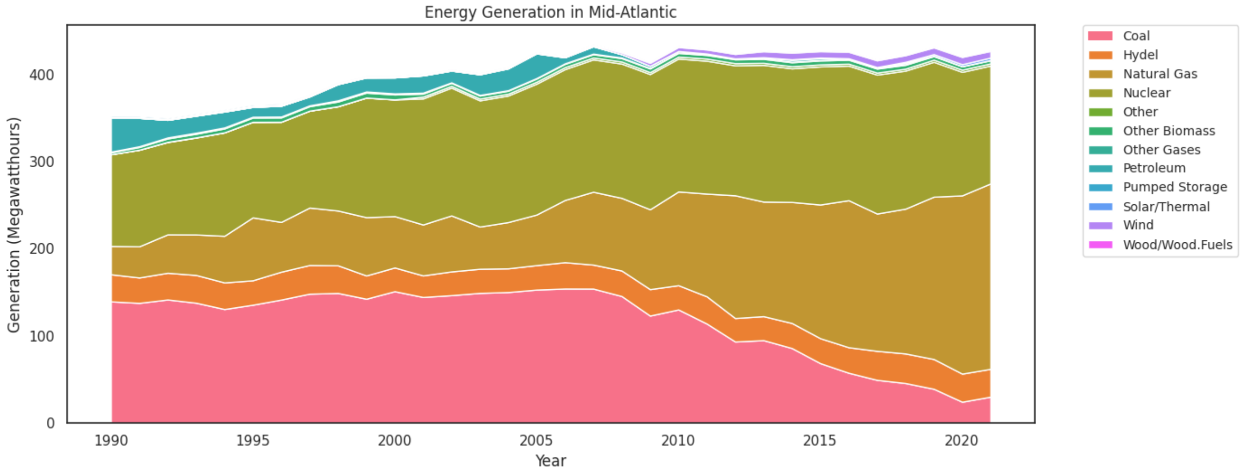
Appendix A. U.S. Census Regions as Designated by U.S. Department of Commerce, Economics and Statistics Administration, and U.S Census Bureau. (Source).



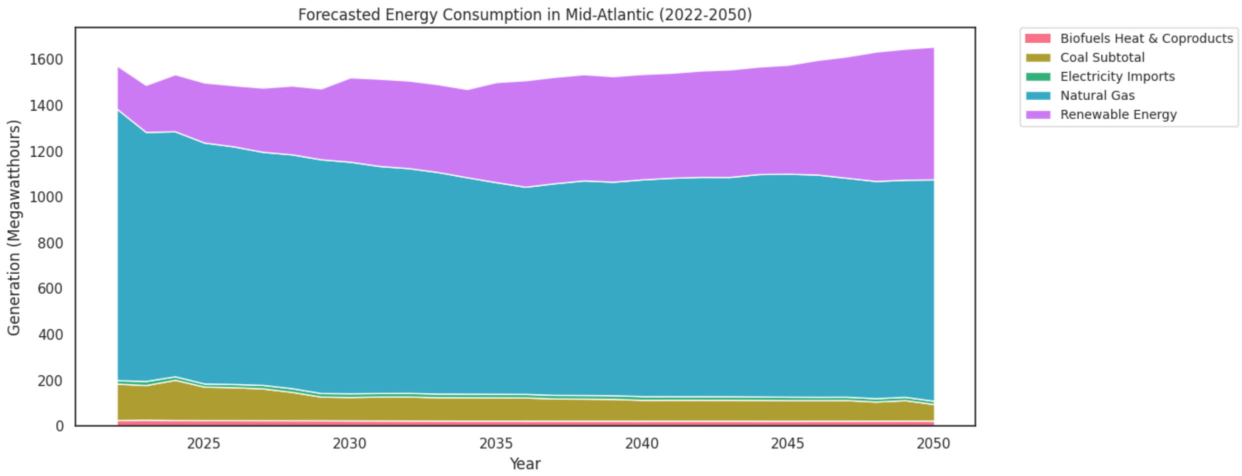
Appendix B. Energy Generation in New England 1990 to 2020



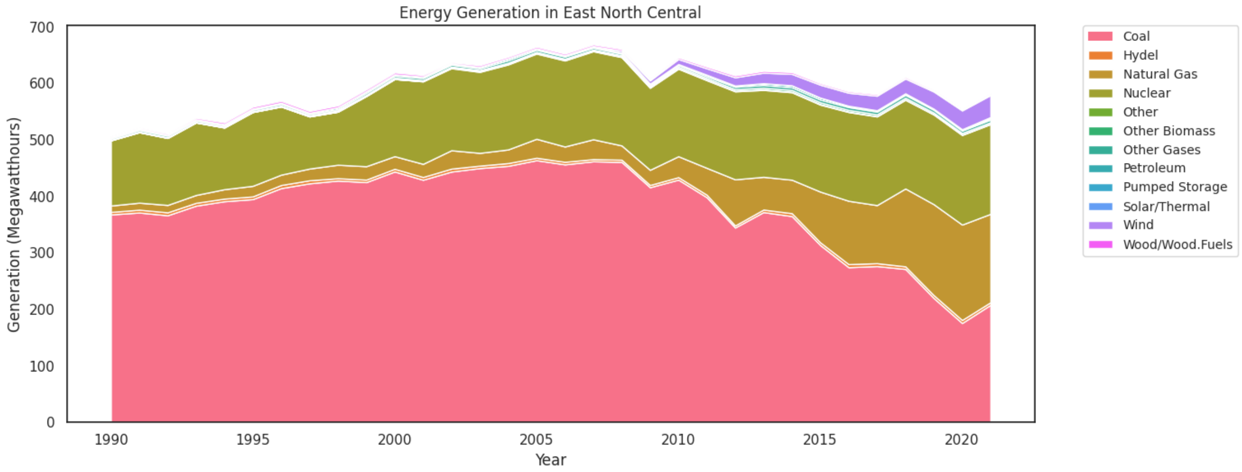
Appendix C. Forecasted Energy Consumption in New England (2022-2050)



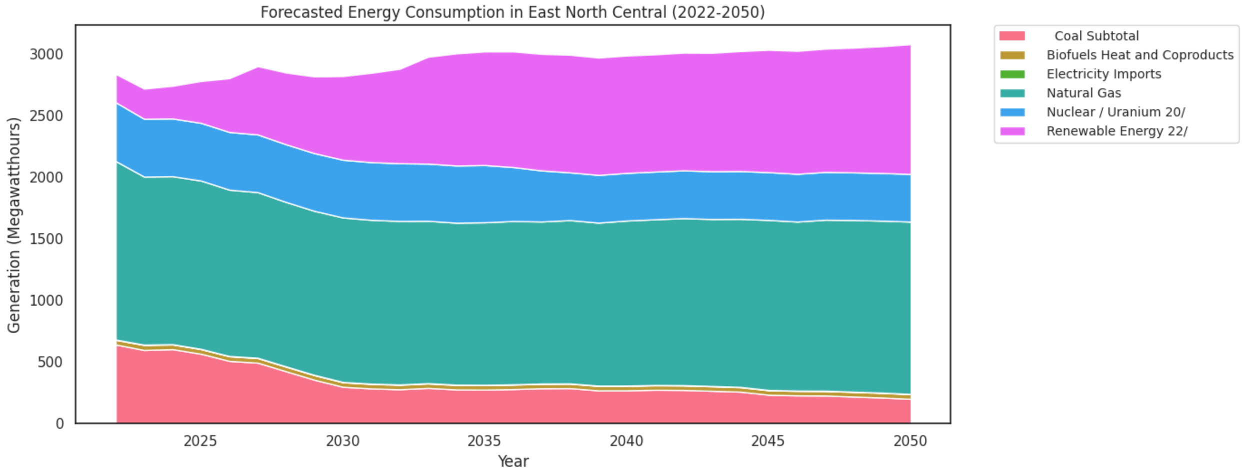
Appendix D. Energy Generation in Mid-Atlantic 1990 to 2020



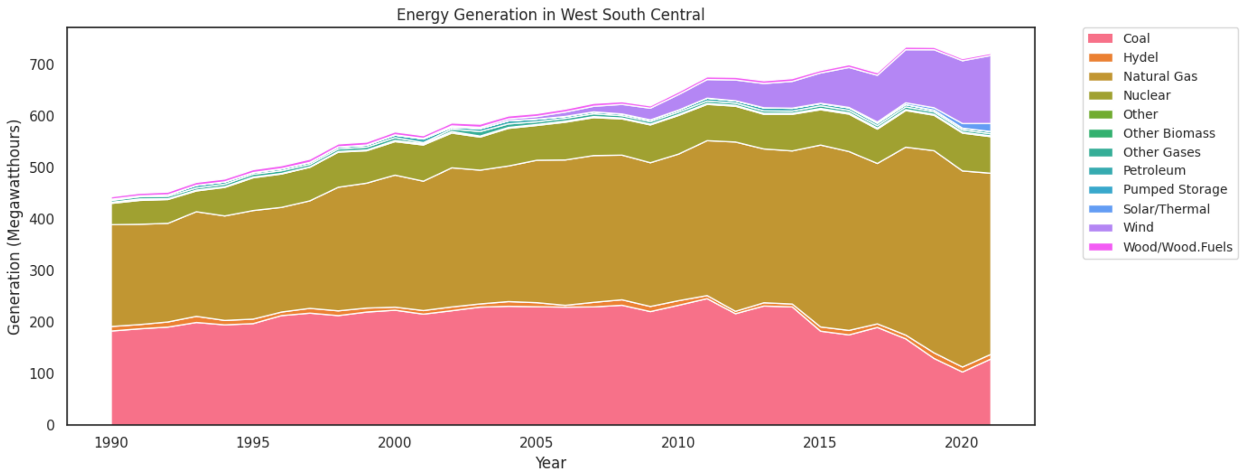
Appendix E. Forecasted Energy Consumption in Mid-Atlantic (2022-2050)



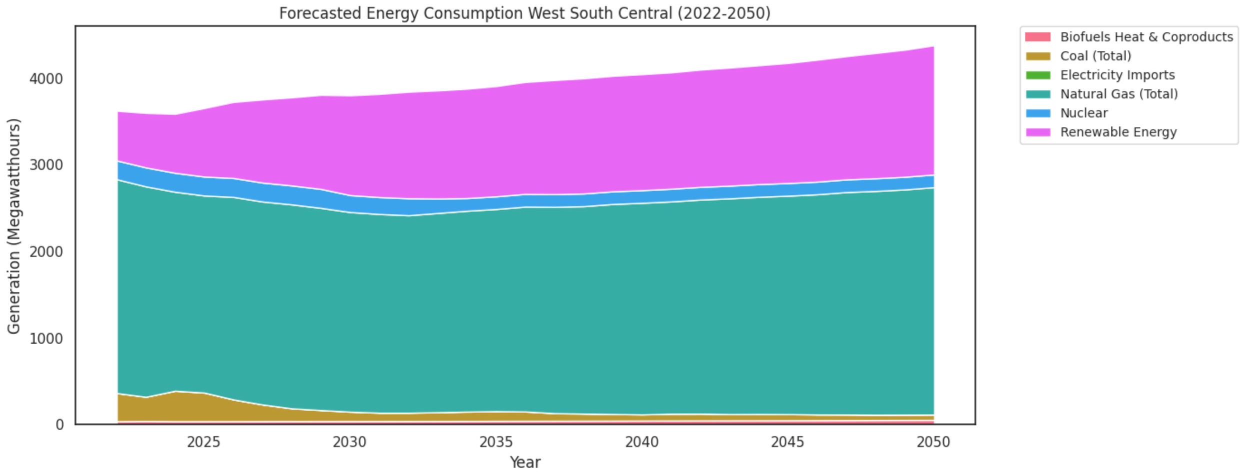
Appendix F. Energy Generation in East North Central 1990 to 2020



