Copyright ©2026
National Centre for Energy and Environment,
Energy Commission of Nigeria, University of Benin:
ISSN 2504-9593
DOI: 10.5281/zenodo.24627862
https://ijree.com/index.php/publications/article/view/105
Int. J. Renew. Energ & Environ Vol.4 (3), pp 59-73(2026)

THE ROLE OF NUCLEAR ENERGY IN MITIGATING CLIMATE CHANGE: A COMPARATIVE ASSESSMENT OF AVOIDED GREENHOUSE GAS EMISSIONS ACROSS THE UNITED STATES

[1*]Alegu, H.A., [2]Umunna, J.C., [3]Amadi, V.N., [4]Ukairo, O.I., [5]Eze, R. E., [6]Chukwu, E.N., [7]Ekpe, J.E., [8]Ukwu, C.N., [9]Yusufu, P.O.

[1] Department of Industrial Physics, Ebonyi State University, Ebonyi State, Nigeria.
[2] Department of Physics, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria.
[3] Department of Physics, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria.
[4] Department of Physics, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria.
[5] Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.
[6] Department of Physics, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria.
[7] Department of Physics, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria.
[8] Department of Physics, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria.
[9] Department of Engineering, Metallurgical Training Institute (MTI), Anambra State, Nigeria.
***Correspondence email Address:**hyginusalegu@gmail.com

Abstract
The study used 2023 state-level data from the Nuclear Energy Institute (NEI) and the U.S. Energy Information Administration (EIA) to quantify greenhouse gas emissions avoided by nuclear power across 28 U.S. states. Avoided emissions of CO_2, SO_2, and NO_x were calculated for each state. Illinois led with 66.6 million metric tons (MMT) of CO_2 avoided, followed by Pennsylvania (35.2 MMT) and Texas (22.9 MMT). Other high performers included South Carolina (36.2 MMT), Tennessee (26.6 MMT), North Carolina (24.5 MMT), Alabama (24.6 MMT), Georgia (19.9 MMT), Arizona (16.5 MMT), and Michigan (16.0 MMT). Illinois also ranked highest for SO_2 (43,783 short tons) and NO_x (25,750 short tons) reductions. Regional totals showed the South avoided 196.9 MMT of CO_2, while the Midwest avoided 119.9 MMT. Simple linear regression was performed to assess how nuclear capacity and reactor count predict avoided CO_2 emissions. Both predictors were significant ($p < 0.001$), with reactor count yielding a slightly stronger fit ($R^2 = 0.847$) than capacity ($R^2 = 0.786$). These results demonstrate that larger nuclear infrastructure correlates with greater emissions avoidance. The paper concludes that sustained investment in nuclear capacity is crucial for maximizing GHG reductions, particularly in regions with rising electricity demand.

***Key words**: nuclear energy, greenhouse gas emissions, climate change mitigation*

1. Introduction

Climate change remains one of the most pressing global challenges facing humanity today. This is primarily driven by the emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Xian et al., 2025; Filonchyk et al., 2024). Climate change has led to rising global temperatures, sea level increases, extreme weather patterns, and severe threats to ecosystems, human health, and economic development (Chen & Mai, 2024; Nimma et al., 2025; Shakir Hanna, 2025). The energy sector accounts for about 73% of global greenhouse gas emissions, making it a key target for cutting emissions from fossil fuels (IEA, 2024). In order to avoid a deadly disaster which will disrupt global environmental health and economy, the Intergovernmental Panel on Climate Change (IPCC) estimates that the global GHG emissions must be reduced by at least 45% by 2030 (IPCC, 2023). This is to prevent global temperatures from rising beyond 1.5°C above pre-industrial levels (IPCC, 2018). To combat the impact of climate change, low-carbon energy sources have become the only alternative solutions. According to IRENA, over 168 countries have demonstrated commitment to transitioning towards renewable energy sources (IRENA, 2023). Nuclear energy has

emerged as a subject of renewed interest in this context due to its capacity to generate electricity at scale without direct carbon dioxide emissions during operation (Abd El-Azeem, 2025). Nuclear energy currently accounts for 10% of global electricity production, preventing the release of approximately 1.5 billion tonnes of CO_2 annually (World Nuclear Association, 2024). Country such as France generates over 70% of its electricity from nuclear power, resulting in electricity sector emissions that are one-sixth of the European average (World Nuclear Association, 2025). Similarly, the United Kingdom has been investing in nuclear infrastructure, with projects like Hinkley Point C and Sizewell C expected to power 40% of UK homes and contribute significantly to the nation's energy security and decarbonization goals (Sizewell, 2025). Despite being the largest nuclear energy generator in the world, the United States is one of the largest contributors to global greenhouse gas emissions, accounting for approximately 11% of total global emissions as of 2023 (EPA, 2023). As a highly industrialized nation, the United States faces a complex responsibility in balancing energy demands with environmental sustainability. The scale of its industrial output, combined with widespread urban development and a large transport network, has made fossil fuels a primary source of energy. In 2023, natural gas alone accounted for over 40 percent of the country's electricity supply (IEA, 2024). Coal and petroleum products still contribute significantly to the national energy mix. These figures point to an enduring dependence on carbon-intensive fuels, despite growing awareness of the climate crisis and an increasing political commitment to decarbonization (Peters et al., 2020).

The United States has long been at the forefront of developing diverse energy solutions to meet its growing demand. In 2023, the nation's energy consumption was predominantly met through fossil fuels (Bawaneh et al., 2024), with petroleum accounting for 38%, natural gas 36%, and coal 9% (as shown in Table 1). Renewable energy sources, including biomass, wind, hydro, solar, and geothermal, contributed 9%. Within the renewable sector, biofuels and wood were significant contributors, supplying approximately 2.82% and 2.02% of total energy consumption, respectively. Wind and solar, at 1.58% and 0.97%, have seen impressive growth, driven by expanding investments in sustainable technologies. Other renewables, such as biomass waste (~0.44%) and geothermal (~0.09%), also play a role, albeit in smaller proportions. Nuclear power accounted for the remaining 9% of the energy mix.

