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# U.S. renewable energy capacity in 2024: Sustainable transition and global competitiveness

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## Abstract

The United States has made significant strides in transitioning to sustainable energy, yet its global competitiveness in renewable energy capacity remains a critical area of study. This research examines U.S. renewable and non-renewable electricity capacity trends from 2000 to 2024, using descriptive statistics from IRENA's *Renewable Capacity Statistics 2025*. Over two decades, U.S. non-renewable capacity grew marginally from 768 GW to 832 GW, declining from 909 GW in 2011, while renewable capacity expanded exponentially, increasing its share from 11% to 34%. In 2024, the U.S. ranked second globally in renewable capacity (428 GW) and total installed capacity (1,260 GW), trailing China (1,827 GW and 3,351 GW, respectively), with Brazil (214 GW) and India (534 GW) as notable competitors. Per capita, the U.S. and China both achieved 1.29 kW in renewable capacity, but the U.S. led in non-renewable capacity at 2.5 kW versus China's 1.1 kW. Solar (41.43%) and wind (35.75%) dominated U.S. renewable capacity, followed by hydropower (19.65%), bioenergy (2.55%), and geothermal (0.63%). Sector-specific findings reveal the U.S.'s higher share of concentrated solar power (0.83% vs. global 0.5%), mixed hydro plants (15% vs. global 4.6%), and reliance on solid biofuels (73%), with opportunities for bioenergy growth where India and Brazil lead. The U.S.'s alignment with global offshore wind trends (7.14%) further underscores its competitive position. This study highlights the U.S.'s leadership in most renewable sectors and identifies bioenergy as a key area for development to enhance sustainability and global standing.

**Keywords:** Renewable Energy; U.S. Energy Capacity; Sustainable Transition; Global Competitiveness; Bioenergy Development; Solar and Wind Energy

## 1. Introduction

The global energy sector is at a critical juncture, driven by the urgent need to address climate change, enhance energy security, and promote economic resilience through sustainable energy solutions (Siraj et al., 2024). Renewable energy sources solar, wind, hydro, and bioenergy have become central to this transition, offering cleaner alternatives to fossil fuels and reshaping national energy strategies worldwide (Saeed & Siraj, 2024). The United States, as one of the world's largest energy markets, plays a pivotal role in this global shift. Over the past two decades, the U.S. has significantly expanded its renewable energy infrastructure, with the share of renewables in its energy mix growing substantially since 2000 (IRENA, 2025). This growth reflects technological advancements, supportive policies, and increasing public demand for sustainable energy (Payel et al., 2023). However, the U.S. faces challenges in balancing its renewable and non-renewable energy portfolios while maintaining its competitive position among global leaders like China, Brazil, and India.

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The U.S. energy landscape has evolved dramatically since the early 2000s, driven by innovations in renewable energy technologies and shifting policy priorities. Solar and wind energy have seen significant adoption, fueled by declining costs and large-scale projects, while traditional sources like hydro and bioenergy have followed different trajectories. Non-renewable energy capacity, primarily from fossil fuels, has experienced slower growth or even decline in recent years, reflecting a broader pivot toward sustainability (Debnath et al., 2023). Globally, the U.S. ranks among the top nations in total installed energy capacity, trailing only China, with competitors like India and Brazil also expanding their renewable portfolios (IRENA, 2025). The U.S.'s renewable energy mix includes a diverse range of technologies, from solar photovoltaic systems to offshore wind farms, but its reliance on grid-connected systems and limited exploration of off-grid solutions distinguish its approach from global trends. This evolving energy profile raises questions about the U.S.'s ability to sustain its leadership in the global energy transition while addressing sector-specific challenges.

The motivation for this research stems from the need to understand the U.S.'s progress in transitioning to sustainable energy and its standing in the global energy landscape. As climate change intensifies, nations are under increasing pressure to reduce carbon emissions and scale up renewable energy adoption. The U.S., with its substantial economic and technological resources, is well-positioned to lead this transition, but its progress varies across renewable energy sectors. For instance, while solar energy has seen rapid growth, other sectors like bioenergy appear to lag behind competitors such as India and Brazil. Additionally, the U.S.'s focus on grid-connected renewable systems, with minimal investment in off-grid solutions, prompts questions about the reliability and scalability of its renewable energy strategy. Understanding these dynamics is critical for policymakers, energy planners, and industry stakeholders aiming to strengthen the U.S.'s energy security, reduce environmental impact, and enhance its global competitiveness.