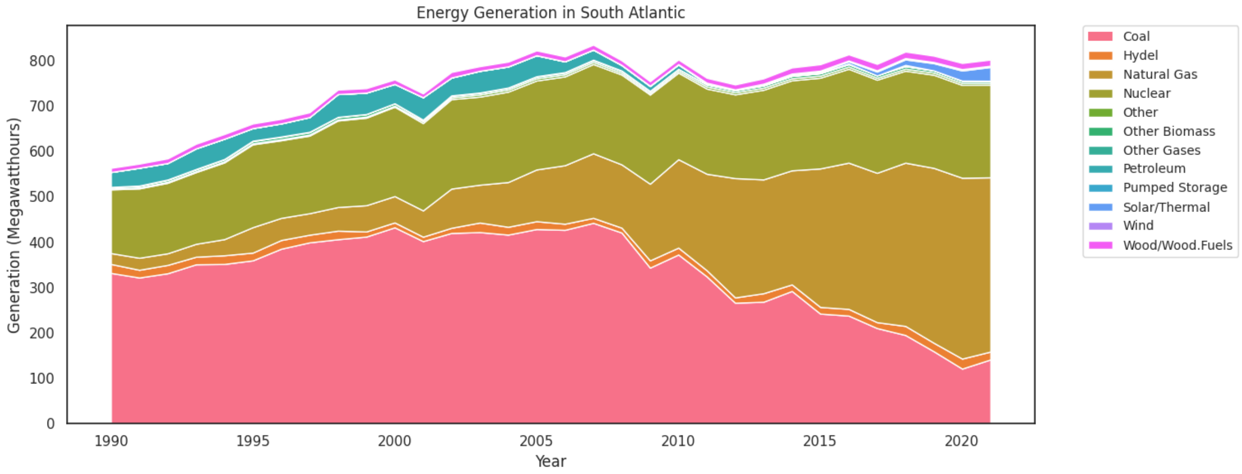
Appendix G. Forecasted Energy Consumption in East North Central (2022-2050)



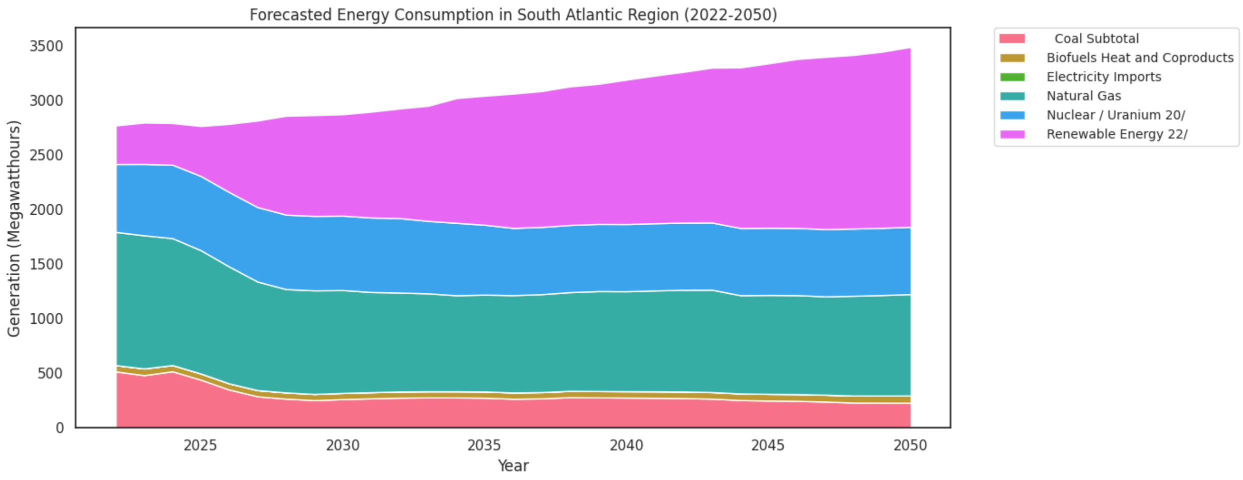
Appendix H. Energy Generation in West South Central 1990 to 2020



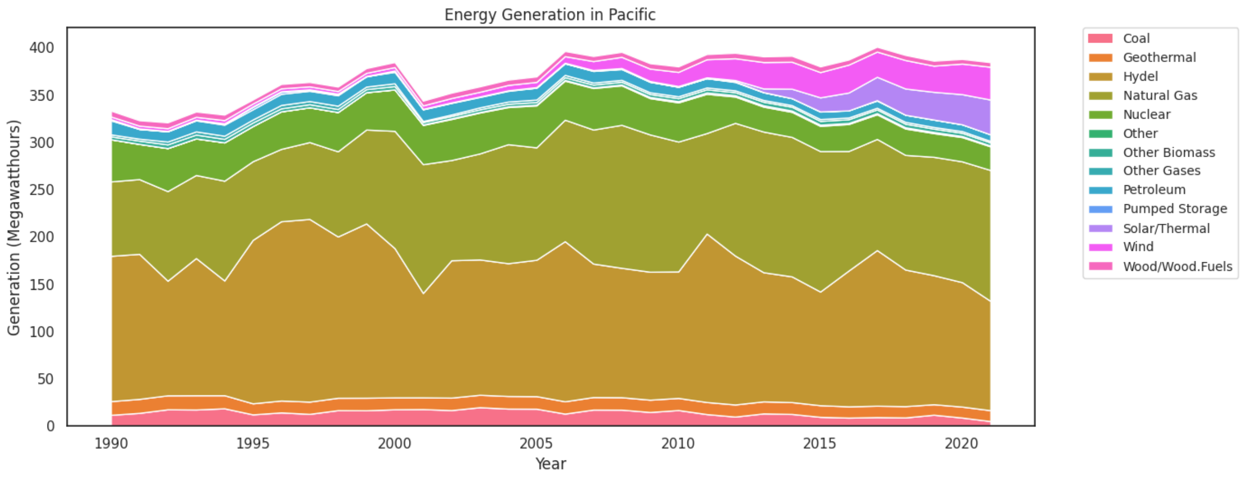
Appendix I. Forecasted Energy Consumption West South Central (2022-2050)



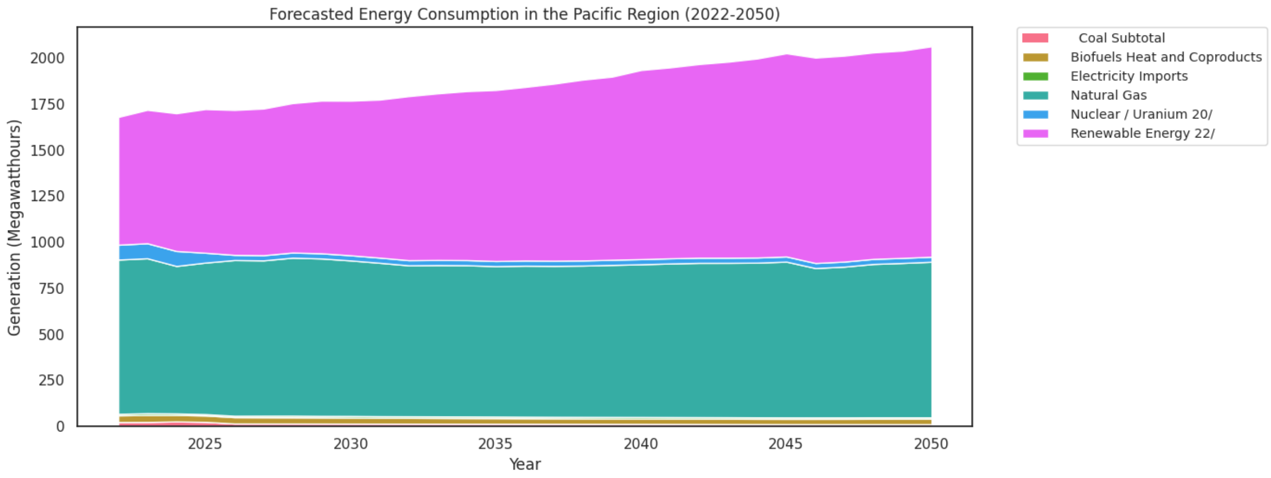
Appendix J. Energy Generation in South Atlantic 1990 to 2020



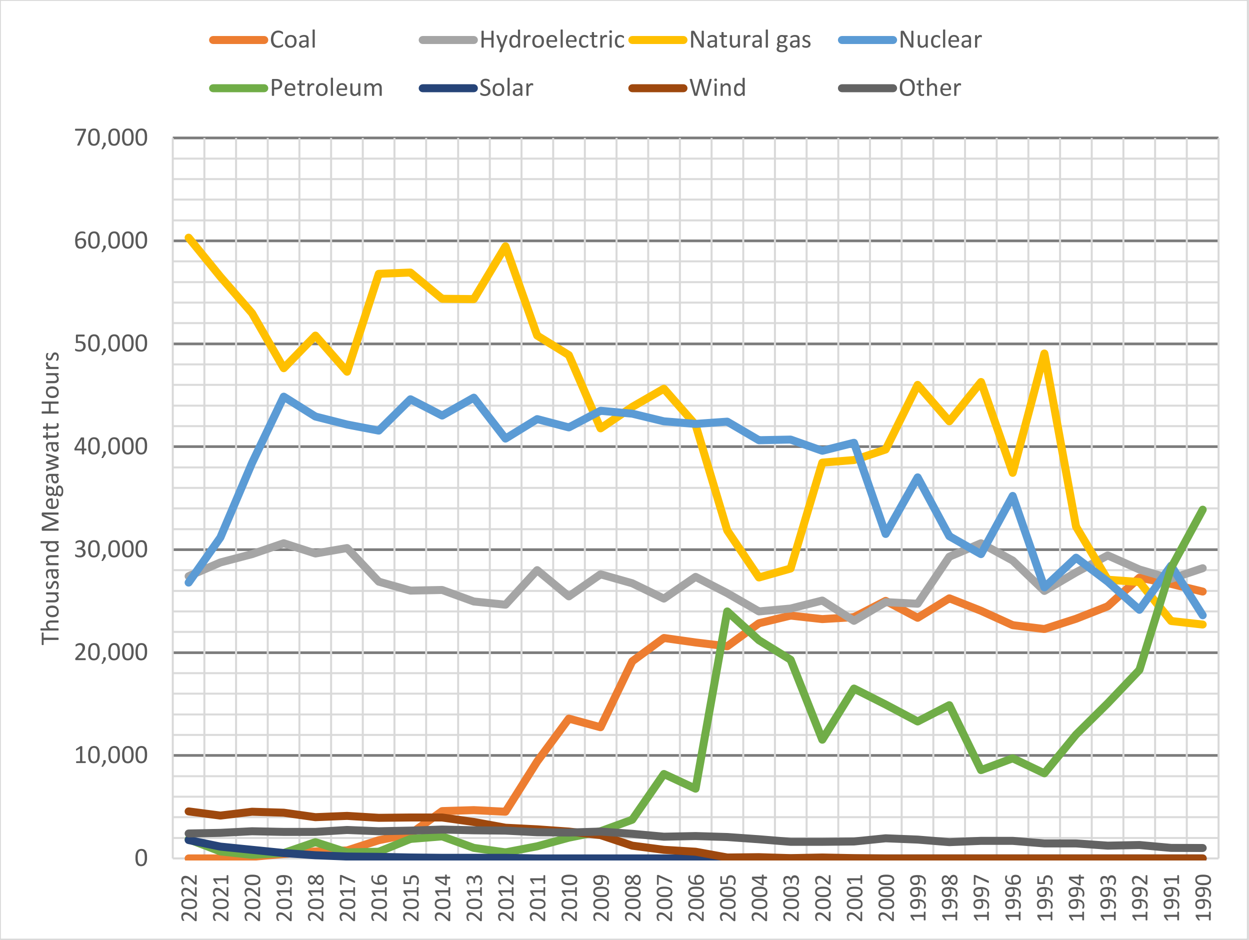
Appendix K. Forecasted Energy Consumption in South Atlantic Region (2022-2050)



