Solar Energy
And Sustainable Development
Refereed, biannual scientific journal issued by:
The Libyan Center for Solar Energy Research and Studies

Global Renewable Energy Infrastructure: Pathways to Carbon Neutrality and Sustainability

Syed Salman Saeed[1*], Md. Tanvir Siraj[1].

[1]Department of Mechanical Engineering,Bangladesh University of Engineering and Technology.

E-*mail:* salmansbuet@gmail.com, tanvir25392@gmail.com.

ARTICLE INFO.

Article history:
Received 15 Jun 2024
Received in revised form 23 Jun 2024
Accepted 28 Aug 2024
Available online 31 Aug 2024

KEYWORDS

Renewable energy capacity; Renewable energy sources; Global energy transition; Sustainable Development Goals; Energy policy.

ABSTRACT

The transition from fossil fuels to renewable energy is crucial for achieving environmental sustainability and carbon neutrality. The research focuses on the global landscape of renewable energy capacity, utilizing data from the 2024 report by the International Renewable Energy Agency (IRENA). The data was meticulously cleaned and organized based on countries and renewable energy sources, followed by sorting in descending order and performing Pareto analysis to identify the top 80% user countries. Graphical analyses, including bar and pie charts, were employed alongside linear percentage calculations to determine frequency distribution.

The findings reveal that 15 countries—China, the United States, Brazil, India, Germany, Japan, Canada, Spain, France, Italy, Türkiye, Russia, the United Kingdom, Australia, and Vietnam—account for over 80% (3,099,959 MW) of the world's total installed renewable energy capacity. China leads with 1,453,701.25 MW, followed by the USA with 387,548.59 MW, and Brazil with 194,084.66 MW. Solar energy is the largest contributor, representing 36.67% of global renewable capacity, followed by hydropower at 32.76% and wind energy at 26.29%. Bioenergy, geothermal, and marine energy contribute 3.88%, 0.38%, and 0.01%, respectively. The concentration of renewable energy capacity in a few countries and key sources underscores significant disparities in adoption and investment. The research emphasizes the need for tailored energy policies that consider regional resource availability, socio-economic structures, and geopolitical contexts to ensure equitable and sustainable energy development. Addressing these disparities is crucial for achieving the United Nations' Sustainable Development Goals (SDGs), particularly SDG 7,

*Corresponding author.

DOI: https://doi.org/10.51646/jsesd.v13i2.243

which focuses on affordable and clean energy for all. This study provides valuable insights for policymakers, highlighting the importance of a diversified and balanced approach to renewable energy adoption to contribute to global carbon neutrality and environmental sustainability.

البنية التحتية العالمية للطاقة المتجددة: مسارات الكربون الحياد و الاستدامة

سيد سليمان سعيد، محمد تنوير سراج.