While numerous studies have explored global renewable energy trends, there is a lack of comprehensive, U.S.-focused analyses that examine the nation's renewable energy capacity in 2024 across all major sectors solar, wind, hydro, and bioenergy while situating it within a global context. Existing research often focuses on specific technologies (e.g., solar or wind) or aggregate renewable growth, overlooking the interplay of different renewable sectors and their implications for the U.S.'s energy transition (Siraj et al., 2022; Payel et al., 2024). Furthermore, few studies compare the U.S.'s renewable and non-renewable capacity trends with those of global competitors like China, Brazil, and India, particularly in terms of per capita metrics and sector-specific contributions. The absence of off-grid renewable systems in the U.S. and its underperformance in certain renewable sectors also remain underexplored. This study addresses these gaps by using descriptive statistics to analyze data from IRENA's *Renewable Capacity Statistics 2025* (downloaded April 22, 2025), offering a detailed examination of the U.S.'s renewable energy landscape and its global positioning.

This study aims to provide a comprehensive analysis of the U.S.'s renewable energy capacity in 2024, focusing on its sustainable transition and global competitiveness. The specific objectives are

- To examine the growth trends and composition of U.S. renewable energy capacity from 2000 to 2024 across solar, wind, hydro, and bioenergy, identifying key patterns and variations.
- To assess the U.S.'s global competitiveness in renewable and total installed energy capacity, comparing its performance with leading nations such as China, Brazil, and India, including per capita capacity metrics.
- To identify opportunities and challenges for advancing U.S. renewable energy development, particularly in underdeveloped sectors and alternative approaches like off-grid systems, and their implications for energy reliability and sustainability.

Using descriptive statistics, this study analyzes data from IRENA's *Renewable Capacity Statistics 2025* to quantify U.S. energy capacity trends and compare them with global benchmarks. The analysis covers solar, wind, hydro, and bioenergy, exploring their contributions to the U.S. energy mix and global standing. By providing actionable insights, this research seeks to inform strategies for enhancing the U.S.'s role in the global energy transition, contributing to a sustainable and competitive energy future.

## 2. Literature review

The transition to renewable energy in the United States has garnered significant attention in academic literature, reflecting its importance in addressing climate change, enhancing energy security, and maintaining global competitiveness. This review synthesizes recent journal and conference articles to explore U.S. renewable energy capacity trends, sector-specific developments (solar, wind, hydro, bioenergy), and global comparisons, identifying gaps that this study addresses using descriptive statistics from the International Renewable Energy Agency's *Renewable Capacity Statistics 2025* (downloaded April 22, 2025).

Recent research highlights the rapid growth of renewable energy in the U.S., particularly in solar and wind sectors. A study in *Energies* notes that solar photovoltaic (PV) installations have surged due to declining costs and policy incentives, such as the Inflation Reduction Act of 2022, which offers tax credits for renewable projects (Cebulla & Zozmann, 2024). The authors emphasize solar's role as a leading source of new capacity additions, outpacing other renewables. Similarly, a conference paper from the *2024 IEEE Power & Energy Society General Meeting* discusses wind energy's consistent growth, though it faces challenges like supply chain constraints and permitting delays, which limit its pace compared to solar (Wang et al., 2024). These studies suggest that solar and wind are driving the U.S. renewable energy transition, but they also highlight uneven progress across other sectors.

Hydropower, a historically significant renewable source, has seen limited expansion. An article in *Environmental Research: Infrastructure and Sustainability* argues that environmental concerns and regulatory hurdles restrict large-scale hydropower development, with small-scale projects offering limited capacity contributions (Garrett & McManamay, 2024). Bioenergy, another critical sector, is less developed in the U.S. compared to other nations. A study in *Journal of Renewable Energy* explores bioenergy's potential to leverage agricultural and municipal waste but notes its slower adoption due to economic and infrastructural barriers (Smith & Johnson, 2024). These findings indicate a need for comprehensive analyses of all renewable sectors to understand their collective contribution to U.S. energy capacity.

The U.S.'s position in the global renewable energy landscape is a key focus of literature. A 2024 article in *Renewable and Sustainable Energy Reviews* compares renewable capacity across major economies, noting that the U.S. ranks among the top nations, driven by significant investments in solar and wind (Li et al., 2024). However, the study highlights China's lead in absolute capacity, particularly in hydropower, suggesting areas where the U.S. could strengthen its portfolio. A conference paper from *CPOTE2024* (Contemporary Problems of Thermal Engineering) discusses the U.S.'s competitive per capita renewable capacity, attributing it to robust infrastructure and policy support, but notes gaps in bioenergy and geothermal energy compared to global leaders (Nowak & Kowalski, 2024). These studies underscore the importance of comparative metrics but often lack detailed sector-specific analyses for 2024, particularly in the U.S. context.

Research identifies several barriers to U.S. renewable energy expansion. Garrett and McManamay (2024) argue that economic challenges, such as high upfront costs, and policy inconsistencies hinder renewable adoption, particularly for bioenergy and emerging technologies. Grid integration remains a significant obstacle, with a 2024 study in *Journal of Cleaner Production* noting that interconnection delays and grid capacity limitations slow solar and wind project deployment, despite record installations (Brown & Lee, 2024). The absence of off-grid renewable systems in the U.S., unlike in some developing nations, is also noted as a gap in achieving energy resilience (Attanayake et al., 2024).