Appendix L. Energy Generation in Pacific

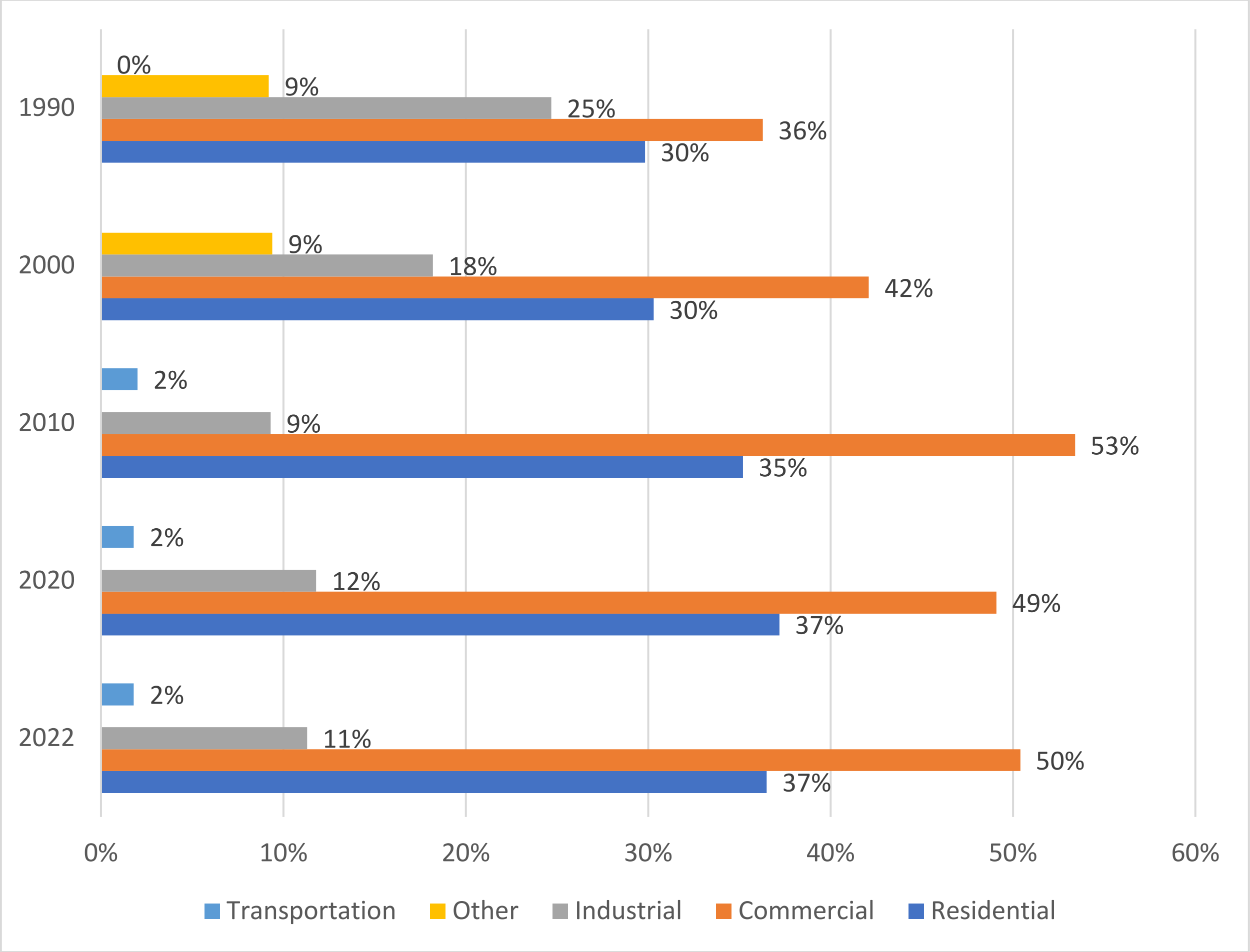


Appendix M. Forecasted Energy Consumption in the Pacific Region (2022-2050)

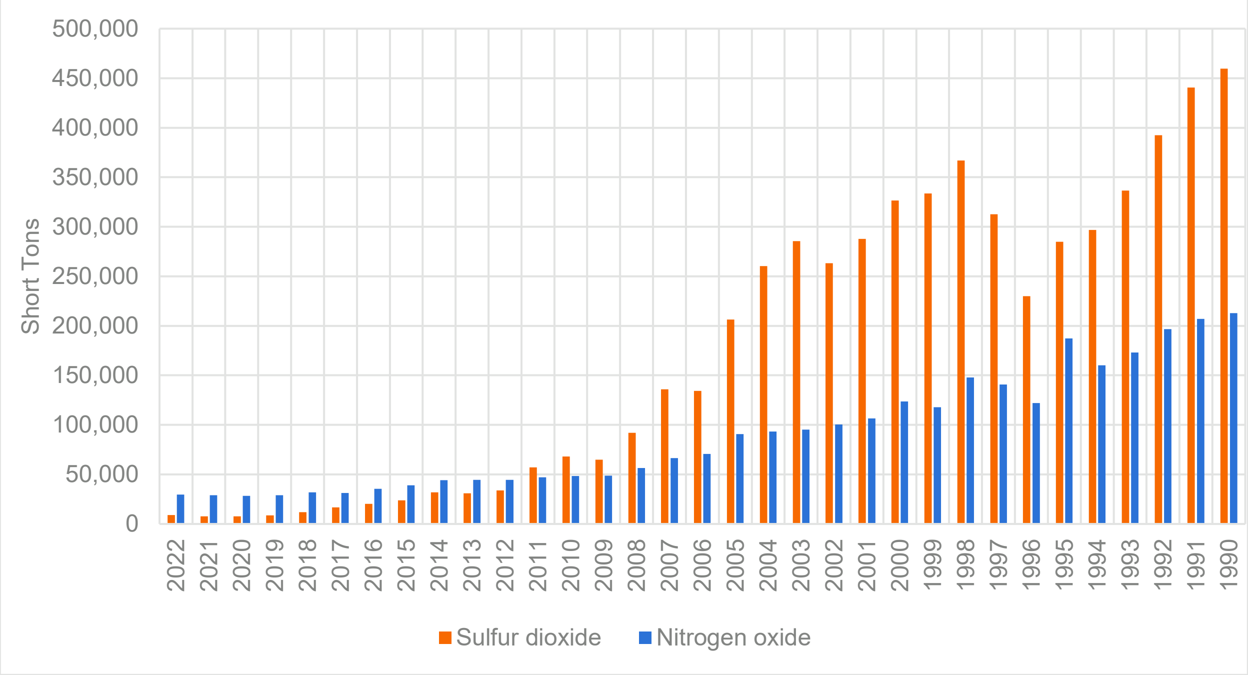


Appendix N. New York State Electric Power Industry Generation by Primary Energy Source, 1990-2020. *Source*: EIA ;

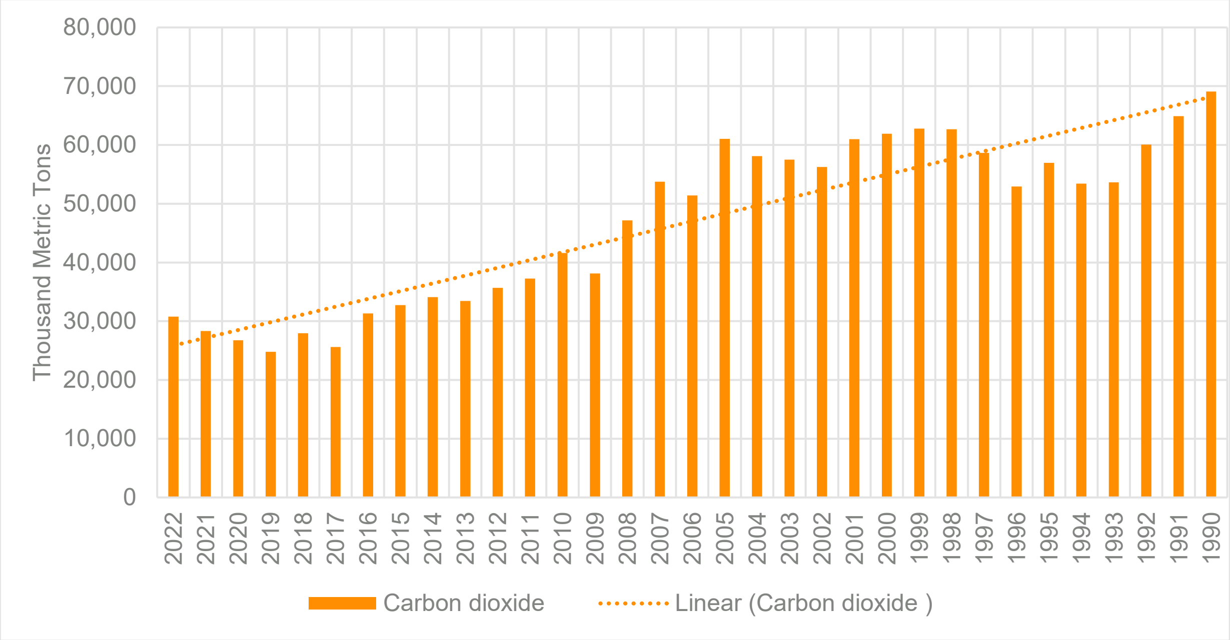
* Note: “Other” includes: “Battery, Other, Other Biomass, Other Gas, Pumped Storage, & Wood”



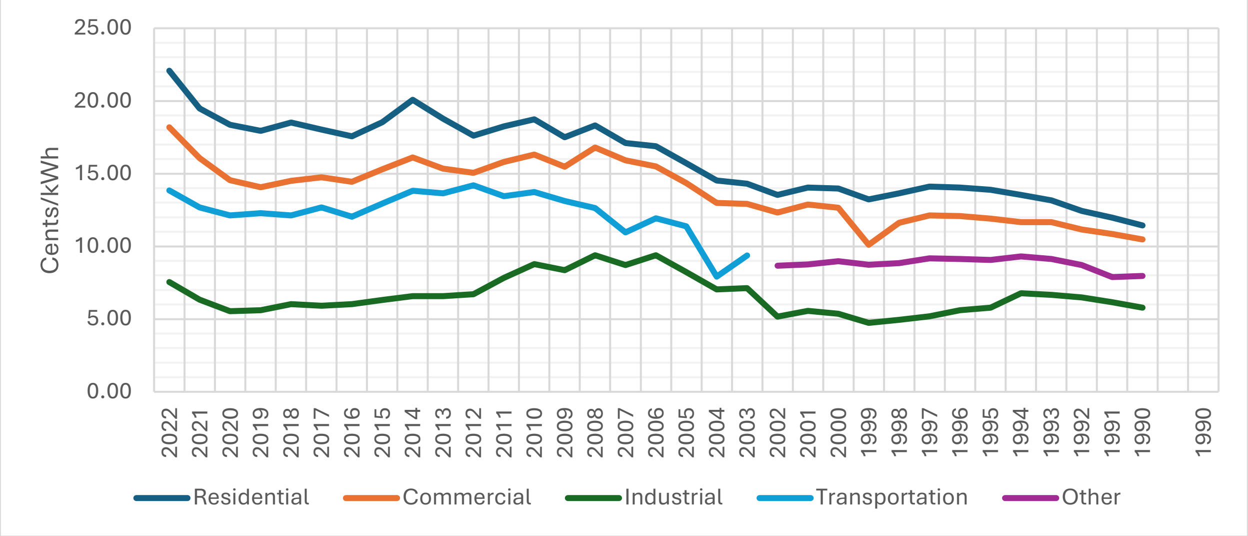
Appendix O. New York State Electric Power Industry Generation by Primary Energy Source, 1990-2020. *Source*: EIA ;