Table 1: U.S. Energy Consumption by Source, 2023 (EIA, 2025)

Energy Source	Quadrillion Btu	Percentage of Total
Petroleum	35.6	38%
Natural Gas	33.6	36%
Coal	8.4	9%
Nuclear Power	8.1	9%
Renewable Energy	8.2	9%
➢ **- Biofuels**	2.6	2.82%
➢ **- Wood**	1.9	2.02%
➢ **- Wind**	1.5	1.58%
➢ **- Solar**	0.9	0.97%
➢ **- Biomass Waste**	0.4	0.44%
➢ **- Geothermal**	0.1	0.09%
➢ **- Hydroelectric**	0.8	0.88%
Total	93.6	100%

Converted to Exajoules (EJ) using SI units (1 Quad Btu = 1.055 EJ)

However, despite having a low share in the energy mix, nuclear energy has remained a steady component of the America energy landscape. With 93 reactors operating across 28 states, the United States generates more electricity from nuclear sources than any other country in the world (EIA, 2023). In 2023, these facilities produced approximately 775 terawatt-hours of power, which is nearly one-fifth of the nation's total electricity generation (EIA, 2025). In 2024, U.S. nuclear energy investment surged to nearly $14 billion, doubling the previous year's total. The plan aims to add 200 gigawatts (GW) of new capacity by 2050, including constructing new reactors, upgrading existing facilities, and restarting previously retired plants, with short-term goals of 35 GW operational or under construction by 2035 and a sustained deployment rate of 15 GW per year starting in 2040 (DOE, 2022).

Unlike solar and wind, nuclear power does not depend on weather conditions, making it a reliable option for base-load energy (Forsberg et al., 2025). However, despite its consistent contribution to the U.S. energy mix, the adoption of nuclear energy remains low in some states, especially in some highly industrialized regions that should be leading the transition due to their significant role in greenhouse gas emissions (Bistline et al., 2019; NEI, 2023). This limitation is due to a combination of public resistance, stringent regulatory frameworks, and the significant financial investments required for the construction of new plants. Furthermore, many states have prioritized other energy sources, such as natural gas over nuclear power. California, for instance, has focused heavily on renewable sources like solar and wind but has made little headway in expanding its nuclear capacity since the planned closure of the Diablo Canyon plant in 2025 (CEC, 2023).

The role of nuclear energy in the broader climate strategy remains a subject of ongoing debate. Concerns about plant safety, the management of radioactive waste, the high cost of construction, and public resistance continue to influence policy and limit widespread adoption (Holdsworth & Ireland, 2024; Fernández-Arias et al., 2024). Even so, recent innovations in reactor technology, particularly the development of small modular reactors and enhancements in safety systems are beginning to change the direction of nuclear power discussions. These advancements present new possibilities for reducing emissions, especially when nuclear energy is used alongside other clean energy sources. Crucially, nuclear plants prevent large volumes of greenhouse gas emissions that would otherwise be produced by fossil fuel facilities. This avoidance plays a direct role in national and global efforts to meet climate goals. By examining these avoided emissions, it becomes possible to assess the practical climate benefits of nuclear energy and to evaluate how it compares to other low-carbon energy solutions.

The United States has both the capacity and infrastructure to expand and become more advanced in low-carbon energy development. It also holds decades of operational data that allow for a thorough analysis of the environmental impact of nuclear energy. Yet despite its long-standing presence in the national grid and its contribution to reducing emissions, questions remain. How does nuclear energy compare to other clean energy sources in terms of avoided greenhouse gas emissions? And what should its role be in the country's long-term climate strategy? This study aims to explore these questions by assessing the extent to which nuclear energy has helped reduce emissions across different states over time.

2.1 Methodology

This study utilized real, state-level data on greenhouse gas emissions avoided by nuclear power generation in the United States during 2023. Primary data were obtained from the Nuclear Energy Institute (NEI, 2024) database titled *"Emissions Avoided by U.S.*

Nuclear Industry by State", which provides estimates of carbon dioxide (CO_2) in million metric tons, sulfur dioxide (SO_2), and nitrogen oxides (NO_x) in short tons avoided due to nuclear electricity generation. Supplemental information on nuclear generating capacity (megawatts electric, MWe) and the number of reactors per state was sourced from the World (WNA, 2023b). Additional context and verification were drawn from the U.S. Energy Information Administration (EIA).

2.2 Data Processing

Data were compiled for 28 states with operational nuclear reactors, enabling a comparative assessment of avoided emissions across these states. Nuclear infrastructure variables, specifically, total nuclear capacity and the number of reactors were correlated against avoided CO_2 emissions to understand their predictive relationship.

To comply with international standards and the journal's requirement for the use of SI units with proper decadic prefixes, all energy data originally reported in British thermal units (Btu) were converted to SI units, using the following standard conversion factors:

- **1 Btu = 1,055.06 joules (J)**
- **1 Quadrillion Btu = 10^{15} Btu = 1.055 × 10^{18} J = 1.055 EJ**

2.3 Statistical Analysis

To quantitatively evaluate the association between nuclear infrastructure and environmental benefits, simple linear regression analyses were performed using Python. Two models were developed:

1.**Nuclear Capacity (MWe) as Predictor of CO_2 Emissions Avoided:**

This model assessed the linear relationship between total nuclear generating capacity and avoided CO_2 emissions at the state level.

2. **Number of Reactors as Predictor of CO_2 Emissions Avoided:**

This model examined how the number of reactors relates to avoided CO_2 emissions.

Key regression outputs included the coefficient of determination (R^2), slope coefficients (β_1), p-values, and standard errors. A higher R^2 and statistically significant p-values ($p < 0.05$) were interpreted as indicators of strong predictive capability and model validity.

2.4 Sensitivity and Limitations

This study assumes that nuclear power generation displaces fossil fuel-based generation on a one-to-one basis, which may vary across regional electricity grids due to differences in grid mix and operational factors. To enhance robustness, future work could include sensitivity analyses applying ±5% variation in grid emission factors, quantifying the potential variability in avoided emissions estimates. Additionally, temporal trends were not analyzed here but could further contextualize these findings.

3. Results of the Study

Table 2 presents the state-by-state greenhouse gas emissions avoided due to nuclear power generation in 2023, emphasizing the environmental benefits of nuclear energy. Illinois achieved the highest CO_2 emissions reduction (66.6 million metric tons), followed by Pennsylvania (35.2 Mt) and South Carolina (36.2 Mt). These states also saw significant reductions in SO_2 and NO_x emissions.