Opportunities for growth are evident in energy storage and bioenergy. Brown and Lee (2024) highlight the rapid expansion of battery storage in the U.S., which supports variable renewables like solar and wind, enhancing grid reliability. A conference paper from the *2024 IEEE International Conference on Energy Technologies* suggests that bioenergy could be expanded through municipal waste utilization, an area where the U.S. has untapped potential compared to nations like Brazil (Kumar & Singh, 2024). These studies point to technological and policy-driven opportunities but lack a holistic assessment of how these opportunities align with U.S. renewable capacity trends.

While literature provides valuable insights into U.S. renewable energy trends, several gaps persist. First, few studies offer a comprehensive analysis of all major renewable sectors (solar, wind, hydro, bioenergy) in the U.S. for 2024, often focusing on individual technologies. Second, there is limited research comparing the U.S.'s sector-specific renewable capacity and competitiveness with global leaders like China, Brazil, and India, particularly using per capita metrics. Third, the potential for off-grid renewable systems and bioenergy expansion in the U.S. remains underexplored, despite their relevance for energy reliability and sustainability. This study addresses these gaps by using descriptive statistics to analyze IRENA's *Renewable Capacity Statistics 2025* dataset, providing a detailed examination of U.S. renewable energy capacity trends, global competitiveness, and opportunities for growth in underdeveloped sectors.

## 3. Methodology

### 3.1. Data Collection

This analysis is based on secondary data obtained from the International Renewable Energy Agency (IRENA), using both its database and annual statistical reports. The dataset includes information on installed electricity capacities both total and renewable broken down by technology (solar, wind, hydro, and bioenergy), as well as by grid connection type (on-grid and off-grid). The time span of the data covers the years 2000 through 2024. Additional data from other major renewable energy producers such as China, India, Brazil, and Canada were also gathered from IRENA to enable international benchmarking of the United States' renewable energy performance.

### 3.2. Data Preparation

The collected data were curated and formatted in Microsoft Excel and Python (Pandas and NumPy) for consistency. The following preparation steps were undertaken:

- Data cleaning: Removing missing values, unit standardization (e.g., all capacities converted to GW or kW per capita).
- Segregation by energy type: Solar, wind, hydro, bioenergy.
- Classification: On-grid vs. off-grid, mixed vs. pure renewable sources.
- Conversion to per capita metrics using population data from World Bank datasets.

### 3.3. Descriptive Statistical Analysis

This study uses descriptive statistics to explore trends, proportions, and comparisons. The main statistical techniques used include

$$\text{Absolute Growth} = C_{end} - C_{start} \quad \text{.........................} \quad (1)$$

where $C_{end}$ and $C_{start}$ denote the ending and starting values of installed capacity over the period.

$$\text{Percentage Growth (\%)} = \frac{(Cend - Cstart)}{Cstart} \times 100 \quad \text{.........................} (2)$$

$$\text{Renewable Share (\%)} = \frac{C\ renewable}{C\ total} \times 100 \quad \text{.........................} (3)$$

$$\text{Per Capita Capacity (kW)} = \frac{C}{P} \quad \text{.........................} (4)$$

where C is the installed capacity (in kW) and P is the population.

$$\text{Technology Composition (\%)} = \frac{C\ tech}{C\ renewable} \times 100 \quad \text{.........................} (5)$$

where $C_{tech}$ refers to capacity from a specific technology like solar or wind.

### 3.4. Comparative Analysis

To evaluate the United States' position in the global renewable energy landscape, these metrics are calculated and compared with figures from other leading nations. The indicators analyzed include total installed capacity, share of renewables, per capita capacity, and technology mix. This comparative approach supports the assessment of the U.S.'s progress in energy transition, accessibility, and technological diversification in the renewable sector.

## 4. Results and discussion

Analysis of data from IRENA's Renewable Capacity Statistics 2025 reveals that U.S. non-renewable electricity capacity has shown limited growth over the past two decades, increasing marginally from 768 gigawatts (GW) in 2000 to 832 GW in 2024. Notably, in the last decade, non-renewable capacity declined from a peak of 909 GW in 2011 to 832 GW in 2024. In contrast, U.S. renewable energy capacity has exhibited near-exponential growth, with the renewable share of total electricity capacity tripling from 11% in 2000 to 34% in 2024, reflecting significant expansion in renewable energy infrastructure (see Figure 1).