ملخص: التحول من الوقود الأحفوري إلى الطاقة المتجددة أمر بالغ الأهمية لتحقيق الاستدامة البيئية والحياد الكربوني. تركز هذه الدراسة على المشهد العالمي لقدرة الطاقة المتجددة، حيث تم استخدام بيانات من تقرير عام 2024 الصادر عن الوكالة الدولية للطاقة المتجددة. (IRENA) تم تنظيف البيانات وتنظيمها بدقة بناءً على البلدان ومصادر الطاقة المتجددة، تلاها ترتيب تنازلي وإجراء تحليل باريتو لتحديد البلدان التي تشكل 80 ٪ من أكبر مستخدمي الطاقة المتجددة. تم استخدام تحليلات بيانية، بما في ذلك الرسوم البيانية الشريطية والدائرية، إلى جانب حسابات النسبة المئوية الخطية لتحديد توزيع التردد. تكشف النتائج أن 15 دولة – الصين، الولايات المتحدة، البرازيل، الهند، ألمانيا، اليابان، كندا، إسبانيا، فرنسا، إيطاليا، تركيا، روسيا، المملكة المتحدة، أستراليا، وفيتنام – تشكل أكثر من 80٪ (3,099,959) ميجاواط من إجمالي قدرة الطاقة المتجددة المثبتة في العالم. تتصدر الصين القائمة بقدرة 1,453,701.25 ميجاواط، تليها الولايات المتحدة بـ 387,548.59 ميجاواط، والبرازيل بـ 194,084.66 ميجاواط. تعد الطاقة الشمسية أكبر مساهم، حيث تمثل 36.67٪ من القدرة العالمية للطاقة المتجددة، تليها الطاقة الكهرومائية بنسبة 32.76٪ وطاقة الرياح بنسبة 26.29٪. تساهم الطاقة الحيوية، والطاقة الحرارية الأرضية، والطاقة البحرية بنسبة 3.88٪ و0.38٪ و0.01٪ على التوالي. يبرز تركيز قدرة الطاقة المتجددة في عدد قليل من البلدان والمصادر الرئيسية التباينات الكبيرة في التبني والاستثمار. تشدد الدراسة على الحاجة إلى سياسات طاقة مخصصة تأخذ في الاعتبار توفر الموارد الإقليمية، والهياكل الاجتماعية والاقتصادية، والسياقات الجيوسياسية لضمان تنمية طاقة مستدامة وعادلة. يعد معالجة هذه التباينات أمرًا حيويًا لتحقيق أهداف التنمية المستدامة للأمم المتحدة، وخاصة الهدف السابع (SDG 7)، الذي يركز على توفير طاقة نظيفة وميسورة التكلفة للجميع. توفر هذه الدراسة رؤى قيمة لصناع السياسات، مسلطةً الضوء على أهمية اتباع نهج متنوع ومتوازن لاعتماد الطاقة المتجددة من أجل المساهمة في تحقيق الحياد الكربوني العالمي والاستدامة البيئية.

الكلمات المفتاحية – قدرة الطاقة المتجددة، مصادر الطاقة المتجددة، التحول العالمي في مجال الطاقة، أهداف التنمية المستدامة، سياسة الطاقة .

1. INTRODUCTION

During the global energy crisis, the supply-demand imbalance driven by geopolitical issues is pushing policymakers to shift from fossil fuel-based infrastructure to renewable energy. Over the past few decades, environmental sustainability and carbon neutrality have become key drivers of renewable energy adoption [1], [2]. A significant portion of the global population is suffering from the negative impacts of carbon emissions. Over 410 million people are at risk of sinking below sea level due to rising temperatures caused by fossil fuel use [3]. In this context, modern civilization must reduce carbon emissions by increasing renewable energy use worldwide. However, the varying ability of regions to afford modern technology is hindering global efforts to effectively utilize renewable energy sources.

Among the United Nations' 17 SDGs, clean energy, particularly SDG 7, is highly important. However, it is not just about clean energy but also affordability [4]. Policymakers emphasize renewable energy use globally without fully considering factors like population size, Gross Domestic Product (GDP), and country area. The key question remains: will the same approach work for all countries?

Research shows that lower and lower-middle-income economies struggle to adopt renewable energy due to challenges like population density, high initial costs, established fossil fuel infrastructure, large land requirements, and lack of foreign investment [5], [6], [7]. But how severe are these challenges? A significant portion of the global population lives in these countries. Achieving SDG 7 while neglecting this population is unlikely by 2030. Moreover, without global participation, addressing issues like global warming, carbon emissions, and rising sea levels is not feasible.

This necessitates research on global accessibility to renewable energy by different countries, which is currently limited. An overview of renewable energy use worldwide can provide insights for both local and global policymakers on how the paradigm shift from fossil fuel-based energy to renewable energy will occur.

So, there are specific research questions (RQ) to be answered:

RQ1: Which countries are the major renewable energy users?

RQ2: What are the major renewable energy sources?

RQ3: What is the global scenario for these different sources?

As global energy demand rises, installed electricity capacity from both renewable and non-renewable sources has increased over the past two decades (see Figure 1). Non-renewable energy capacity grew from approximately 2,761,932 MW in 2000 to 5,093,539 MW in 2023, an 84% increase. In contrast, renewable energy capacity grew from 752,192 MW in 2000 to 3,869,704 MW in 2023, a 414% increase. However, the global focus should shift toward enriching renewable sources, as there is still a long way to go for balanced growth worldwide. Tailored policies considering each country's geopolitical context, socio-economic structure, and population size are essential for making this transition more effective. This research highlights country-wise expansion and utilization of renewable sources to identify specific patterns.