Table 2: Greenhouse Gas Emissions Avoided by U.S. Nuclear Power Plants across States in 2023

STATE	STATE CODE	CO_2 EMISSIONS AVOIDED (MILLION METRIC TONS)	SO_2 EMISSIONS AVOIDED (SHORT TONS)	NO_x EMISSIONS AVOIDED (SHORT TONS)
ALABAMA	AL	24.6	1,100	6,832
ARIZONA	AZ	16.5	3,426	6,364
ARKANSAS	AR	9.4	8,516	4,815
CALIFORNIA	CA	7.4	41	556

CONNECTICUT	CT	5.5	120	547
FLORIDA	FL	13.1	1,586	3,677
GEORGIA	GA	19.9	3,794	7,202
ILLINOIS	IL	66.6	43,783	25,750
KANSAS	KS	8.9	1,522	4,857
LOUISIANA	LA	5.9	1,930	3,060
MARYLAND	MD	7.6	1,338	1,792
MICHIGAN	MI	16.0	9,481	8,168
MINNESOTA	MN	8.3	1,690	4,092
MISSISSIPPI	MS	5.5	568	2,399
MISSOURI	MO	7.6	12,696	6,104
NEBRASKA	NE	6.1	14,130	6,226
NEW HAMPSHIRE	NH	6.4	545	1,858
NEW JERSEY	NJ	11.0	63	1,533
NEW YORK	NY	12.4	307	3,413
NORTH CAROLINA	NC	24.5	6,154	16,189
OHIO	OH	9.0	5,720	3,098
PENNSYLVANIA	PA	35.2	12,416	7,156
SOUTH CAROLINA	SC	36.2	10,556	15,127
TENNESSEE	TN	26.6	9,119	10,093
TEXAS	TX	22.9	12,522	10,235
VIRGINIA	VA	13.4	306	3,747
WASHINGTON	WA	4.6	503	1,984
WISCONSIN	WI	6.4	700	1,974

Source: Nuclear Energy Institute (NEI, 2024)

Notes: Values represent metric tons (Mt = 10^6 t for CO_2; t = 10^3 kg for SO_2 and NO_x).

Table 3: Nuclear Capacity and Emissions Avoided in Leading U.S. States for 2023 (WNA, 2023b).

Table 3 outlines the ten U.S. states with the highest nuclear capacity and correlates their infrastructure with avoided emissions. Illinois, with 11 reactors and over 11,000 MWe capacity, leads in CO_2, SO_2, and NO_x reductions. States like Pennsylvania, Texas, and South Carolina also recorded substantial emissions avoidance.

State	Total Capacity (MWe)	Number of Reactors	**CO_2 Emissions Avoided (Million Metric Tons)**	**SO_2 Emissions Avoided (Short Tons)**	**NO_x Emissions Avoided (Short Tons)**
Illinois	11,284	11	66.6	43,783	25,750
Pennsylvania	8,736	7	35.2	12,416	7,156
Texas	4,960	4	22.9	12,522	10,235
South Carolina	4,428	5	36.2	10,556	15,127
Georgia	4,245	4	19.9	3,794	7,202
Arizona	3,937	3	16.5	3,426	6,364
Virginia	3,568	4	13.4	306	3,747
New Jersey	3,499	3	11.0	63	1,533
Tennessee	3,453	3	26.6	9,119	10,093
Florida	3,626	4	13.1	1,586	3,677

Source: World Nuclear Association (WNA, 2023b).

Notes: Values represent metric tons (Mt = 10^6 t for CO_2; t = 10^3 kg for SO_2 and NO_x).

Table 4: Regional Distribution of Greenhouse Gas Emissions Avoided by U.S. Nuclear Power Plants in 2023

Table 4 categorizes emissions avoided by nuclear plants into four U.S. regions. The South led with 196.9 Mt CO_2 avoided, followed by the Midwest (119.9 Mt). The Northeast and West recorded lower values but still contributed meaningfully to national emissions reductions.

Region	States Included	CO_2 Avoided (MMT)	SO_2 Avoided (Short Tons)	NO_x Avoided (Short Tons)
Northeast	CT, NH, NJ, NY, PA	70.5	13,451	14,507
South	AL, AR, FL, GA, LA, MS, NC, SC, TN, TX, VA	196.9	58,661	83,366
Midwest	IL, KS, MI, MN, MO, NE, OH, WI	119.9	90,002	60,269
West	AZ, CA, WA	28.5	3,970	8,904

Source: adapted by Authors from Nuclear Energy Institute (NEI, 2024).

Table 5: Simple Linear Regression Analysis of Reactor Characteristics and CO_2 Emissions Avoided (2023)

Table 5 shows strong positive relationships between nuclear capacity and the number of reactors with CO_2 *emissions avoided. Both predictors are statistically significant, with the number of reactors exhibiting a stronger correlation ($R^2 = 0.85$) than capacity ($R^2 = 0.79$).*

Predictor Variable	Slope (β_1)	Intercept (β_0)	R^2	p-value	Standard Error
Reactor Capacity (MWe)	0.0056	-2.7153	0.7857	0.00063	0.00103
Number of Reactors	6.2011	-3.6252	0.8469	0.00016	0.9321

4. Discussion

4.1 State-Level Emissions Avoided by Nuclear Energy

Table 1 highlights the extent to which nuclear power contributed to the emissions avoidance of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) across United States. Illinois emerged as the top-performing state, avoiding approximately 66.6 million metric tons of CO_2 emissions (figure 1). This reflects the state's extensive nuclear infrastructure and its continued reliance on nuclear energy as a baseload power source. Other high-performing states include South Carolina (36.2 Mt), Pennsylvania (35.2 Mt), and Tennessee (26.6 Mt), which also have a significant concentration of nuclear facilities. On the lower end of the spectrum, states such as California (7.4 Mt), Wisconsin (6.4 Mt), and New Hampshire (6.4 Mt) recorded more modest reductions. These differences may be linked to either reduced nuclear capacity or greater dependence on alternative clean energy sources such as hydroelectricity or solar power (European Parliament, 2023). According to the World Nuclear Association, such variation in emissions avoidance can be attributed to the interplay between installed capacity, electricity demand, and energy mix (WNA, 2022).