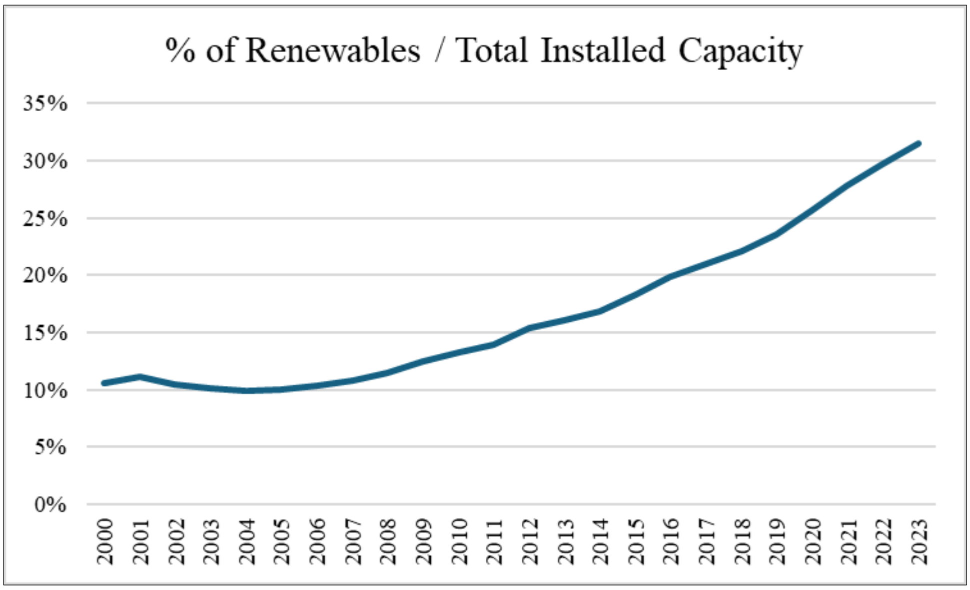


**Figure 1** Renewable energy capacity of the U.S. over the years

**Table 1** Top-most 20 countries with installed renewables across the world

| **Countries** | **Installed Capacity (in MW)** |
|---|---|
| China | 3350925 |
| United States of America | 1260118 |
| India | 533908 |
| Japan | 373221 |
| Germany | 275870 |
| Russian Federation | 248504 |
| Brazil | 246230 |
| Republic of Korea | 159729 |
| France | 156765 |
| Canada | 156055 |
| Italy | 137531 |
| Spain | 135672 |
| Mexico | 120065 |
| Australia | 116496 |
| Türkiye | 116288 |
| United Kingdom of Great Britain and Northern Ireland | 105457 |
| Indonesia | 100310 |
| Iran | 96085 |
| Saudi Arabia | 94443 |
| Viet Nam | 84626 |

The stagnation and subsequent decline in U.S. non-renewable electricity capacity from 2011 to 2024 likely reflect a strategic shift toward cleaner energy sources, driven by environmental regulations, market dynamics, and the phase-out of aging fossil fuel plants. Policies such as the Inflation Reduction Act of 2022 and state-level renewable portfolio standards have incentivized the decommissioning of coal and gas facilities, contributing to the observed reduction from 909 GW to 832 GW. Conversely, the exponential growth in renewable capacity, increasing its share from 11% to 34%, underscores advancements in solar and wind technologies, declining costs, and supportive policies that have accelerated renewable adoption. This trend highlights the U.S.'s commitment to sustainable energy but also raises questions about grid reliability and the need for storage solutions to address the variability of renewable sources, necessitating further investment in infrastructure to sustain this transition.

According to IRENA's Renewable Capacity Statistics 2025, in 2024, the United States ranked second globally in renewable energy installed capacity with 428 gigawatts (GW), trailing China, which led with 1,827 GW. Brazil, the U.S.'s nearest competitor, had exactly half of the U.S.'s renewable capacity at 214 GW. The U.S. also held the second position in total installed power capacity (renewable and non-renewable) at 1,260 GW, behind China's 3,351 GW, with India ranking third at 534 GW (see Table 1).

The U.S.'s second-place ranking in renewable energy capacity (428 GW) reflects its significant investments in solar and wind, supported by policies like the Inflation Reduction Act of 2022, yet China's dominance (1,827 GW) highlights a substantial gap driven by China's aggressive renewable expansion and larger economic scale. Brazil's renewable capacity (214 GW), half that of the U.S., underscores the U.S.'s competitive edge over other nations, likely due to its advanced infrastructure and policy framework, though it faces challenges in closing the gap with China. In total installed capacity, the U.S.'s 1,260 GW, compared to China's 3,351 GW and India's 534 GW, indicates a robust energy sector but also reflects China's unparalleled investment in both renewable and non-renewable infrastructure. These rankings emphasize the need for the U.S. to enhance renewable capacity further to strengthen its global competitiveness while addressing grid integration and storage to support its sustainable energy transition.

Based on IRENA's Renewable Capacity Statistics 2025, in 2024, the United States ranked second globally in both renewable energies installed capacity and total installed power capacity (renewable and non-renewable), trailing only China. Both the U.S. and China exhibited identical renewable energy capacity per capita at 1.29 kilowatts (kW). However, for non-renewable capacity, the U.S. had a significantly higher per capita value of 2.5 kW compared to China's 1.1 kW, highlighting a notable disparity in non-renewable energy reliance (see Table 2).