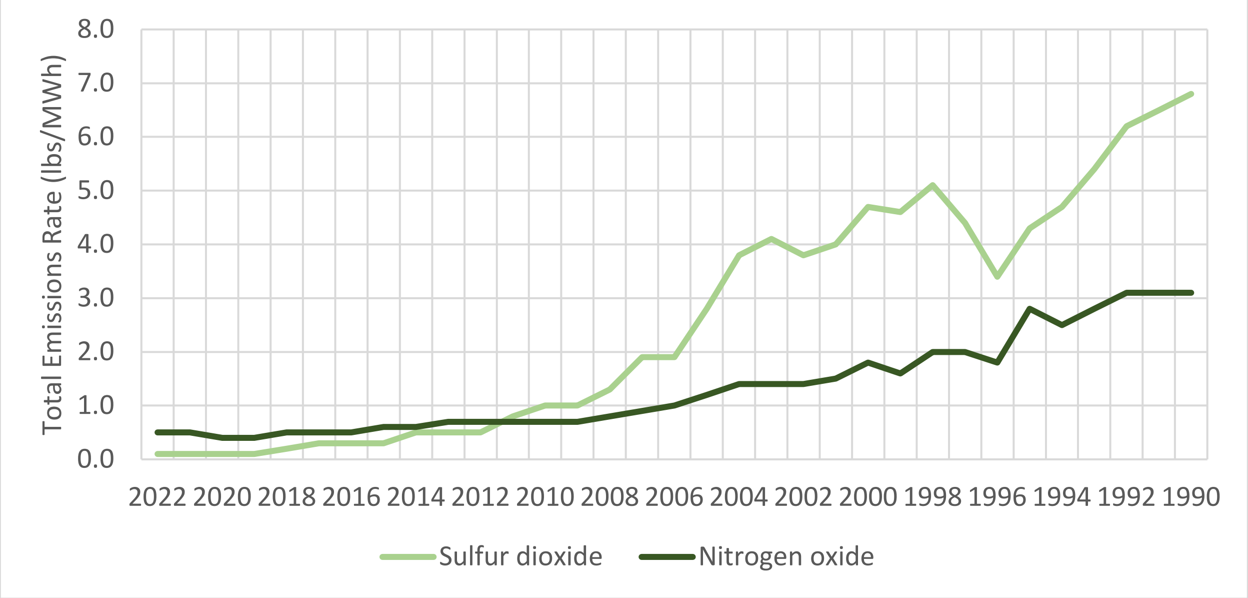
Appendix P. New York State Electric Power Generation Sulfur Dioxide and Nitrogen Oxide Emissions, 1990-2020. *Source*: EIA ;



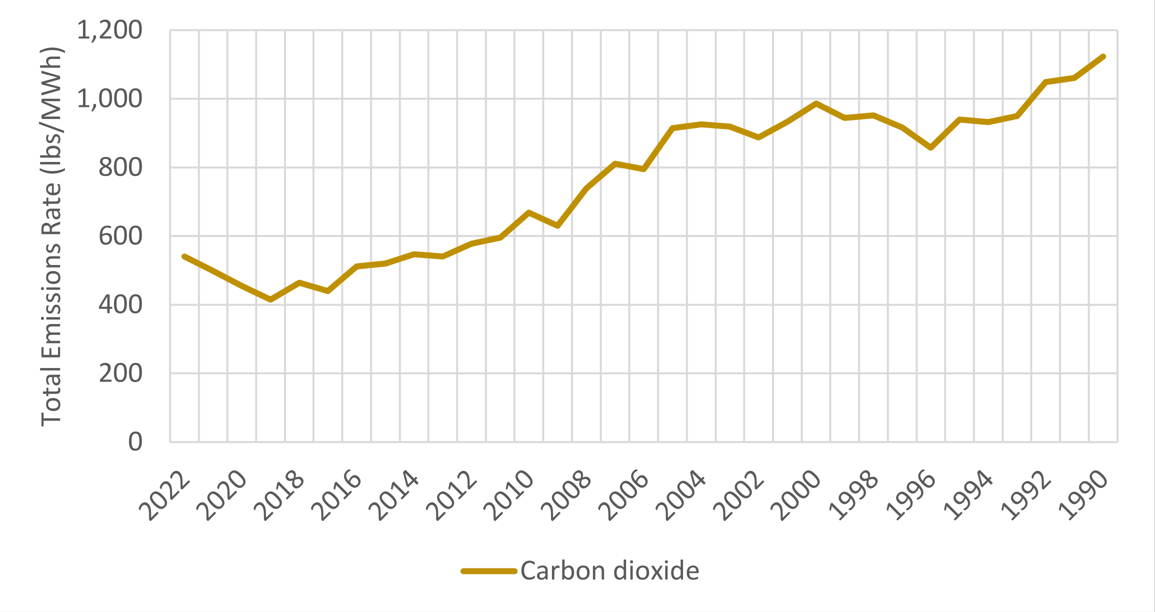
Appendix Q. New York State Electric Power Generation Carbon Dioxide Emissions, 1990-2020. *Source*: EIA ;



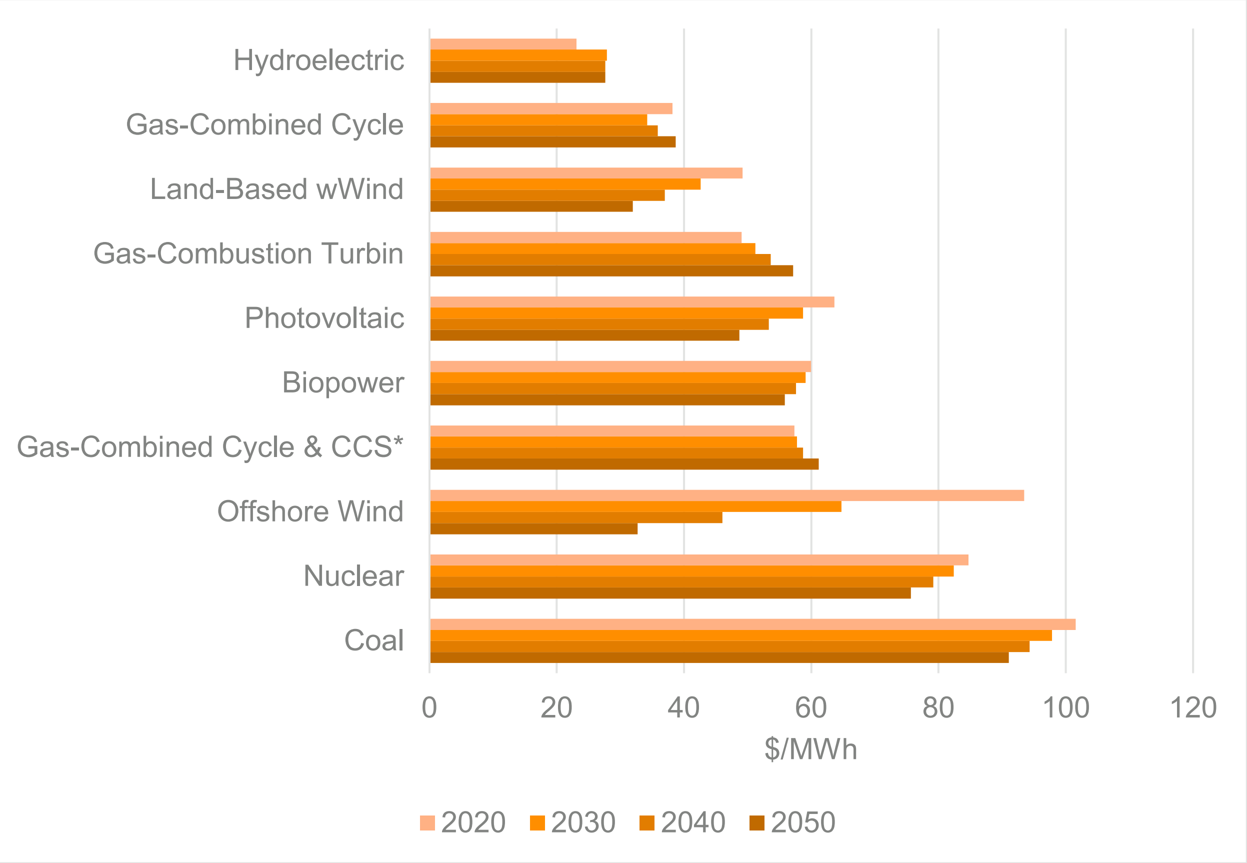
Appendix R. New York State Electric Power Average Price by Primary Source in U.S. Cents Per Megawatt hours, 1990-2022. *Source*: EIA



Appendix S. New York Electric Power Industry lbs. of Emissions per Megawatt hour: Sulfur Dioxide and Nitrogen Oxide Emissions, 1990-2022. *Source*: EIA

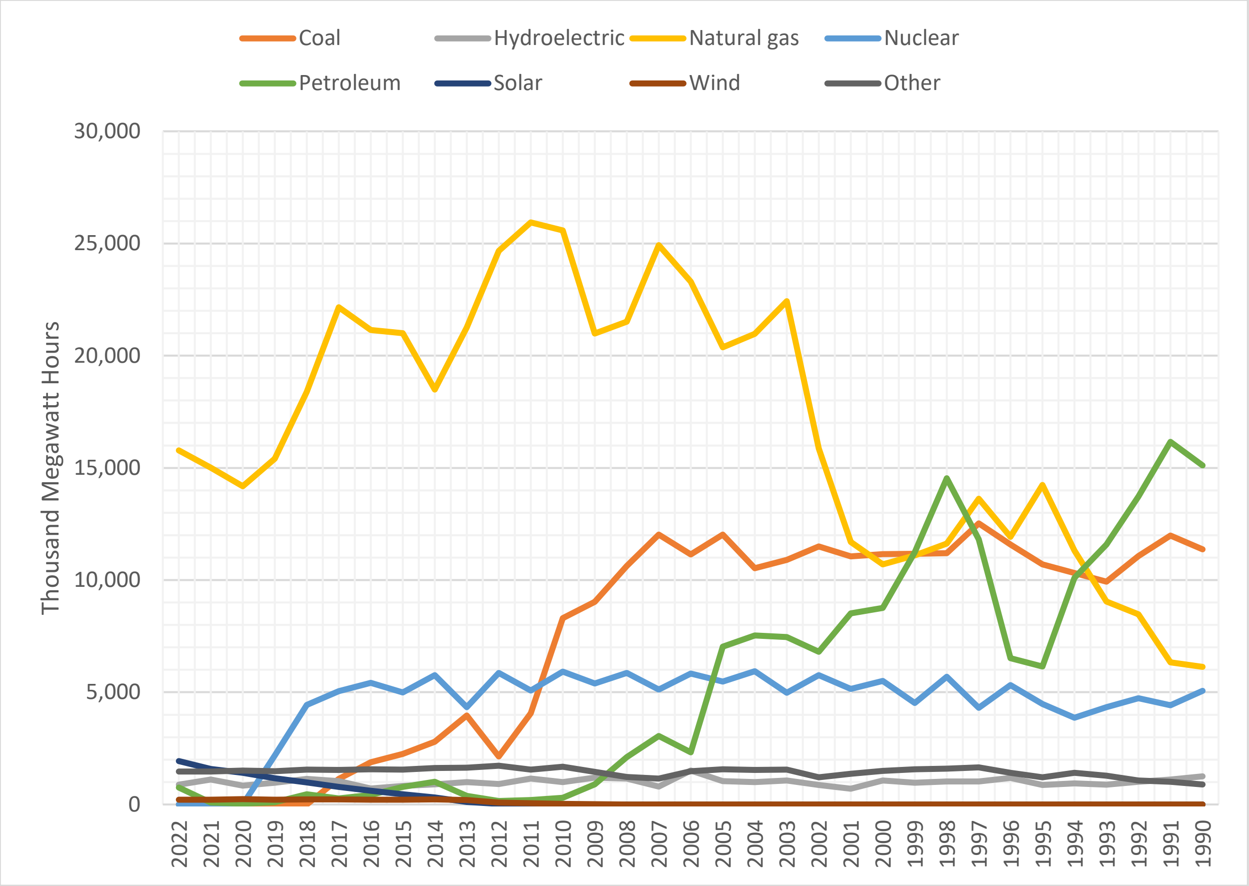


Appendix T. New York Electric Power Industry lbs. of Emissions per Megawatt hour: Carbon Dioxide Emissions, 1990-2022. *Source*: EIA