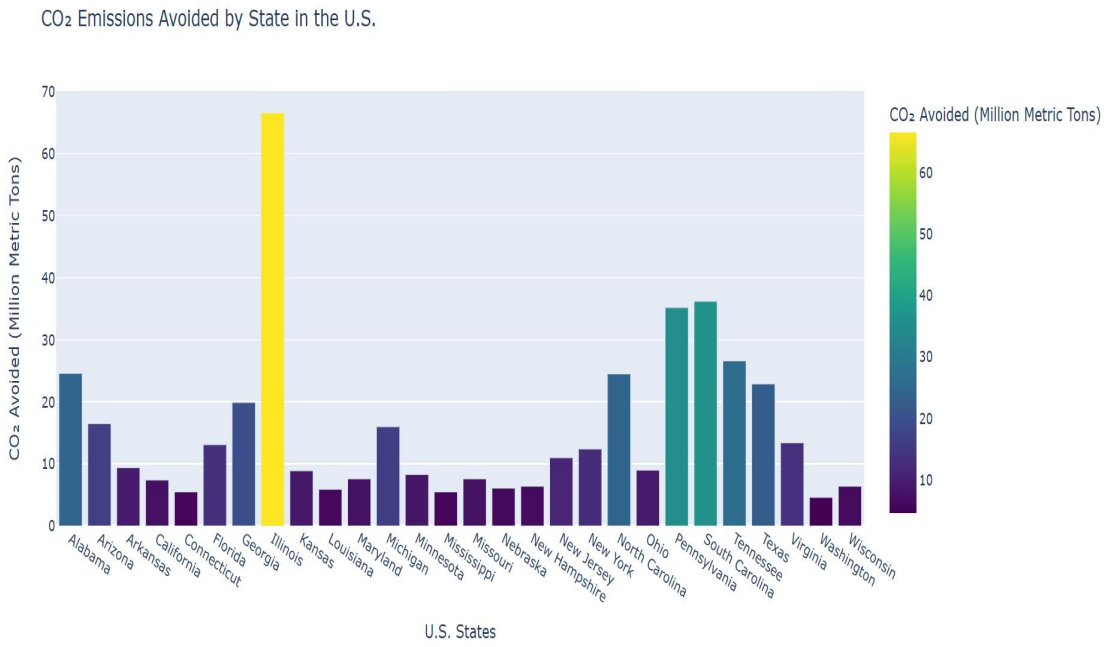

Figure 1: CO_2 Emissions Avoided by U.S. Nuclear Power Plants by State.
Plotted by the authors using data from the Nuclear Energy Institute (2024).

This chart illustrates the CO_2 emissions avoided by nuclear power generation across U.S. states in 2023. Illinois stands out with the highest reduction, avoiding 66.6 million metric tons of CO_2, followed by South Carolina with 36.2 million metric tons.

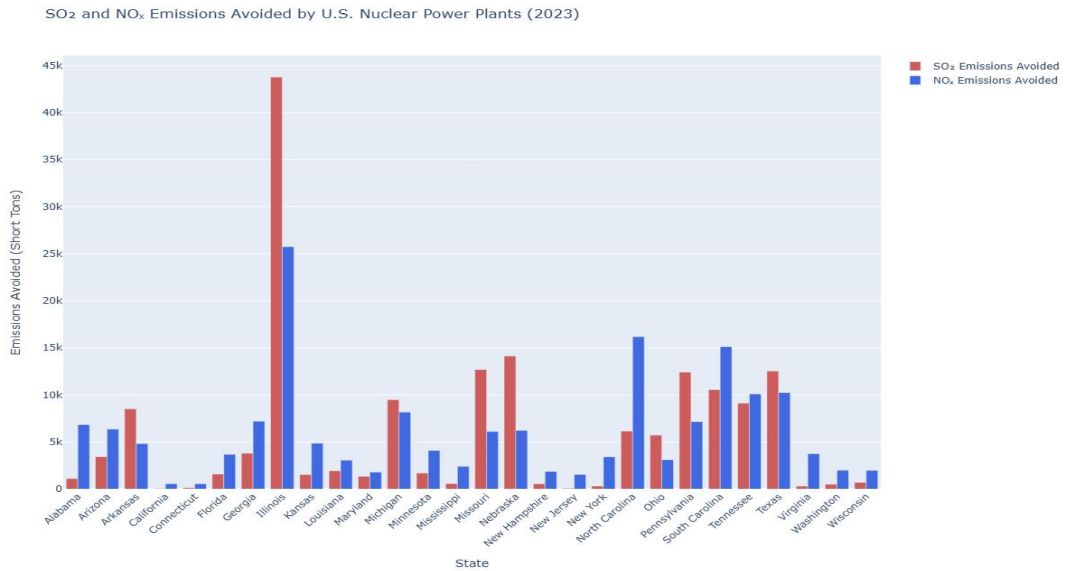

Figure 2: SO_2 and NO_x Emissions Avoided by U.S. Nuclear Power Plants by State
Plotted by the authors using data from the Nuclear Energy Institute (2024).
This chart compares the reduction in sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions across various U.S. states due to nuclear power generation in 2023.

In addition to CO_2 reductions, the data also show substantial avoidance of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) (Figure 2). Although SO_2 (sulfur dioxide) and NO_x (nitrogen oxides) are not typically classified as greenhouse gases (GHGs), they are

primarily air pollutants that contribute to acid rain and respiratory issues (Wami-Amadi, 2025). However, NO_x can indirectly influence GHG effects by contributing to the formation of ozone, a GHG, and affecting atmospheric chemistry (Gurav et al., 2024). Illinois again led the nation, avoiding 43,783 short tons of SO_2 and 25,750 short tons of NO_x, outcomes consistent with its overall emissions profile and its efforts to displace coal-based generation (EPA, 2023). States like Missouri and Nebraska recorded particularly high SO_2 reductions (12,696 and 14,130 short tons, respectively), reflecting their transition away from coal. North Carolina (16,189 short tons), South Carolina (15,127 short tons), and Texas (10,235 short tons) also achieved significant NO_x reductions, suggesting that nuclear power can serve as an important tool in addressing both climate change and public health concerns (IEA, 2021).

This evidence reinforces the broader environmental value of nuclear energy. If extrapolated nationwide, U.S. nuclear facilities could potentially avoid over 400 million metric tons of CO_2 emissions annually (DOE, 2022). This would represent a substantial contribution to achieving national climate objectives, including the 2050 net-zero targets established under the Paris Agreement (UNFCCC, 2022). Furthermore, the simultaneous reduction in SO_2 and NO_x emissions implies that nuclear energy supports environmental quality on multiple fronts. Its high-capacity factor (which is over 90% on average) also gives it an advantage over more variable renewable sources (EIA, 2025). Despite its promise, the full environmental benefits of nuclear power will only be realized if challenges such as high initial investment, long permitting processes, and public skepticism are effectively addressed. Advancements in next-generation nuclear technologies and small modular reactors (SMRs) may help overcome some of these obstacles (DOE, 2023).