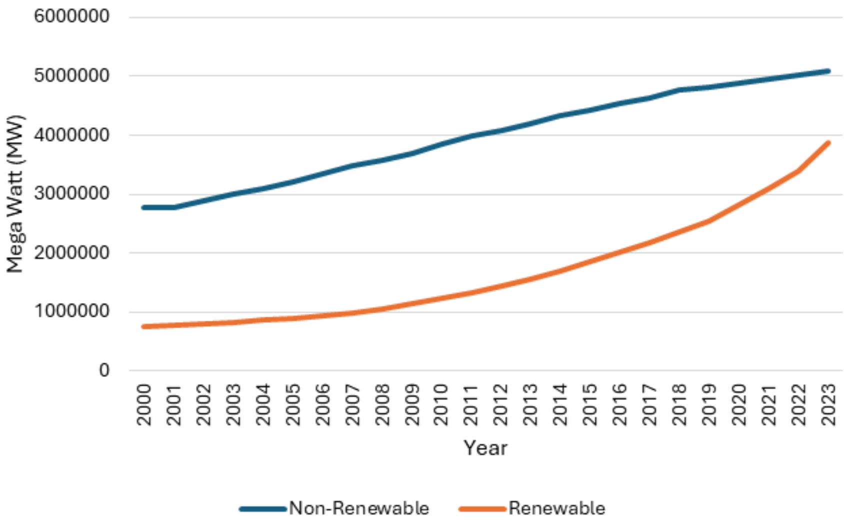


Figure 1. Global electricity installed capacity from 2000 to 2023 [8].

Several recent studies have explored various aspects of global renewable energy expansion. For instance, Yang et al. [9] examined renewable energy pathways toward carbon neutrality in Brazil, Russia, India, China, and South Africa (BRICS) from 1995 to 2021; Hassan et al. [10] identified significant differences in renewable energy adoption and technological advancements across countries, with renewable energy potentially supplying two-thirds of global energy by 2050; Qing et al. [11] demonstrated that investments in renewable energy and green financing helped 12 Chinese provinces move toward carbon neutrality and improved environmental quality from 2000 to 2019; Zhou [12] reviewed low-carbon transformation techniques, carbon trading systems, and global decarbonization roadmaps, emphasizing the need for strategies balancing economic pressures with renewable energy adoption; and Erdogan et al. [13] examined the impact of renewable energy investments on reducing petroleum-derived carbon emissions in Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States, collectively known as the Group of Seven (G7). However, a specific research gap remains in exploring global renewable energy infrastructure to determine pathways to carbon neutrality and sustainability. The ongoing research aims to address this gap and answer the previously raised research questions by fulfilling the following research objectives (RO):

RO1: Determine the major renewable energy-using countries in the world.

RO2: Identify the types of renewable energy sources used worldwide by their usage percentages.

To achieve these objectives, secondary data from a 2024 report by the IRENA is used. The study employs simple descriptive statistics, including data cleaning, sorting, Pareto analysis, linear percentage, and graphical analysis, to keep methods, results, and visualizations straightforward for researchers and policymakers. This approach provides novel insights that can be further developed using complex mathematical and statistical models.

Previous research has predominantly focused on regional situations, such as the European status, Asian status, G7 country status, higher-income country status, and middle-income country status. However, studies examining the overall global renewable energy scenario are very limited. Furthermore, past research has concentrated on the challenges to renewable energy adoption, critical success factors, and the characteristics and applications of various types of renewable energy sources. What remains unclear in the literature is the density of renewable energy use worldwide. Is renewable energy use equally distributed across the globe? If not, why are some countries more advanced while others lag behind? Is the disparity solely due to financial reasons, or do geopolitical factors, geographic location, and other elements play a significant role? These questions highlight the need for tailored solutions in policymaking rather than a one-size-fits-all approach.