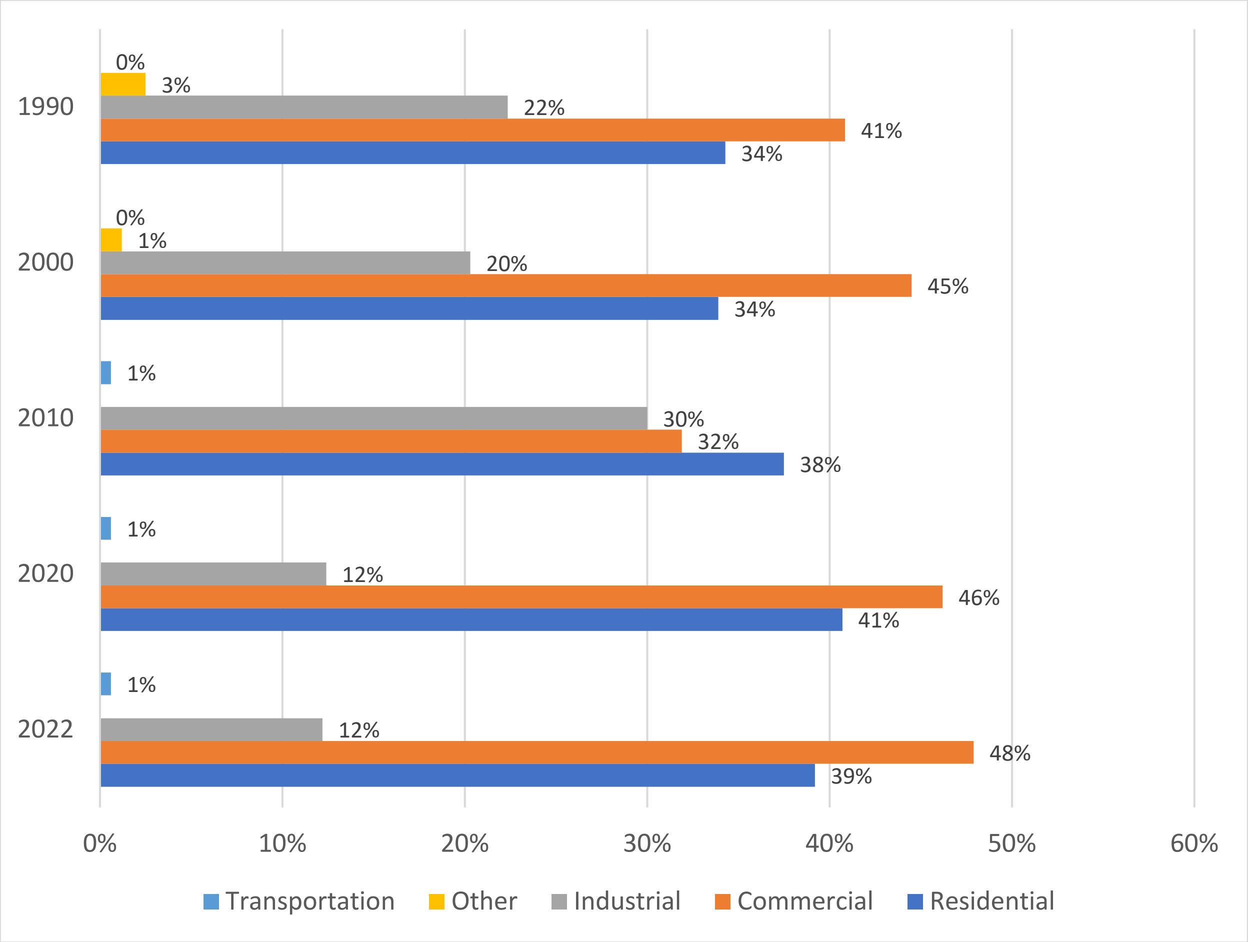
Appendix U. New York State Projected Levelized Cost of Electricity: Created with National Renewable Energy Lab State and Local Planning for Energy Datasets

MASSACHUSETTS SUPPORTING FIGURES & TABLES



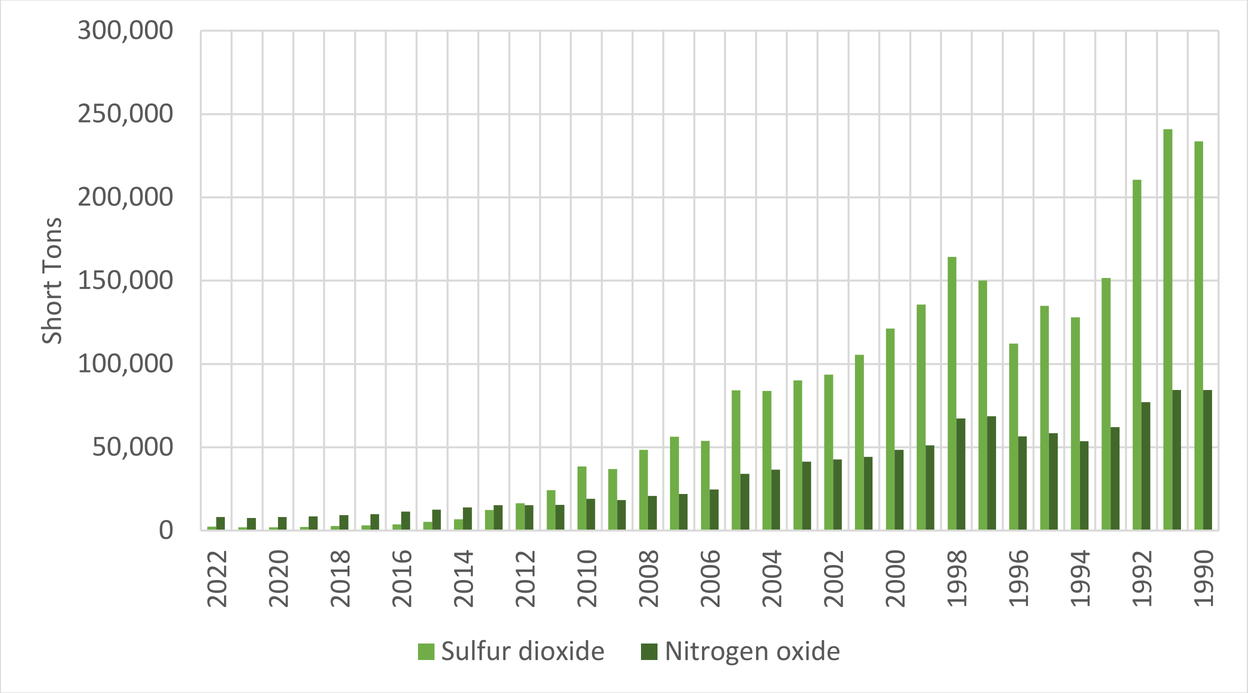
Appendix V. Massachusetts Electric Power Industry Generation by Primary Energy Source, 1990-2020. *Source*: EIA ;

* Note: “Other” includes: “Battery, Other, Other Biomass, Pumped Storage, & Wood”