4.2 Nuclear Capacity and Emissions Impact

The relationship between nuclear generating capacity and emission reductions is clearly demonstrated in Table 2. Illinois, with 11 reactors and a total capacity of 11,284 megawatts electric (MWe), recorded the highest levels of avoided emissions in 2023. This included 66.6 million metric tons of CO_2, along with notable reductions in SO_2 and NO_x. The trend is echoed in states such as Pennsylvania (7 reactors, 8,736 MWe) and South Carolina (5 reactors, 4,428 MWe), which also demonstrated strong performance in emissions avoidance. In contrast, New Jersey which has 3 reactors and 3,499 Mwe achieved more limited reductions, underscoring the link between installed capacity and emissions impact. This relationship is further supported by the regression analysis (in table 5), where both reactor capacity and the number of reactors show statistically significant positive correlations with CO_2 emissions avoided. The high R^2 values (0.79 for capacity and 0.85 for number of reactors) indicate that these variables explain a substantial portion of the variability in emissions reductions.

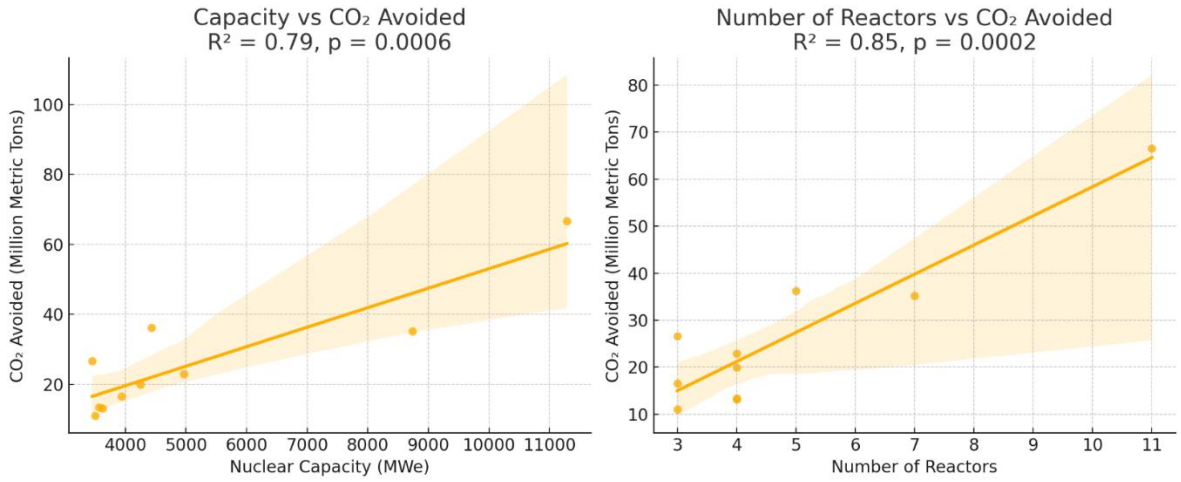

Figure 3: CO_2 Emissions Avoided vs Nuclear Capacity

The plot shows strong linear relationships between both reactor capacity and the number of reactors with CO_2 emissions avoided. While both variables are clearly linked to reductions in CO_2, the number of reactors appears to be a slightly better predictor of emissions avoidance, as indicated by its higher R^2 value and lower p-value.

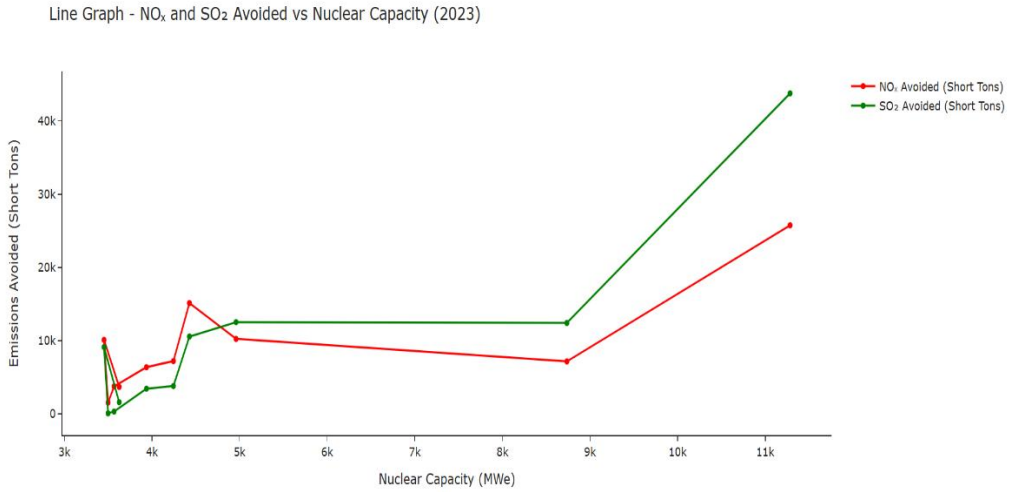

Figure 4: NO_x and SO_2 Emissions Avoided vs Nuclear Capacity

Plotted by the authors using data from the Nuclear Energy Institute (2024).

The line graph shows the relationship between nuclear capacity (in MWe) and the emissions avoided for NO_x and SO_2. The chart highlights two lines: the first representing the reduction in NO_x emissions and the second representing the reduction in SO_2 emissions.

Globally, this correlation holds true. France, for example, avoided approximately 300 million metric tons of CO_2 in 2022 through its 56-reactor nuclear fleet, which supplies over 60% of its electricity (World Nuclear Association, 2023a). Canada, with 19 reactors producing 13.5 gigawatts electric (GWe), prevented an estimated 80 million metric tons of CO_2 emissions annually (IEA, 2022). These international examples support the argument that nuclear energy's environmental benefits scale with capacity. Uptime performance also matters. U.S. nuclear plants consistently operate with a capacity factor above 90%, significantly higher than those of wind (approximately 35%) and solar (around 25%) (EIA, 2025). Therefore, while installed capacity is crucial,

operational reliability and policy frameworks are equally vital in maximizing nuclear energy's contribution to emission reductions. The growing interest in SMRs offers a promising avenue for expanding capacity in a modular and potentially more cost-effective manner (An et al., 2025; Van Hee et al., 2024; Wang et al., 2024)

4.3 Regional Impact of Nuclear Energy

Table 3 provides a regional breakdown of greenhouse gas and air pollutant emissions avoided through nuclear energy generation in 2023.