These gaps are addressed in this research by providing a global perspective, examining how renewable energy use varies among countries and identifying the underlying reasons for these disparities. By focusing on both global and country-specific analyses, valuable insights for policymakers at both local and global levels will be provided. This dual approach will assist in developing tailored policies suited to the unique circumstances of different countries, rather than relying on a common formula. The novel contribution of this study lies in highlighting the uneven distribution of renewable energy use and proposing specific strategies to enhance renewable energy adoption based on each country's unique context.

The rest of the paper is structured as follows: Section 2 discusses various aspects of non-renewable and renewable energy for electricity generation; Section 3 outlines the research method applied; Section 4 presents the results, the discussion, the implications, and the limitations; and Section 5 concludes the paper by highlighting the unique findings and future research scope.

2. NON-RENEWABLE AND RENEWABLE ENERGY FOR ELECTRICITY GENERATION

Modern civilization demands energy for everyday home appliances, industrial production, transportation, and more. One of the most utilized forms of energy worldwide is electricity, and the installed capacity of electricity is generally simple to analyze due to data availability. Therefore, the installed capacity of electricity is considered in the study to explore different aspects of non-renewable and renewable energy.

2.1. Aspects of non-renewable energy

Non-renewable energy comes from sources that cannot be replenished within a human lifetime, such as fossil fuels like coal, oil, and natural gas, which are formed over millions of years from plant and animal remains [14]. Once depleted, they cannot be replaced, raising concerns about sustainability and environmental impact.

Electricity generation plants convert the chemical energy in fossil fuels into electrical energy [15]. In traditional coal, oil, or natural gas-fired plants, fossil fuels are burned to produce heat, which converts water into steam. The steam drives a turbine connected to a generator, converting mechanical energy into electricity. Afterward, the steam is cooled, condensed back into water, and cycled back to the boiler.

Reciprocating engine-based power plants also use non-renewable energy sources [16]. These plants operate with internal combustion engines, similar to those in vehicles but on a larger scale. Fossil fuels combust within the engine's cylinders, creating gases that move the pistons, which then turn a generator to produce electricity. These plants are often used for smaller-scale power generation and offer more flexibility in startup and shutdown times [17].

Fossil fuel-based electricity generation significantly impacts the environment and hampers carbon neutrality efforts. For example, a typical coal-fired plant produces around 1.8 kg of $CO2$ per kilowatt-hour (kWh) of electricity. A large coal plant generating 600 megawatts (MW) emits roughly 1,135.55 metric tons of $CO2$ per hour, amounting to over 10 million metric tons annually [15]. Natural gas plants, while cleaner, still emit about 0.30 to 0.40 kg of $CO2$ per kWh. With fossil fuels powering around 57% of global electricity production, the cumulative emissions are substantial (see Figure 2). These emissions contribute to global warming, air pollution, and health issues, underscoring the urgent need to transition to renewable energy to achieve carbon neutrality and mitigate environmental damage.

2.2. Aspects of renewable energy

Renewable energy comes from sources that can be replenished naturally within a human lifetime, such as solar, wind, hydro, bioenergy, geothermal energy, and marine energy. These energy sources are harnessed from natural processes that are continuously replenished, making them sustainable and environmentally friendly [7]. Unlike non-renewable sources, renewable energy does not deplete over time, thus providing a long-term solution to energy needs and significantly reducing environmental impact.

Electricity generation from renewable energy sources involves various technologies that convert natural energy into electrical power. Each technology has its own benefits and limitations, requiring customization based on different countries, weather conditions, expertise, and other factors.

Solar power plants primarily use two technologies to convert solar energy into electricity: Photovoltaic (PV) systems and Concentrated Solar Power (CSP) systems [18]. PV systems use semiconductor cells in solar panels to convert sunlight directly into electricity. These systems are commonly installed on rooftops of homes, businesses, and industrial buildings, making them ideal for decentralized energy production and reducing electricity costs. Large-scale solar farms, or solar parks, also use PV panels to generate electricity for the grid, typically located in areas with high solar irradiance, such as deserts or agricultural lands. PV systems are particularly useful in remote or off-grid locations, powering homes, schools, and medical facilities where extending the electrical grid is not feasible. In contrast, CSP systems use mirrors or lenses to concentrate sunlight onto a small area, using the heat to produce steam that drives a turbine connected to a generator [19]. CSP systems are typically used in large-scale power plants that supply electricity to the grid, requiring significant land and are often situated in regions with high direct sunlight, such as deserts. CSP can also be integrated with other energy sources, like natural gas or biomass, to create hybrid power plants with more consistent power output.