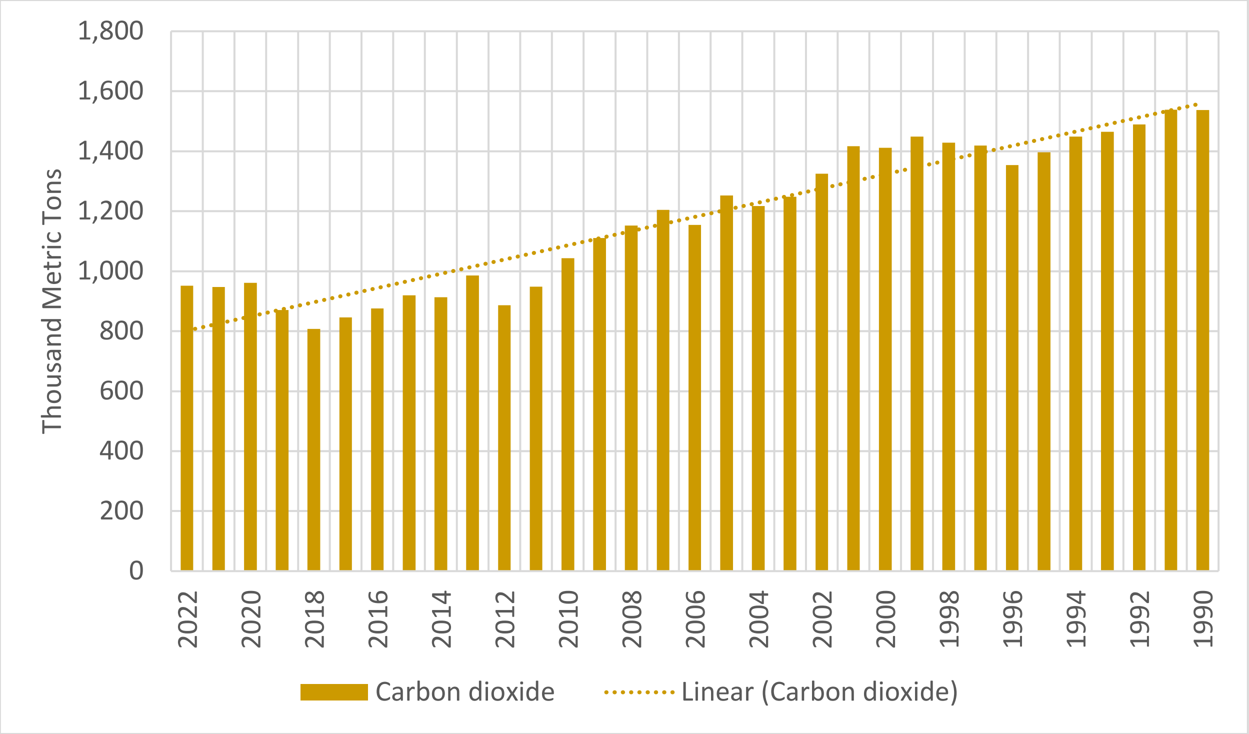


Appendix

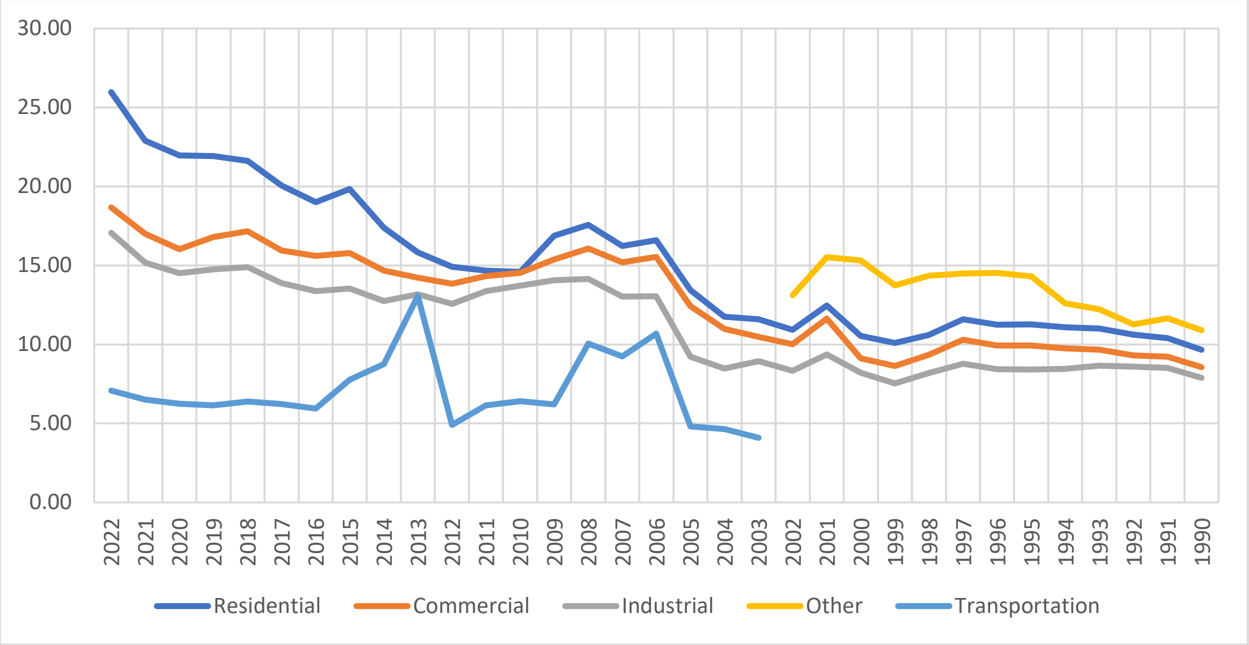
W. Massachusetts Electric Power Industry Generation by Primary Energy Source, 1990-2020. *Source*: EIA ;



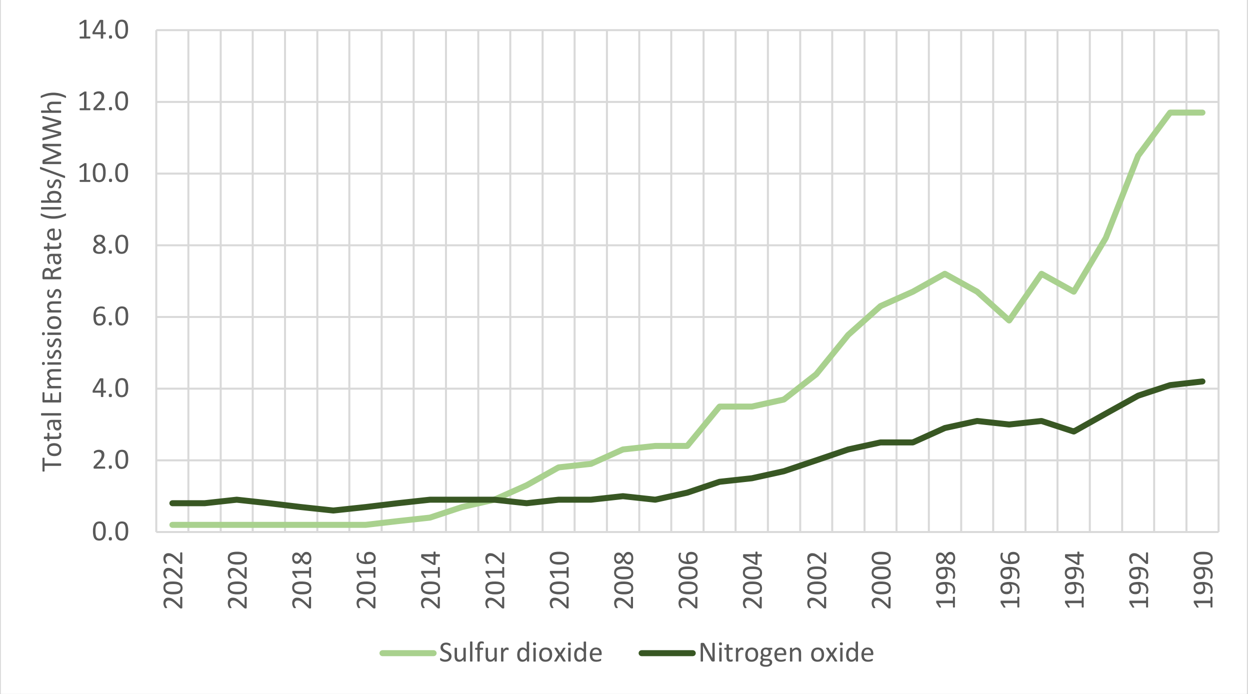
Appendix X. Massachusetts Electric Power Industry Emissions Sulfur Dioxide and Nitrogen Oxide Emissions, 1990-2022. *Source*: EIA



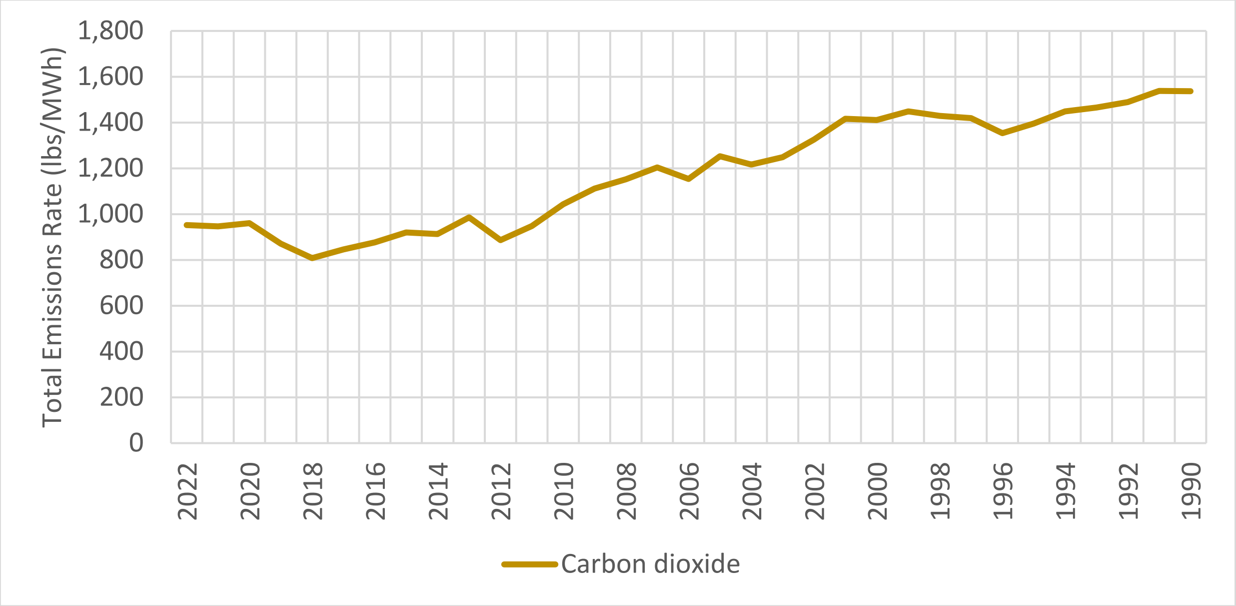
Appendix Y. Massachusetts Electric Power Industry Carbon Dioxide Emissions, 1990-2022. *Source*: EIA



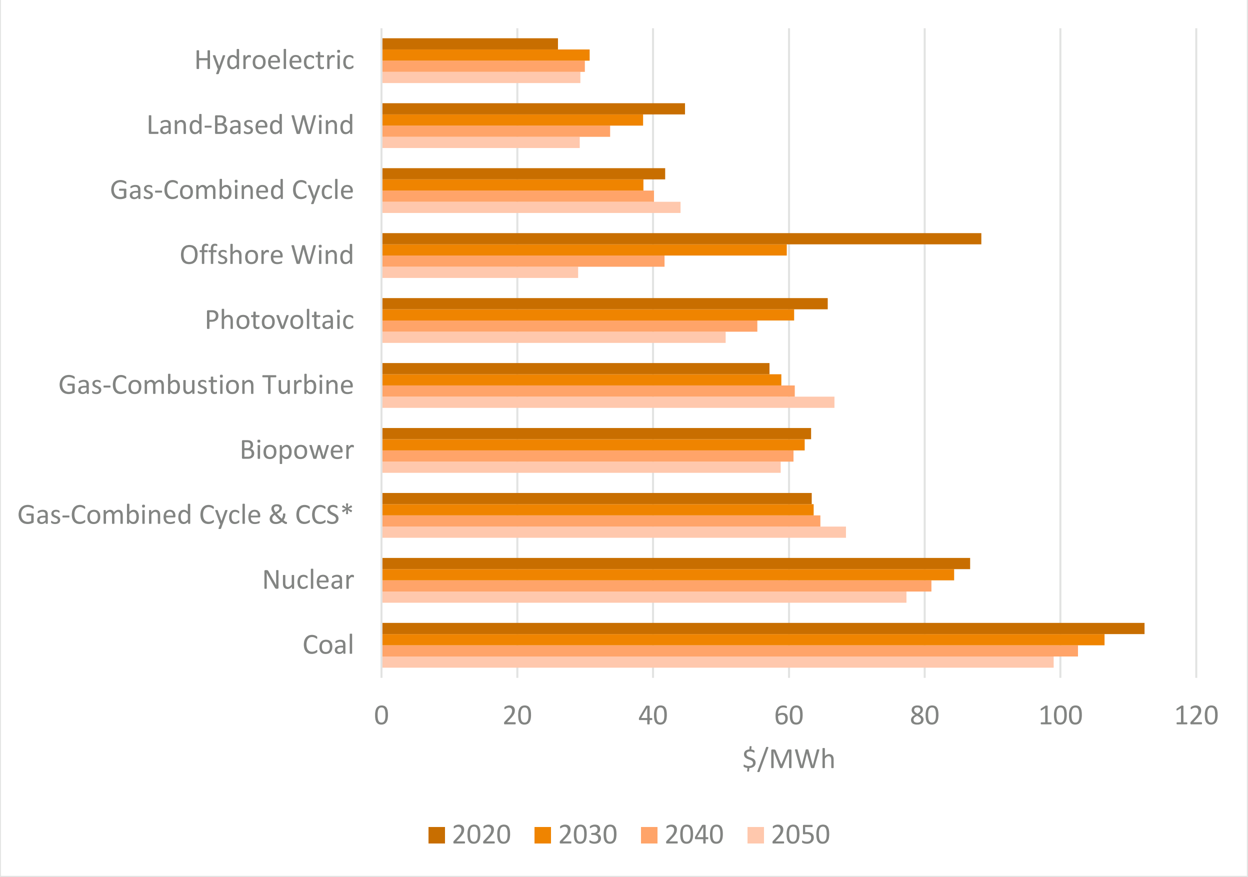
Appendix Z. Massachusetts State Electric Power Average Price by Primary Source in U.S. Cents Per Megawatt hours, 1990-2022. *Source*: EIA