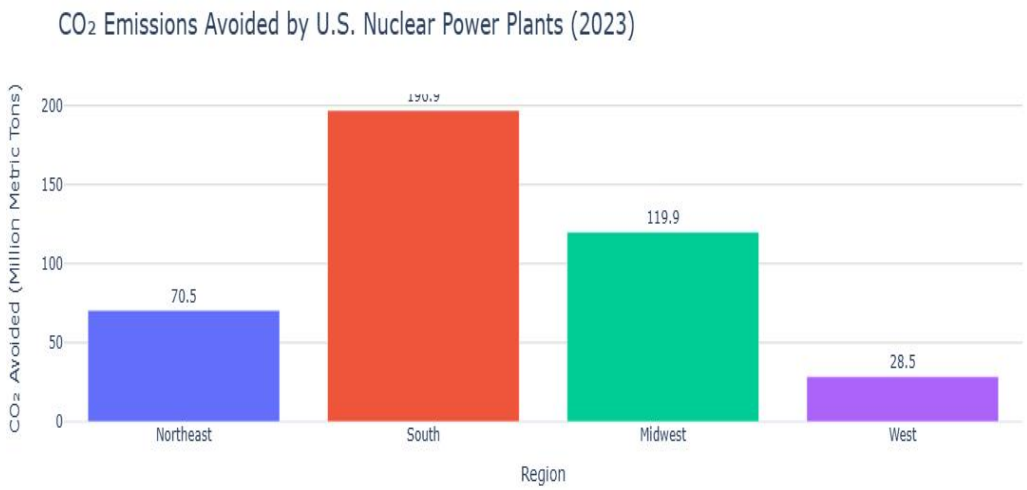

Figure 5: CO_2 Emissions Avoided by U.S. Nuclear Power Plants by Region
Plotted by the authors using data from the Nuclear Energy Institute (2024).
This chart illustrates the regional distribution of carbon dioxide emissions avoided through nuclear power generation in the United States in 2023. The South achieved the highest reduction with 196.9 million metric tons avoided. The Midwest followed with 119.9 million metric tons. The Northeast and West recorded lower totals but still made meaningful contributions to overall emission reduction efforts.

The Southern region achieved the most substantial results, avoiding 196.9 million metric tons of CO_2, (Figure 1). This outcome can be linked to the presence of large nuclear facilities in states such as Texas, South Carolina, and Tennessee, which also rank among the highest electricity consumers and greenhouse gas emitters (EPA, 2023). The Midwest followed with 119.9 million metric tons, reflecting the continuing shift away from fossil fuels in historically coal-dependent states such as Illinois and Ohio. In the Northeast, 70.5 million metric tons were avoided, with major contributions from Pennsylvania and New York. This is especially significant given the population density and environmental concerns in the region. The West recorded the lowest CO_2 avoidance at 28.5 million metric tons. While modest, this figure must be viewed in context: many Western states rely on a blend of nuclear, hydroelectric, and solar energy, reducing dependence on high-emission sources (EIA, 2023).

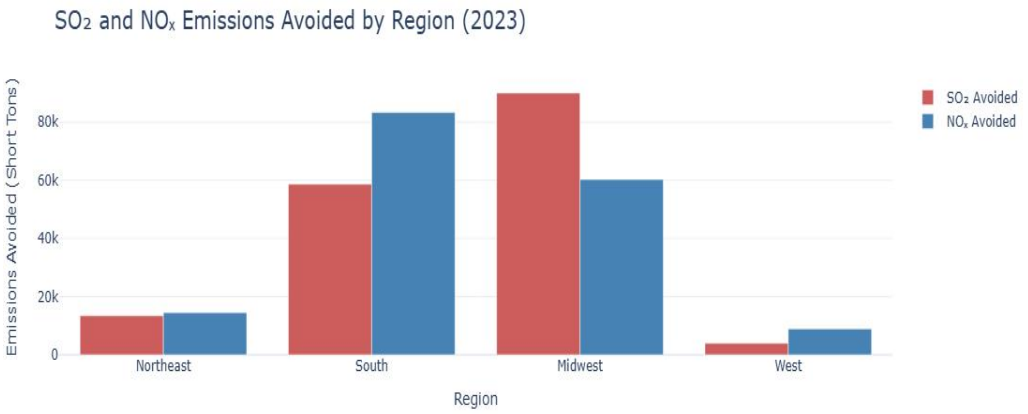

Figure 2: SO_2 and NO_x Emissions Avoided by Region
Plotted by the authors using data from the Nuclear Energy Institute (2024).
This figure presents a comparison of sulfur dioxide and nitrogen oxides emissions avoided across the four U.S. regions. The data shows that the Midwest led in sulfur dioxide reductions, while the South recorded the highest nitrogen oxides avoidance. These differences reflect the varying energy profiles and industrial activities across the regions.

As seen in Figure 2, the Midwest achieved the highest reduction in sulfur dioxide emissions with 90,002 short tons avoided. This is a significant accomplishment, especially given the region's historical reliance on coal-fired power plants, which have long been associated with environmental concerns such as acid rain. The South followed with 58,661 short tons of SO_2 avoided and also led in nitrogen oxides reductions, preventing 83,366 short tons of NO_x from being released into the atmosphere. These figures reflect the effectiveness of nuclear power in improving air quality, particularly in states like Texas and South Carolina. The Northeast, while contributing 13,451 short tons of SO_2 and 14,507 short tons of NO_x avoided, recorded more modest reductions. However, these numbers are significant given the region's urbanization and industrial activities. The West, with 3,970 short tons of SO_2 and 8,904 short tons of NO_x avoided, shows the least impact in these areas. This can be attributed to the region's energy mix, which is less reliant on nuclear energy, and the smaller number of nuclear plants in operation.