Wind power plants use turbines to convert wind's kinetic energy into mechanical power, which is then converted into electricity by a generator. Turbines can be installed onshore or offshore, with offshore turbines benefiting from stronger, more consistent winds [5], [20]. The most common technology is the horizontal-axis wind turbine (HAWT), featuring large blades mounted on a tower [21]. HAWTs are used in both onshore and offshore wind farms, typically located in areas with strong wind currents like plains, coastal regions, and bodies of water. Vertical-axis wind turbines (VAWTs), while less common, are well-suited for urban environments and turbulent wind conditions, as they can capture wind from any direction. Their design allows for installation in limited spaces, such as rooftops and urban areas. Small-scale wind turbines, designed for individual homes, farms, and remote communities, generate less power than large-scale turbines but offer a valuable source of renewable energy for off-grid locations or as a supplement to grid electricity. They provide a sustainable and cost-effective energy solution for homeowners and small businesses.

Hydropower plants generate electricity by harnessing the potential energy of stored water in dams or the kinetic energy of flowing rivers. Water flows through turbines, generating electricity. Hydropower is one of the oldest and most established renewable energy forms, providing significant electricity in countries with abundant water resources [22]. The most common technology is conventional hydroelectric power, involving large dams and reservoirs [7]. Water stored in the reservoir flows through turbines, generating electricity, typically in regions with significant river systems and suitable topography. Run-of-the-river systems divert a portion of river water through a canal or penstock to drive turbines without large reservoirs [23]. These systems have a smaller environmental footprint and are suitable where large dams are impractical. Pumped-storage hydropower acts as large-scale energy storage [24]. During low electricity demand, excess energy pumps water to an upper reservoir, which is released during high demand to generate electricity as it flows back through turbines. Micro-hydropower systems, typically generating less than 100 kilowatts, provide electricity to rural or remote areas. Installed on small streams or rivers, these systems offer a reliable and sustainable power source for local communities [25].

Biomass combustion is a common method of converting bioenergy to electricity, where organic materials like wood, agricultural residues, and waste are burned to generate heat, which then produces steam to drive turbines [26]. This method is widely used in regions with abundant agricultural and forestry resources. Anaerobic digestion, another key technology, breaks down organic materials like manure, food waste, and sewage sludge in the absence of oxygen to produce biogas, a mix of methane and carbon dioxide, which can generate electricity and heat. Biogas upgrading refines this biogas into biomethane, a renewable natural gas suitable for injection into gas grids or use as vehicle fuel, particularly in areas with existing gas infrastructure. Biofuel production converts organic materials into ethanol and biodiesel—ethanol from crops like corn and sugarcane through fermentation, and biodiesel from vegetable oils, animal fats, and recycled cooking oils via transesterification. These biofuels, mainly used in transportation, offer a renewable alternative to gasoline and diesel, especially in agriculturally rich regions. Advanced bioenergy technologies, like cellulosic ethanol and algae-based biofuels, improve sustainability by using non-food feedstocks, thus expanding the range of materials for bioenergy and reducing competition with food crops [27].

Geothermal energy harnesses heat from beneath the Earth's surface to generate electricity. The most common method is dry steam power plants, which use geothermal steam from underground reservoirs to drive turbines. These plants are typically found in regions with natural geothermal reservoirs, such as volcanic areas or tectonic plate boundaries, with notable examples in The Geysers, California, and Larderello, Italy [28]. Flash steam power plants bring high-pressure hot water from geothermal reservoirs to the surface, where it is depressurized into steam to drive turbines, making them ideal for high-temperature regions like Iceland, Indonesia, and the Philippines [29]. Binary cycle power plants use geothermal water to heat a secondary fluid with a lower boiling point, which vaporizes to drive turbines. This method is suitable for lower-temperature geothermal resources, broadening its application to areas like Nevada, USA, and

Turkey [29]. Enhanced Geothermal Systems (EGS) represent an advanced technology that creates artificial geothermal reservoirs by injecting water into hot rock formations deep underground. EGS can be used in various locations, including regions with deep hot rock formations, such as parts of Australia, France, and Germany [30].