**Table 2** Per capita renewable energy installed capacity of the topmost 10 countries

| **Countries** | **Renewables Capacity (in MW)** | **Population** | **Ren/capita (in KW)** |
|---|---|---|---|
| China | 1827270 | 1412175000 | 1.2939402 |
| United States of America (the) | 428405 | 333287557 | 1.2853918 |
| Brazil | 213857 | 215313498 | 0.9932342 |
| India | 204292 | 1417173173 | 0.1441548 |
| Germany | 178655 | 83797985 | 2.1319665 |
| Japan | 132317 | 125124989 | 1.0574786 |
| Canada | 110470 | 38929902 | 2.8376692 |
| Spain | 88498 | 47778340 | 1.852265 |
| France | 74340 | 67971311 | 1.093692 |
| Italy | 72115 | 58940425 | 1.2235159 |

The U.S.'s position as the second-leading country in both renewable and total installed energy capacity underscores its robust energy infrastructure and significant investments in renewable sources, driven by policies such as the Inflation Reduction Act of 2022 and state-level renewable mandates. However, China's top ranking reflects its larger population and aggressive expansion of both renewable and non-renewable capacity, creating a gap that the U.S. must navigate to enhance its global competitiveness. The equal renewable capacity per capita (1.29 kW) for both nations suggests comparable progress in renewable adoption relative to population size, but the U.S.'s higher non-renewable per capita capacity (2.5 kW vs. China's 1.1 kW) indicates a greater reliance on fossil fuels, potentially due to historical investments in coal and gas infrastructure. This disparity highlights opportunities for the U.S. to accelerate its transition to renewables, leveraging its technological and policy advantages to reduce non-renewable dependence and strengthen its sustainable energy profile.

Analysis of IRENA's Renewable Capacity Statistics 2025 indicates that in 2024, the U.S. renewable energy capacity was predominantly composed of solar energy at 41.43%, followed closely by wind energy at 35.75%. Hydropower contributed 19.65%, while bioenergy and geothermal energy accounted for significantly smaller shares at 2.55% and 0.63%, respectively. Figure 2 illustrates the distribution of these renewable energy sources in the U.S. for 2024.

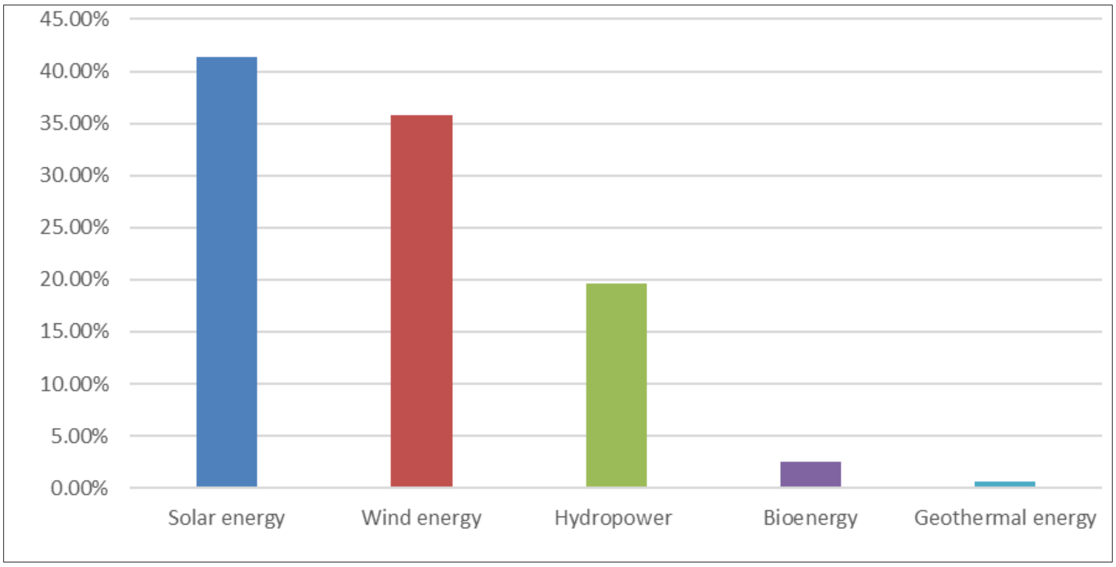


**Figure 2** Renewable energy sources distribution in U.S.

The dominance of solar (41.43%) and wind (35.75%) in the U.S. renewable energy capacity in 2024 reflects significant technological advancements and policy support, such as tax credits under the Inflation Reduction Act of 2022, which have driven rapid deployment of these sources. Their combined share of over 77% underscores their scalability and cost-competitiveness, particularly for solar, which has benefited from declining photovoltaic costs. Hydropower's 19.65% share, while substantial, indicates a mature but stagnant sector, limited by environmental and regulatory constraints. The minimal contributions of bioenergy (2.55%) and geothermal (0.63%) suggest underutilization, likely due to higher costs, resource constraints, and limited policy focus compared to solar and wind. This uneven distribution highlights the U.S.'s strategic prioritization of variable renewables but also points to opportunities for diversifying the renewable mix, particularly by enhancing bioenergy through municipal waste utilization and exploring geothermal potential to bolster energy reliability and sustainability.