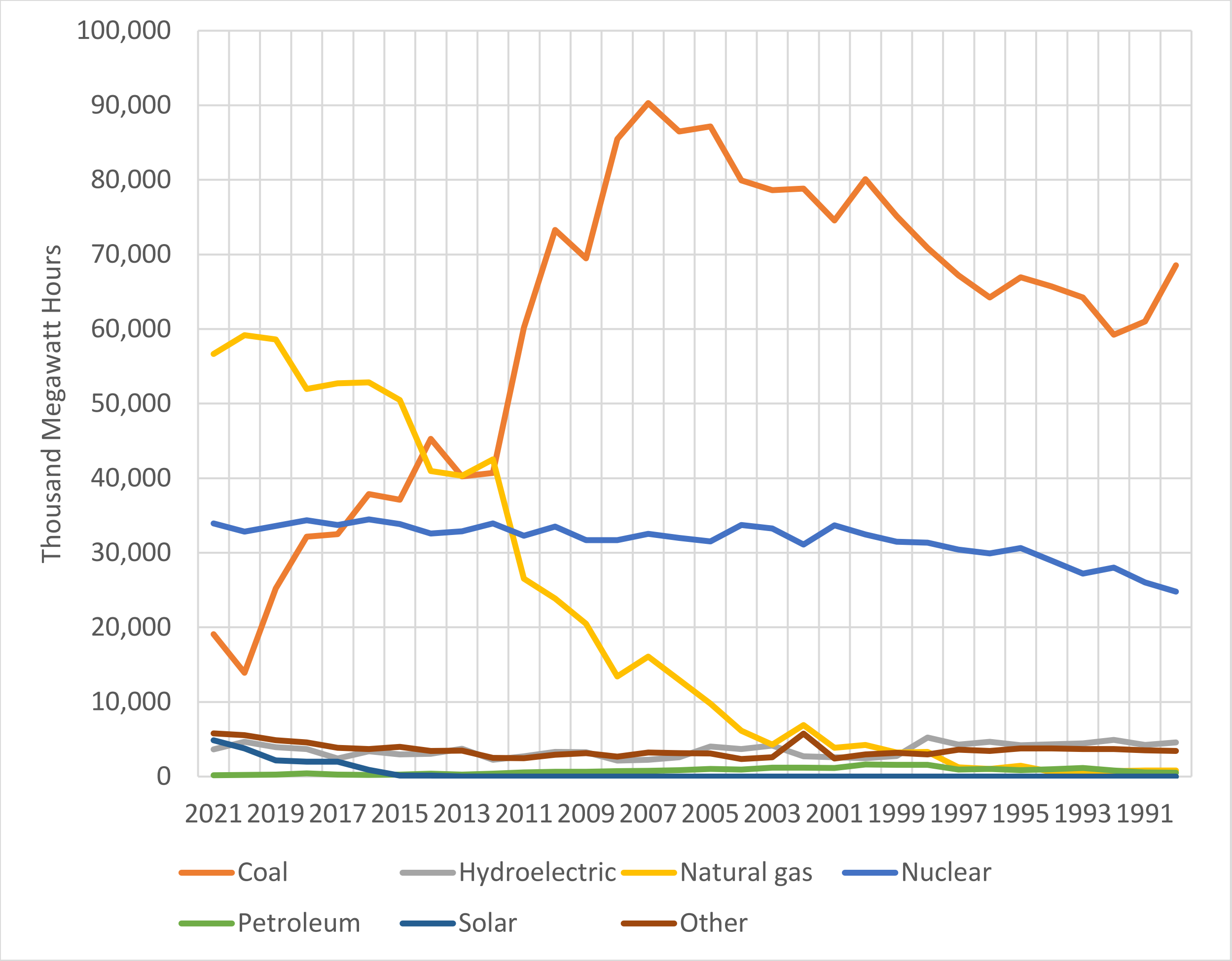
Appendix AA. Massachusetts Electric Power Industry lbs. of Emissions per Megawatt hour: Sulfur Dioxide and Nitrogen Oxide Emissions, 1990-2022. *Source*: EIA



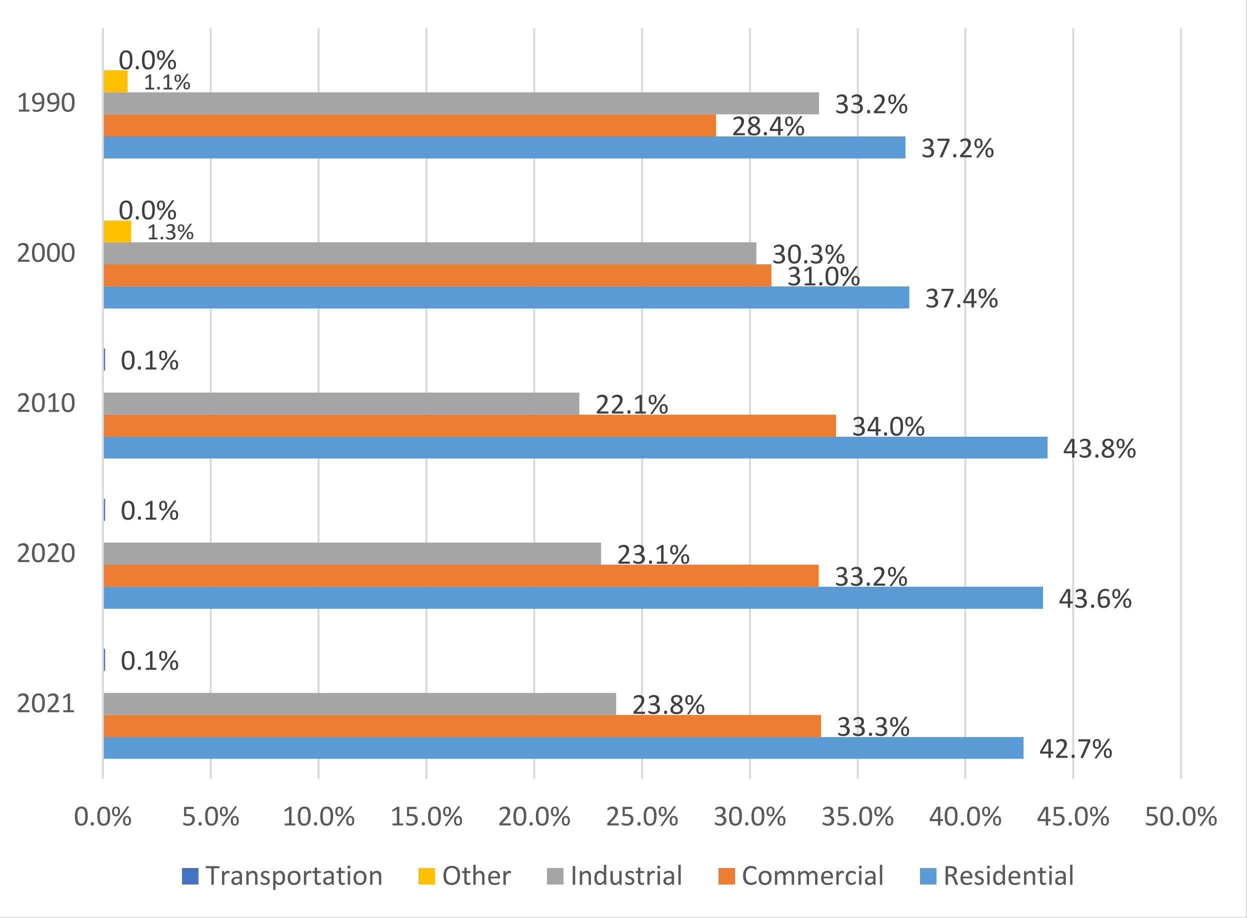
Appendix AB. Massachusetts Electric Power Industry lbs of Emissions per Megawatt hour: Carbon Dioxide Emissions, 1990-2022. *Source*: EIA



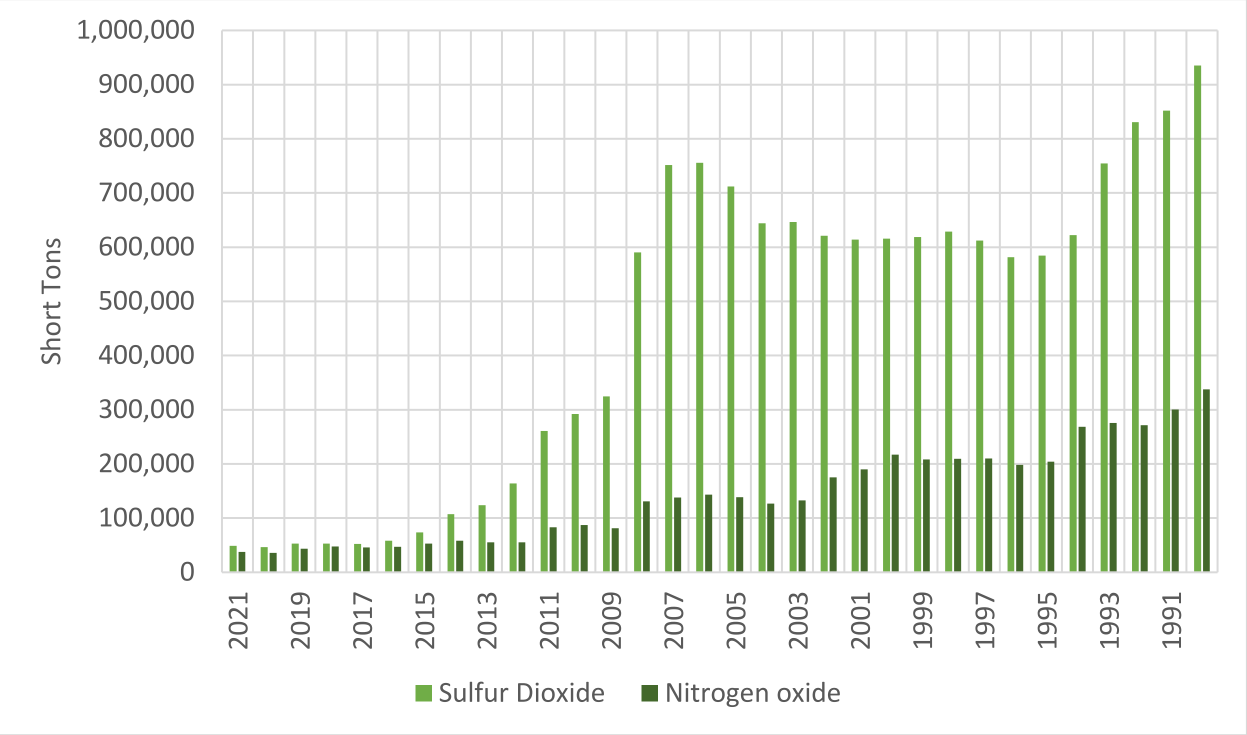
Appendix AC. Massachusetts Projected Levelized Cost of Electricity: Created with National Renewable Energy Lab State and Local Planning for Energy Datasets