Tidal energy is a well-established form of marine energy, harnessing the rise and fall of tides to generate power through tidal stream systems, which capture kinetic energy, or tidal range systems, which utilize potential energy from tidal height differences. Suitable locations include coastal areas with significant tidal ranges, like the Bay of Fundy in Canada and the Severn Estuary in the UK [31]. Wave energy captures energy from ocean surface motion using devices such as point absorbers, oscillating water columns, and attenuators, particularly effective in regions with strong, consistent waves, like the west coasts of Scotland, Portugal, and Australia [32]. Ocean thermal energy conversion (OTEC) generates electricity by exploiting the temperature difference between warm surface water and cold deep water, suitable for tropical regions like Hawaii, Puerto Rico, and parts of Southeast Asia [33]. Marine current energy harnesses kinetic energy from ocean currents, similar to underwater wind turbines, and is ideal for regions with strong currents, such as the Florida Straits and waters around Japan [34][35].

2.3. Comparing non-renewables and renewables

Renewable energy sources significantly contribute to reducing greenhouse gas emissions and combating climate change. For example, a typical 1 MW renewable energy-based power plant can reduce carbon dioxide (CO_2) emissions by several hundred metric tons annually compared to a fossil fuel-based power plant [36].

As of 2023, renewable energy sources accounted for about 43% of global electricity production, a significant increase from previous decades, but still far from the potential needed to achieve carbon neutrality (see Figure 2).

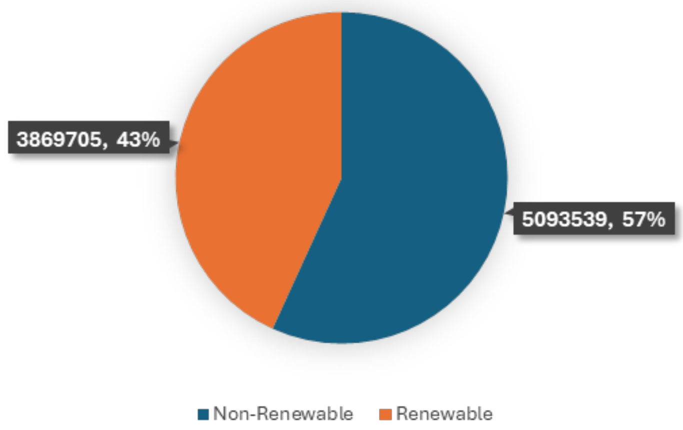


Figure 2. Global electricity installed capacity (in MW) in 2023 [8].

The widespread adoption of renewable energy technologies is essential for reducing global reliance on fossil fuels and mitigating environmental damage. Renewable energy not only provides a sustainable solution to energy needs but also plays a crucial role in enhancing energy security and creating economic opportunities through green jobs and technological innovation. Despite these advancements, the transition to renewable energy faces several challenges, including the need for large initial investments, grid integration issues, and the intermittency of some renewable sources [7]. Solar and wind energy, for instance, depend on weather conditions and time of day, requiring advanced storage solutions and smart grid technologies to ensure a reliable supply [37]. Hydropower, while stable, can be affected by changes in water availability due to climate change. Biomass energy must be managed sustainably to avoid negative impacts on food security and biodiversity.

Governments and policymakers play a vital role in overcoming these challenges by implementing supportive policies, providing financial incentives, and investing in research and development. International cooperation and knowledge sharing are also crucial for accelerating the global adoption of renewable energy technologies. Initiatives like the International Renewable Energy Agency (IRENA) facilitate collaboration and promote best practices to help countries transition to sustainable energy systems [38].