These findings carry broader policy implications. States like Texas, Illinois, and Pennsylvania not only rank among the top greenhouse gas emitters nationally (Rhodium Group, 2023), but also demonstrate how expanding nuclear energy in high-emitting regions could accelerate progress toward national and international climate targets. As such, strategic investments in nuclear capacity (especially in industrial and high-demand zones) could enhance the overall efficiency and fairness of the U.S. decarbonization strategy (NIA, 2024)

5. Conclusion

This study demonstrates that nuclear energy is an essential tool in reducing GHG emissions in the United States and can even play a larger role in the global effort to combat climate change. The findings show that states with large nuclear capacities, such as Illinois, South Carolina, and Pennsylvania, contribute notably to the reduction of CO_2, SO_2, and NO_x emissions. These states have large nuclear fleets that help displace fossil fuel-based electricity, highlighting nuclear power's potential as a low-carbon energy source. The regional distribution of avoided emissions further emphasizes the impact of

nuclear energy, with the Southern region leading in emission reductions due to its high nuclear capacity and electricity demand. As of August 1, 2023, the U.S. operates 93 commercial nuclear reactors across 54 power plants in 28 states, which collectively account for approximately 20% of the nation's electricity generation. While this is a substantial contribution, the U.S. remains the largest GHG emitter in the world, showing the need for further expansion of nuclear energy alongside other clean energy solutions to meet future climate goals.

When compared to countries like France, which generates over 70% of its electricity from nuclear power, or Canada, where nuclear energy makes up a significant portion of their energy mix, it is clear that nuclear energy has proven to be effective in lowering GHG emissions. The U.S., despite its substantial nuclear capacity, still faces challenges in curbing emissions, partly due to its continued reliance on fossil fuels. However, expanding nuclear energy through advanced technologies like Small Modular Reactors (SMRs) could help the U.S. meet its climate goals and contribute to the global push for net-zero emissions. With its high efficiency and capacity to complement intermittent renewable sources, nuclear power should be a central part of the nation's energy strategy as it works to mitigate climate change and reduce emissions on both a national and global scale.

2. Author Contributions

Hyginus Arinze Alegu: Conceptualization, Supervision, Writing, Visualization—review & editing.

Hyginus Arinze Alegu, Jonathan Chibueze Umunna, Vincent Nnamdi Amadi: Methodology, Data curation.

Hyginus Arinze Alegu, Okechukwu Idika Ukairo, Emmanuel Nnaemeka Chukwu: Data collection, Validation.

All authors: Review, Final approval of the version to be published.

3. Availability of Data and Materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

4. Consent for Publication

All authors consent to the publication of this manuscript.

5. Conflicts of Interest

The authors declare that there are no conflicts of interest related to this work.

6. Funding

This research did not receive any external funding.

7. Acknowledgments

None declared.

References

Abd El-Azeem, S. A. (2025). Nuclear energy future in mitigating climate change and achieving sustainable development. *Engineering, Technology & Applied Science Research, 15*(1), 19878–19884. https://doi.org/10.48084/etasr.9439

An, B., Kang, D., Kim, J., & Kyaw Thu, M. (2025). *Small modular reactors (SMRs) and smart energy cities: Techno-socioeconomic analysis of global energy plans*. SSRN. https://doi.org/10.2139/ssrn.5150425

Bawaneh, K., Das, S., & Rasheduzzaman, M. (2024). Energy consumption analysis and characterization of the residential sector in the US towards sustainable development. *Energies, 17*(11), 2789. https://doi.org/10.3390/en17112789

Bistline, J., James, R., & Sowder, A. (2019). Technology, policy, and market drivers of (and barriers to) advanced nuclear reactor deployment in the United States after 2030. *Nuclear Technology, 205*(8), 1075–1094. https://doi.org/10.1080/00295450.2019.1574119

California Energy Commission (CEC). (2023). *California energy plan 2023*. Available at: https://www.energy.ca.gov/data-reports/reports/integrated-energy-

policy-report/2023-integrated-energy-policy-report [Accessed on 11th April, 2025].

Chen, Y., & Mai, R. (2024). Rising tides: Long-term impact of sea level rise on marine ecosystems. *International Journal of Marine Science, 14*(2), 102. https://doi.org/10.5376/ijms.2024.14.0013

European Parliament. (2023). *Report on small modular reactors (2023/2109(INI))*. Available at: https://www.europarl.europa.eu/doceo/document/A-9-2023-0408_EN.html [Accessed on 12th April, 2025].

Fernández-Arias, P., Lampropoulos, G., Antón-Sancho, Á., & Vergara, D. (2024). Progress, challenges, and sustainable perspectives in nuclear energy strategies. *Applied Sciences, 14*(24), 11864. https://doi.org/10.3390/app142411864

Filonchyk, M., Peterson, M. P., Zhang, L., Hurynovich, V., & He, Y. (2024). Greenhouse gases emissions and global climate change: Examining the influence of CO_2, CH_4, and N_2O. *Science of the Total Environment*, 173359. https://doi.org/10.1016/j.scitotenv.2024.173359

Forsberg, C., Parsons, J., & Won, H. (2025). Base load nuclear energy for ammonia, paper, biofuels and mining facilities with dispatchable electricity using high temperature electrolysis. *Nuclear Science and Technology Open Research, 3*(11), 11. https://doi.org/10.12688/nuclscitechnolopenres.17630.1

Gurav, M. T., Shinde, S. P., Nimbalkar, N. J., Jadhav, P. S., Zambare, D. N., & Wategaonkar, S. B. (2024). Air pollutants from sugar industry chimneys: Evaluating environmental hazards and global mitigation strategies. https://doi.org/10.69626/csa.2024.0177

Holdsworth, A. F., & Ireland, E. (2024). Navigating the path of least resistance to sustainable, widespread adoption of nuclear power. *Sustainability, 16*(5), 2141. https://doi.org/10.3390/su16052141

Intergovernmental Panel on Climate Change (IPCC). (2018). *Global warming of 1.5°C*. Available at: https://www.ipcc.ch/sr15/ [Accessed on 12th April, 2025].

Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate change 2023: Synthesis report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/report/ar6/syr/ [Accessed on 12th April, 2025].

International Energy Agency (IEA). (2021). *Global energy review 2021*. Available at: https://www.iea.org/reports/global-energy-review-2021 [Accessed on 12th April, 2025].

International Energy Agency (IEA). (2022). *Nuclear power and secure energy transitions*. Available at: https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions [Accessed on 7th April, 2025].

International Energy Agency (IEA). (2024). *World energy outlook 2024*. Available at: https://www.iea.org/reports/world-energy-outlook-2024 [Accessed on 12th April, 2025].

International Renewable Energy Agency (IRENA). (2023). *World energy transitions outlook 2023: 1.5°C pathway*. Available at: https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023 [Accessed on 12th April, 2025].

Nimma, D., Devi, O. R., Laishram, B., Ramesh, J. V. N., Boddupalli, S., Ayyasamy, R., et al. (2025). Implications of climate change on freshwater ecosystems and their biodiversity. *Desalination and Water Treatment, 321*, 100889. https://doi.org/10.1016/j.dwt.2024.100889

Nuclear Energy Institute (NEI). (2023). *Nuclear by the numbers*. Available at: https://www.nei.org/resources/statistics/nuclear-by-the-numbers [Accessed on 12th April, 2025].