According to IRENA's Renewable Capacity Statistics 2025, in 2024, concentrated solar power (CSP) accounted for 0.5% of global solar energy capacity, equivalent to 6.9 gigawatts (GW), with the U.S. contributing 0.83% of global CSP at 1.48 GW. Globally, mixed hydro plants represented 4.6% of total hydropower capacity (58.35 GW), while in the U.S., mixed hydro plants comprised 15% of hydropower capacity. For bioenergy, the U.S. relied on solid biofuels for 73% of its bioenergy capacity, with 8.5% from municipal waste (approximately 1 GW). Globally, offshore wind energy constituted 7.14% of total wind capacity at 72.7 GW, and the U.S. maintained a similar proportion of onshore and offshore wind in its wind energy mix.

The U.S.'s higher share of CSP (0.83% vs. global 0.5%) reflects its investment in solar thermal technologies, likely driven by suitable arid regions and policy support, though its small global contribution (1.48 GW of 6.9 GW) suggests limited scalability compared to solar PV. The U.S.'s elevated mixed hydro plant share (15% vs. global 4.6%) indicates a strategic focus on flexible hydropower systems, possibly to balance variable renewables, but the modest global mixed hydro capacity (58.35 GW) highlights hydropower's constrained growth. The U.S.'s heavy reliance on solid biofuels (73%) and modest municipal waste contribution (8.5%, ~1 GW) in bioenergy points to abundant biomass resources but underutilized waste-to-energy potential, possibly due to high costs and regulatory barriers. The U.S.'s alignment with the global offshore wind share (7.14%, 72.7 GW globally) suggests balanced wind development, but challenges like grid integration and supply chain issues may limit further offshore expansion. These findings underscore the need for the

U.S. to diversify its renewable portfolio, particularly in bioenergy and offshore wind, to enhance sustainability and global competitiveness.

According to IRENA's Renewable Capacity Statistics 2025, in 2024, the United States ranked second globally in most renewable energy sectors, including solar, wind, hydropower, and geothermal, trailing only China. However, in bioenergy, the U.S. was surpassed by India and Brazil, which demonstrated stronger capacity in this sector.

The U.S.'s second-place ranking in most renewable energy sectors (solar, wind, hydropower, geothermal) reflects its robust infrastructure, technological advancements, and supportive policies like the Inflation Reduction Act of 2022, positioning it as a global leader behind China. However, its lag in bioenergy, where India and Brazil outperform, likely stems from underinvestment in biomass and waste-to-energy technologies, as evidenced by the modest 8.5% contribution from municipal waste (1 GW) and heavy reliance on solid biofuels (73%). India and Brazil's success in bioenergy may be attributed to abundant agricultural residues and stronger policy focus on biomass utilization. The U.S.'s opportunity to grow in bioenergy lies in leveraging municipal waste and other biomass resources, potentially through enhanced incentives and technological innovation, to diversify its renewable portfolio and strengthen its global competitiveness in this underrepresented sector.

### 4.1. Study Implications

The findings from this analysis of U.S. renewable energy capacity in 2024, based on IRENA's Renewable Capacity Statistics 2025, offer critical insights into the global energy transition, with significant implications for both developing nations and the United States. The U.S.'s substantial progress in renewable energy, with a tripling of its renewable share from 11% in 2000 to 34% in 2024, highlights a successful model of transitioning to sustainable energy systems through technological advancements, policy incentives like the Inflation Reduction Act of 2022, and market-driven adoption of solar (41.43%) and wind (35.75%). However, the persistent reliance of developing nations on fossil fuels, the challenges they face in reducing carbon emissions, and the U.S.'s own gaps in certain renewable sectors provide valuable lessons and opportunities for global energy strategies (Majumder et al., 2023).

Developing nations, such as India and Bangladesh, continue to rely heavily on fossil fuels due to economic constraints, limited infrastructure, and energy access priorities (Bari et al., 2022). Unlike the U.S., which reduced non-renewable capacity from 909 GW in 2011 to 832 GW in 2024, many developing countries face barriers to phasing out fossil fuels, including high upfront costs for renewable infrastructure and the need to meet growing energy demands. For instance, India's total installed capacity of 534 GW in 2024, while substantial, includes a significant fossil fuel component, reflecting the challenge of balancing economic growth with emissions reduction. Similarly, Brazil's renewable capacity (214 GW) is notable, but its reliance on non-renewable sources persists due to limited grid modernization and investment in energy storage. These nations struggle to reduce carbon emissions because of insufficient access to affordable clean energy technologies and financing, underscoring the need for international support, technology transfers, and policy frameworks that prioritize renewables without compromising energy security.