3. RESEARCH METHOD

This study employs a systematic approach to analyze the global landscape of renewable energy capacity, using data from the 2024 report by the IRENA. The research method is designed to ensure the accuracy and relevance of the findings, incorporating data cleaning, organization, analysis, and visualization techniques to provide insights into the distribution of renewable energy worldwide.

A simple descriptive statistics method is employed in this study to ensure that the methods, results, and visualizations are straightforward for researchers and policymakers. This approach provides novel insights that can be further developed using more complex mathematical and statistical models. Basic descriptive statistics are essential with any dataset initially to generate fruitful hypotheses, which can then undergo correlation analysis, regression analysis, analysis of variance, or advanced machine learning algorithms like K-means or Random Forest to understand and predict data patterns [39], [40]. Moreover, recent research highlights the integration of artificial intelligence (AI) for accurate climate predictions, demonstrating AI's potential in enhancing energy efficiency, optimizing smart grids, and reducing carbon emissions [41]. Training AI models with various types of data, such as those generated through descriptive statistics, can carry great significance. The primary aim of this study is to support policymakers by demonstrating that a common policy is not viable for all. Simplified statistics make this argument easily understandable for everyone. Upon completion of the research, the results are expected to provide a foundation for proposing effective hypotheses on renewable energy utilization, offering robust research opportunities in the future.

3.1. Data Collection and Cleaning

The data source for this study is the 2024 IRENA report (*https://www.irena.org/Publications/2024/Mar/Renewable-capacity-statistics-2024*), which provides detailed information on renewable energy capacities across various countries. The raw data was first meticulously cleaned to remove any inconsistencies, errors, or outliers. Data cleaning involved:

i) Identifying and Handling Missing Data: Missing values were identified and handled appropriately, either through imputation methods or by excluding incomplete records where necessary.

ii) Standardization: The data was standardized to ensure consistency in units and formats across different countries and energy sources. This process included converting energy capacities to a common unit of measurement (megawatts, MW).

3.2. Data Organization

Following the cleaning process, the data was organized based on two key dimensions:

i) Countries: Each country's renewable energy capacity was categorized and aggregated to

represent its total installed capacity.
ii) Renewable Energy Sources: The data was further categorized by types of renewable energy sources, including solar, wind, hydropower, bioenergy, geothermal, and marine energy.

3.3. Data Analysis Techniques

Several analytical methods were employed to derive meaningful insights from the organized data:
i) Sorting and Ranking: The data was sorted in descending order based on each country's total renewable energy capacity. This allowed for the identification of the top contributors to global renewable energy capacity.
ii) Pareto Analysis: Pareto analysis was performed to identify the top 80% of countries contributing to the global renewable energy capacity. Pareto analysis is based on the Pareto principle, which states that roughly 80% of effects come from 20% of the causes. This method helped in highlighting the countries that play a dominant role in the global renewable energy landscape.

$$P(x) = \frac{Cumulative\ Capacity\ of\ Top\ Countries}{Total\ Global\ Capacity} \times 100\% \qquad ......(1)$$

Where P(X) represents the percentage contribution of the top countries to the global renewable energy capacity.
iii) Frequency Distribution: Linear percentage calculations were used to determine the frequency distribution of renewable energy capacities across different countries and energy sources. This helped in understanding the spread and concentration of renewable energy capacity worldwide.

$$F_i = \frac{n_i}{N} \times 100\% \qquad ....(2)$$

Where,
F_i is the frequency percentage of country i; n_i is the renewable energy capacity of country i; and N is the total global renewable energy capacity.

3.4. Data Visualization

To effectively communicate the findings, following graphical analysis techniques were employed:
i) **Bar Charts:** Bar charts were used to visualize the total renewable energy capacity of the top-ranked countries. This allowed for a clear comparison of capacities between countries.
ii) **Pie Charts:** Pie charts were employed to represent the distribution of different types of renewable energy sources within the top countries. This visual approach made it easier to comprehend the proportional contributions of each energy source.
iii) **Choropleth Map:** Choropleth maps were used to visualize the distribution of renewable energy capacity across different countries. This technique allowed for a clear representation of regional disparities, with denser colors indicating higher capacities and lighter colors showing lower capacities.