Nuclear Energy Institute (NEI). (2024). *Emissions avoided by U.S. nuclear industry by state*. Available at: https://www.nei.org/resources/statistics/emissions-avoided-by-us-nuclear-industry-by-state [Accessed on 12th April, 2025].

Nuclear Innovation Alliance (NIA). (2024). *Industrial decarbonization with nuclear energy*. Available at: https://nuclearinnovationalliance.org/sites/default/files/2024-06/NIA_Industrial%20Decarbonization%20RFI%20Submission.pdf [Accessed on 12th April, 2025].

Peters, G. P., Andrew, R. M., Canadell, J. G., Friedlingstein, P., Jackson, R. B., Korsbakken, J. I., & Peregon, A. (2020). Carbon dioxide emissions continue to grow amidst slowly emerging climate policies. *Nature Climate Change, 10*(1), 3–6. https://doi.org/10.1038/s41558-019-0659-6

Shakir Hanna, S. H. (2025). Climate change and human imprint consequences. In *Climate changes impacts on aquatic environment: Assessment, adaptation, mitigation, and road map for sustainable development* (pp. 3–19). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-74897-4_1

Sizewell C. (2025). *MP update shows Sizewell C "the best prepared nuclear project in modern nuclear history"*. Available at: https://www.sizewellc.com/news-views/mp-update-shows-sizewell-c-the-best-prepared-nuclear-project-in-modern-nuclear-history/ [Accessed on 12th April, 2025].

U.S. Department of Energy (DOE). (2022). *Industrial decarbonization roadmap*. Available at: https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf [Accessed on 12th April, 2025].

U.S. Department of Energy (DOE). (2023). *Benefits of small modular reactors (SMRs)*. Available at: https://www.energy.gov/ne/benefits-small-modular-reactors-smrs [Accessed on 12th April, 2025].

U.S. Energy Information Administration (EIA). (2023). *Nuclear power plants have generated about 20% of U.S. electricity since 1990*. Available at: https://www.eia.gov/energyexplained/nuclear/nuclear-power-plants.php [Accessed on 7th April, 2025].

U.S. Energy Information Administration (EIA). (2025). *Electric power monthly, Table 6.07.B*. Available at: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b [Accessed on 11th April, 2025].

U.S. Environmental Protection Agency (EPA). (2023). *2023 power plant emissions data*. Available at: https://www.epa.gov/newsreleases/epa-releases-2023-power-plant-emissions-data [Accessed on 10th April, 2025].

United Nations Framework Convention on Climate Change (UNFCCC). (2022). *Paris Agreement—Nationally determined contributions*. Available

at: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs [Accessed on 12th April, 2025].

Van Hee, N., Peremans, H., & Nimmegeers, P. (2024). Economic potential and barriers of small modular reactors in Europe. *Renewable and Sustainable Energy Reviews, 203*, 114743. https://doi.org/10.1016/j.rser.2024.114743

Wami-Amadi, C. F. (2025). The impact of air borne toxins from gas flaring on cardiopulmonary and other systemic functions. *Scholars International Journal of Anatomy and Physiology, 8*(1), 12–28. https://doi.org/10.36348/sijap.2025.v08i01.003

Wang, Y., Chen, W., Zhang, L., Zhao, X., Gao, Y., & Dinavahi, V. (2024). Small modular reactors: An overview of modeling, control, simulation, and applications. *IEEE Access*. https://doi.org/10.1109/ACCESS.2024.3351220

World Nuclear Association (WNA). (2022). *World nuclear performance report 2022*. Available at: https://world-nuclear.org/images/articles/World-Nuclear-Performance-Report-2022.pdf [Accessed on 11th April, 2025].

World Nuclear Association (WNA). (2023b). *Nuclear reactors in United States of America*. Available at: https://world-nuclear.org/nuclear-reactor-database/summary/United%20States%20Of%20America [Accessed on 12th April, 2025].

World Nuclear Association (WNA). (2024). *World nuclear performance report 2024*. Available at: https://world-nuclear.org/our-association/publications/world-nuclear-performance-report-2024 [Accessed on 11th April, 2025].

World Nuclear Association (WNA). (2025). *Nuclear power in France*. Available at: https://world-nuclear.org/information-library/country-profiles/countries-a-f/france [Accessed on 12th April, 2025].

Xian, Y., Wang, H., Zhang, Z., Yang, Y., & Zhong, Y. (2025). Driving factors and reduction paths dynamic simulation optimization of carbon dioxide emissions in China's construction industry under the perspective of dual carbon targets. *Environmental Impact Assessment Review, 112*, 107789. https://doi.org/10.1016/j.eiar.2024.107789

Appendix 1: Net Generation by Energy Source (All Sectors) in the U.S in 2023

Generation at Utility Scale Facilities

Period	Coal	Petroleum Liquids	Petroleum Coke	Natural Gas	Other Fossil Gas	Nuclear	Hydroelectric Conventional	Solar	Renewable Sources Excluding Hydroelectric and Solar
Year 2023									
January	61,357	983	421	138,339	945	70,870	22,754	7,806	44,03
February	46,374	1,233	395	124,892	891	60,807	19,961	9,435	46,46
March	50,096	924	314	133,558	1,028	62,820	21,331	12,213	49,00
April	40,233	868	301	119,878	866	56,662	19,820	15,062	47,62
May	43,804	880	330	137,296	1,011	61,155	27,651	17,281	37,56
June	57,772	878	389	161,851	974	64,819	21,572	17,834	32,72
July	78,903	964	651	199,289	1,046	69,888	21,978	18,894	33,39
August	78,112	958	651	199,000	1,088	69,744	21,293	17,744	33,87
September	59,959	894	592	166,151	983	65,560	16,916	15,583	33,46
October	50,933	990	293	140,655	924	61,436	15,673	14,121	41,06
November	51,209	906	179	135,358	959	62,258	17,026	10,446	41,77
December	56,365	920	318	149,798	1,062	68,854	19,028	9,113	43,71

Source: EIA. Electric Power Annual 2023. U.S. Energy Information Administration, Washington, D.C. Available at: https://www.eia.gov/electricity/annual/table.php?t=epa_03_01_a.html [Accessed on 12th April, 2025].