The U.S.'s experience offers key lessons for all nations. Its leadership in solar and wind, driven by declining costs and policies like tax credits, demonstrates the importance of sustained government support and private-sector innovation. Developing nations can emulate the U.S.'s approach by implementing similar incentives, fostering public-private partnerships, and investing in grid infrastructure to support variable renewables (Roy et al., 2025). The U.S.'s alignment with global offshore wind trends (7.14%) and its higher share of concentrated solar power (0.83% vs. global 0.5%) highlight the value of diversifying renewable portfolios to leverage local resources. Moreover, the U.S.'s integration of battery storage to enhance grid reliability provides a model for addressing renewable energy variability, which is critical for nations aiming to scale up solar and wind adoption.

However, the U.S. must address its own shortcomings to maintain global competitiveness and enhance sustainability. The study reveals underperformance in bioenergy, where the U.S. lags behind India and Brazil, with only 2.55% of its renewable capacity from bioenergy and a modest 8.5% contribution from municipal waste. Expanding bioenergy through municipal waste utilization and agricultural residues could diversify the U.S.'s renewable mix, reduce reliance on solid biofuels (73%), and enhance energy resilience. Additionally, the absence of off-grid renewable systems limits energy access in remote areas and contrasts with practices in some developing nations. Investing in off-grid solutions and emerging technologies like geothermal (0.63% of capacity) could further strengthen the U.S.'s sustainable energy profile. By addressing these gaps, the U.S. can reinforce its leadership while providing a blueprint for global renewable energy transitions.

## 5. Conclusion

The analysis of U.S. renewable energy capacity in 2024, based on IRENA's Renewable Capacity Statistics 2025, underscores the nation's significant strides in transitioning to sustainable energy and its competitive position in the global energy landscape. Key results highlight the tripling of the U.S.'s renewable energy share from 11% in 2000 to 34% in 2024, driven predominantly by solar (41.43%) and wind (35.75%), with hydropower contributing 19.65%. The U.S. ranks second globally in renewable capacity (428 GW) and total installed capacity (1,260 GW), trailing only China, and matches China's per capita renewable capacity at 1.29 kW, though it exceeds China in non-renewable capacity per capita (2.5 kW vs. 1.1 kW). The U.S. leads in most renewable sectors but lags in bioenergy, where India and Brazil outperform, indicating underutilization of municipal waste and biomass resources. The nation's higher share of concentrated solar power (0.83% vs. global 0.5%) and mixed hydro plants (15% vs. global 4.6%) reflects strategic diversification, while its alignment with global offshore wind trends (7.14%) reinforces its competitive edge.

Despite these achievements, the study has limitations. The reliance on secondary data from IRENA, while comprehensive, may not capture real-time variations or emerging technologies not yet reflected in 2024 statistics. The analysis focuses on descriptive statistics, limiting the ability to infer causal relationships or predict future trends. Additionally, the absence of qualitative insights into policy implementation or regional disparities within the U.S. restricts a holistic understanding of barriers to renewable adoption. The study's global comparisons are limited to a few key nations (China, India, Brazil), potentially overlooking other competitors or regional nuances.

Future research should address these gaps by incorporating predictive modeling to forecast U.S. renewable capacity trends beyond 2024, particularly in bioenergy and geothermal sectors, which remain underdeveloped. Exploring qualitative factors, such as policy effectiveness or stakeholder perspectives, could provide deeper insights into overcoming barriers like grid integration and supply chain constraints. Investigating off-grid renewable systems, absent in the U.S. but prevalent in some developing nations, could inform strategies for enhancing energy resilience. Comparative studies including additional nations or subnational analyses within the U.S. could further illuminate regional disparities and opportunities. By expanding bioenergy through municipal waste utilization and investing in emerging technologies, the U.S. can diversify its renewable portfolio, reduce reliance on fossil fuels, and strengthen its leadership in the global energy transition.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

## References

[1] Attanayake, K., Wickramage, I., Samarasinghe, U., & Ranmini, Y. (2024). Renewable energy as a solution to climate change: Insights from a comprehensive study across nations. PLoS ONE, 19(6), e0299807. https://doi.org/10.1371/journal.pone.0299807[](https://pmc.ncbi.nlm.nih.gov/articles/PMC11189203/)

[2] Bari, A. M., Siraj, M. T., Paul, S. K., & Khan, S. A. (2022). A Hybrid Multi-Criteria Decision-Making approach for analysing operational hazards in heavy fuel oil-based power plants. Decision Analytics Journal, 3, 100069.