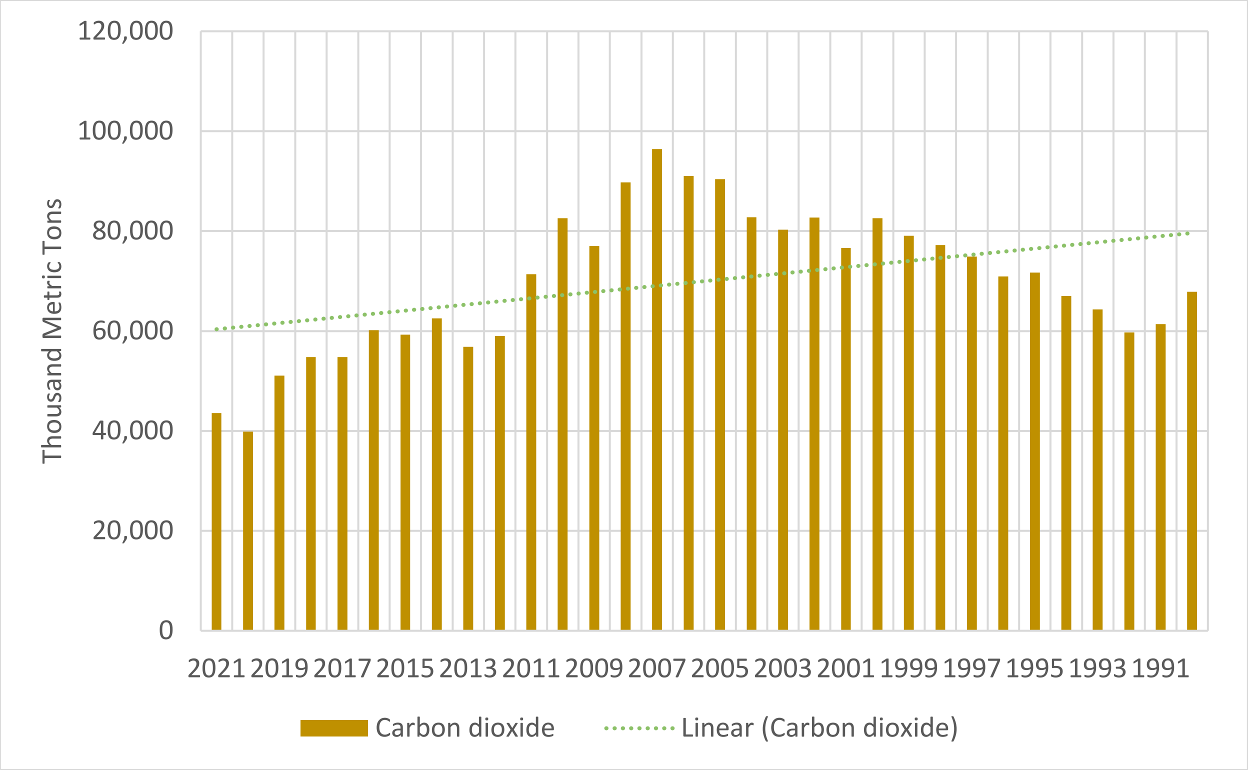
Appendix AD. Georgia Electric Power Industry Generation by Primary Energy Source, 1990-2021. *Source*: EIA ;
* Note: “Other” includes: “Battery, Other, Other Biomass, Pumped Storage, & Wood”



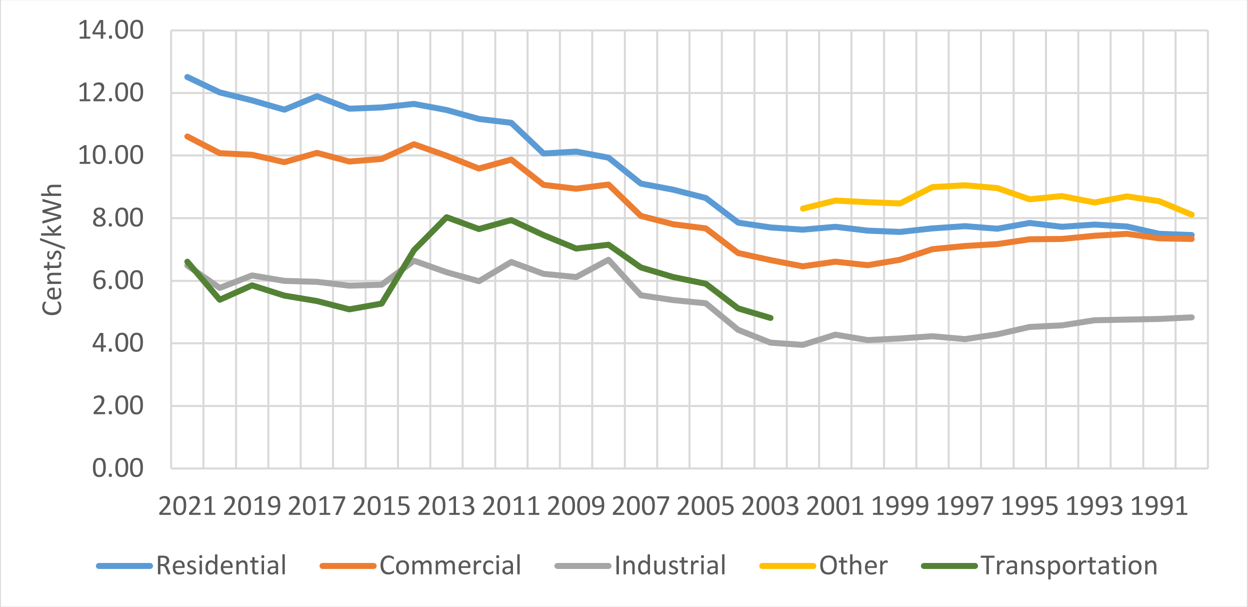
Appendix AE. New York State Electric Power Industry Generation by Primary Energy Source, 1990-2020. *Source*: EIA ;



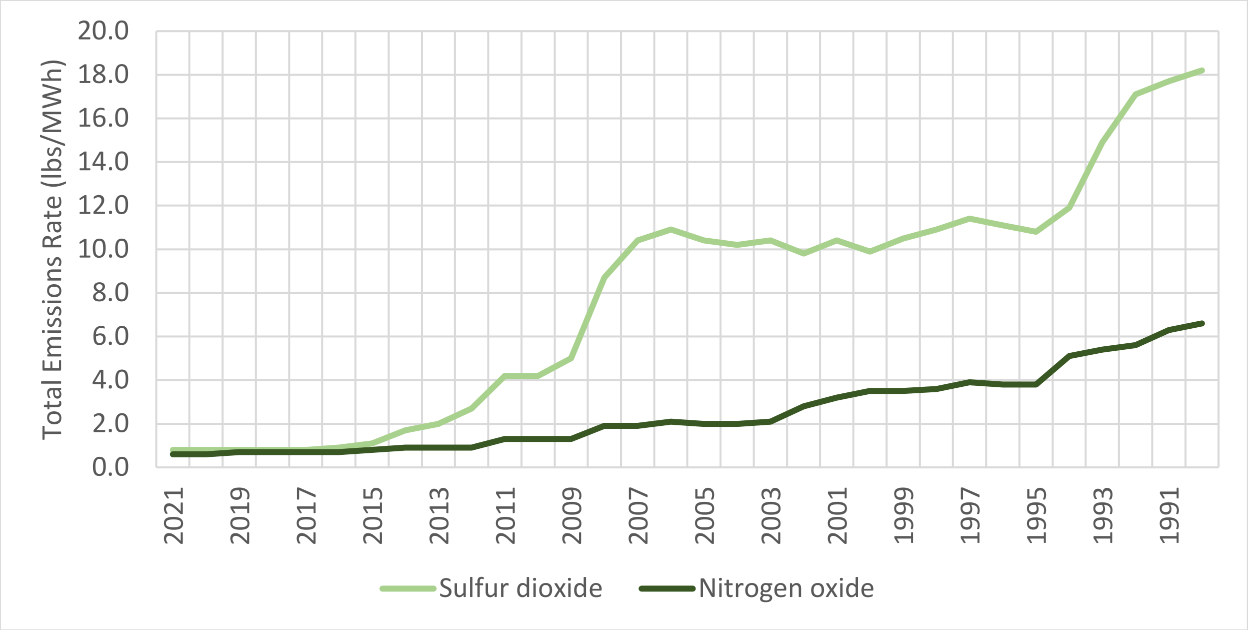
Appendix AF. Georgia Electric Power Industry Emissions Sulfur Dioxide and Nitrogen Oxide Emissions, 1990-2022. *Source*: EIA



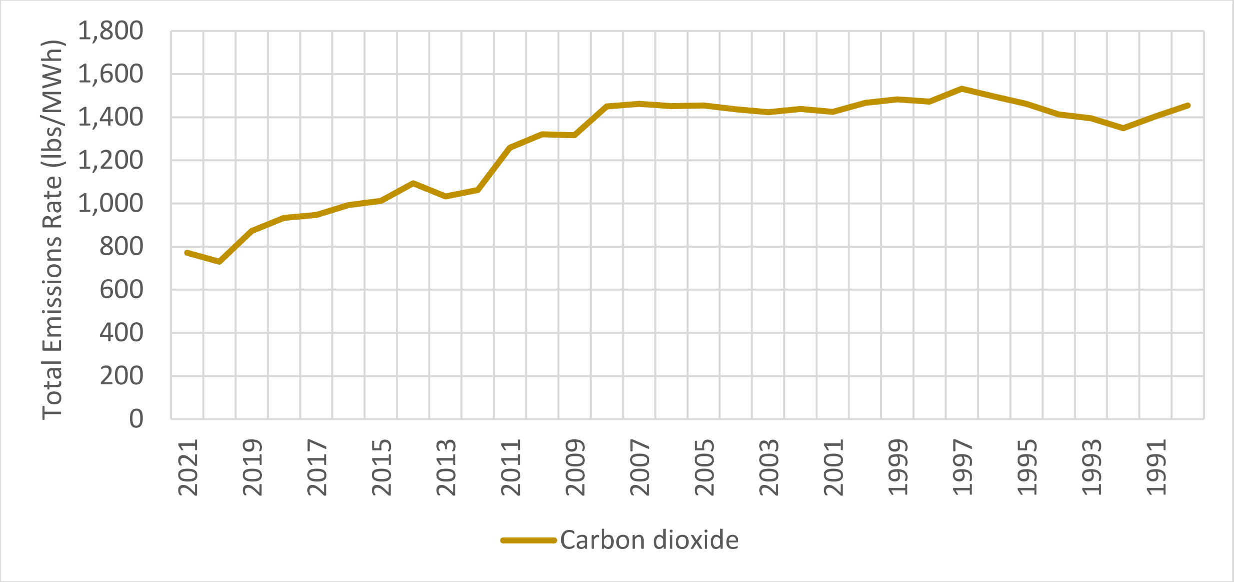
Appendix AG. Georgia Electric Power Industry Carbon Dioxide Emissions, 1990-2022. *Source*: EIA



Appendix AH. Georgia Electric Power Average Price by Primary Source in U.S. Cents Per Megawatt hours, 1990-2021. *Source*: EIA



Appendix AI. Georgia Electric Power Industry lbs. of Emissions per Megawatt hour: Sulfur Dioxide and Nitrogen Oxide Emissions, 1990-2021. *Source*: EIA



Appendix AJ. Georgia Electric Power Industry lbs. of Emissions per Megawatt hour: Carbon Dioxide Emissions, 1990-2021. *Source*: EIA

Dr. Jay Golden is the Pontarelli Professor of Environmental Sustainability and Finance in the Maxwell School of Citizenship and Public Affairs at Syracuse University. Dr. Golden is also the faculty director for the Dynamic Sustainability Lab. He is the author of the recently published book: **Dynamic Sustainability: Implications for Markets, Policy and National Security** by Cambridge University Press.

Golden received his Ph.D. in engineering from the University of Cambridge and his master's degree in Environmental Engineering and Sustainable Development from a joint program of the Massachusetts Institute of Technology and the University of Cambridge. He also holds a Professional Mastery of Project Management Certificate from Stanford University, an MLE in Higher Education from Harvard, and has a B.A. degree in Management.

His full bio can be located at: https://www.dynamicslab.org/dr-golden

His email is JGolde04@Syr.edu

Mr. Aaron Otis is a project manager in the Dynamic Sustainability Lab where he focuses on Energy and Net-Zero Carbon Transitions. He holds a Master’s in Environmental Studies from SUNY ESF where he also obtained a BA in Economics and Political Science. Mr. Otis also obtained a Master’s in Public Administration from Syracuse University. He can be reached at: Aaotis@Syr.edu

ABOUT THE DYNAMIC SUSTAINABILITY LAB

Launched during the fall of 2021, The Dynamic Sustainability Lab examines the opportunities as well as risks and unintended consequences resulting from the rapid transition to a new generation of sustainable technologies, strategies and policies for the Net-Zero Carbon Economy. Our focus is in providing interdisciplinary scientific approaches that support organizations in realizing sustainability transition opportunities by identifying the dynamic risks and developing policies, strategies and tools to achieve success.

Follow the Lab at: www.DynamicsLab.org

DYNAMIC SUSTAINABILITY LAB™
AT SYRACUSE UNIVERSITY