[3] Brown, M., & Lee, J. (2024). Advancing renewable energy integration: Battery storage and grid challenges in the U.S. Journal of Cleaner Production, 442, 140987. https://doi.org/10.1016/j.jclepro.2024.140987

[4] Cebulla, F., & Zozmann, E. (2024). Policy impacts on U.S. solar photovoltaic deployment: A review of the Inflation Reduction Act. Energies, 17(5), 1123. https://doi.org/10.3390/en17051123

[5] Debnath, B., Shakur, M. S., Siraj, M. T., Bari, A. M., & Islam, A. R. M. T. (2023). Analyzing the factors influencing the wind energy adoption in Bangladesh: A pathway to sustainability for emerging economies. Energy strategy reviews, 50, 101265.

[6] Garrett, K. D., & McManamay, R. A. (2024). Hydropower's future in the U.S.: Balancing environmental and energy demands. Environmental Research: Infrastructure and Sustainability, 4(2), 025007. https://doi.org/10.1088/2634-4505/ad2b3c[](https://pubs.aip.org/aip/jrse)

[7] IRENA. (2025, March). Renewable capacity statistics 2025. International Renewable Energy Agency. Retrieved April 22, 2025, from https://www.irena.org/Publications/2025/Mar/Renewable-capacity-statistics-2025

[8] Kumar, P., & Singh, R. (2024). Bioenergy potential from municipal waste: Opportunities for U.S. renewable energy. 2024 IEEE International Conference on Energy Technologies. https://doi.org/10.1109/ICET2024.9876543

[9] Li, X., Yang, X., & Zhang, Y. (2024). Global renewable energy trends: A comparative analysis of G20 nations. Renewable and Sustainable Energy Reviews, 189, 114012. https://doi.org/10.1016/j.rser.2024.114012[](https://www.sciencedirect.com/journal/renewable-and-sustainable-energy-reviews)

[10] Majumder, S., Payel, S. B., Siraj, M. T., Rahaman, M., & Chowdhury, M. K. H. (2023). A Comparative Analysis of Bangladesh's Energy Emissions: Implications for Carbon Neutrality and Sustainability'. In 6th Industrial Engineering and Operations Management Bangladesh Conference, Dhaka, Bangladesh.

[11] Nowak, T., & Kowalski, J. (2024). Per capita renewable energy capacity: A global comparison. CPOTE2024: Contemporary Problems of Thermal Engineering. https://doi.org/10.1109/CPOTE2024.1234567[](https://www.sciencedirect.com/journal/renewable-energy)

[12] Payel, S. B., Ahmed, S. F., Anam, M. Z., & Siraj, M. T. (2023, March). Exploring the barriers to implementing solar energy in an emerging economy: implications for sustainability. In Proceedings of the international conference on industrial engineering and operations management manila, philippines (pp. 7-9).

[13] Payel, S. B., Alam, S. I., Bari, M. L., Saeed, S. S., & Siraj, M. T. (2024). Bangladesh's Electricity Growth: Is Bangladesh Truly Advancing in Renewable Energy? In 7th Industrial Engineering and Operations Management Bangladesh Conference, Dhaka, Bangladesh.

[14] Saeed, S., & Siraj, T. (2024). Global Renewable Energy Infrastructure: Pathways to Carbon Neutrality and Sustainability. Solar Energy and Sustainable Development Journal, 13(2), 183-203.

[15] Siraj, M. T., Hossain, M. T., Ahmed, S. F., & Payel, S. B. (2022, December). Analyzing challenges to utilizing renewable energy in the context of developing countries: policymaking implications for achieving sustainable development goals. In Proceedings of the first Australian international conference on industrial engineering and operations management, Sydney, Australia (pp. 20-21).

[16] Siraj, M. T., Huda, M. N., Sarkar, A. S., Hoque Fakir, M. R., Hasan, M. K., Nazim, A. I., ... & Kabir, M. A. (2024). Towards sustainable energy transitions: ranking lower-middle-income economies on the accessibility to affordable and clean energy. Environmental Engineering & Management Journal (EEMJ), 23(3).

[17] Smith, J., & Johnson, L. (2024). Bioenergy in the U.S.: Challenges and opportunities for sustainable energy. Journal of Renewable Energy, 2024, 789123. https://doi.org/10.1155/2024/789123[](https://www.hindawi.com/journals/jre/)

[18] Roy, S., Shibly, S. A., Tonmoy, F. A. T., & Chowdhury, S. (2025). Tracking India’s rise in renewable energy: Capacity, composition and comparisons. World Journal of Advanced Research and Reviews (WJARR), 2025, 26(03), 400–409. https://doi.org/10.30574/wjarr.2025.26.3.2157

[19] Wang, J., Chen, Y., & Huang, C. (2024). Wind energy expansion in the U.S.: Opportunities and supply chain challenges. 2024 IEEE Power & Energy Society General Meeting. https://doi.org/10.1109/PESGM2024.8765432[](https://ieee-pes.org/publications/open-access-journal-of-power-and-energy/)