4. RESULTS, DISCUSSION, LIMITATIONS, AND IMPLICATIONS

This study has identified the major renewable energy-using countries, the primary renewable energy sources, and their various characteristics and patterns. A summary of the results of this study can be found in Figure 3.

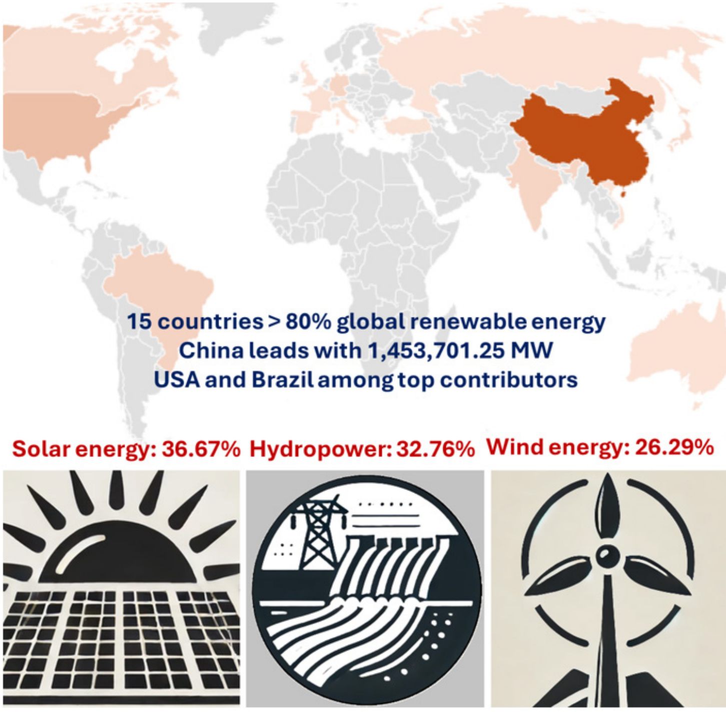


Figure 3: Summary of key findings.

4.1. Results on major players in global renewable energy

In 2023, among the 3,869,705 MW of installed electricity capacity from renewable energy sources, around 80% (3,099,959 MW) is concentrated in just 15 countries. These countries are China, the United States of America (USA), Brazil, India, Germany, Japan, Canada, Spain, France, Italy, Türkiye, the Russian Federation (Russia), the United Kingdom (UK), Australia, and Vietnam. See Figure 4 for the installed electricity capacity from renewable sources in these 15 countries.

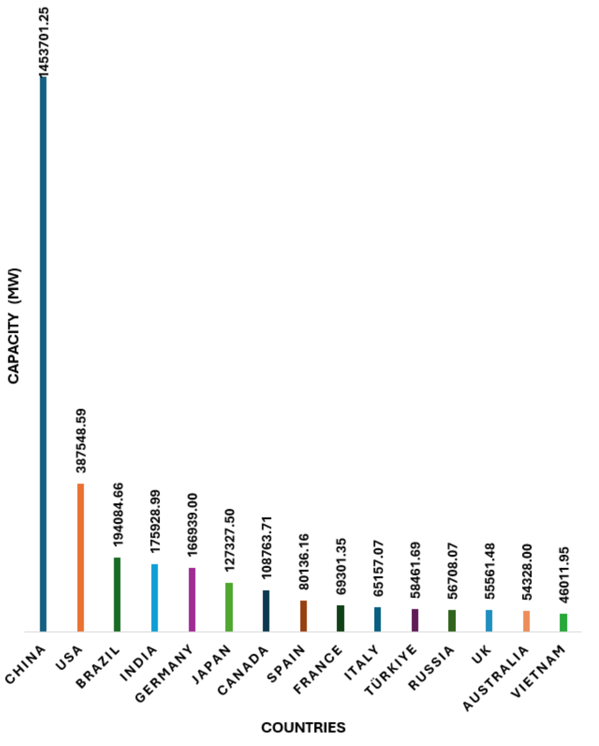


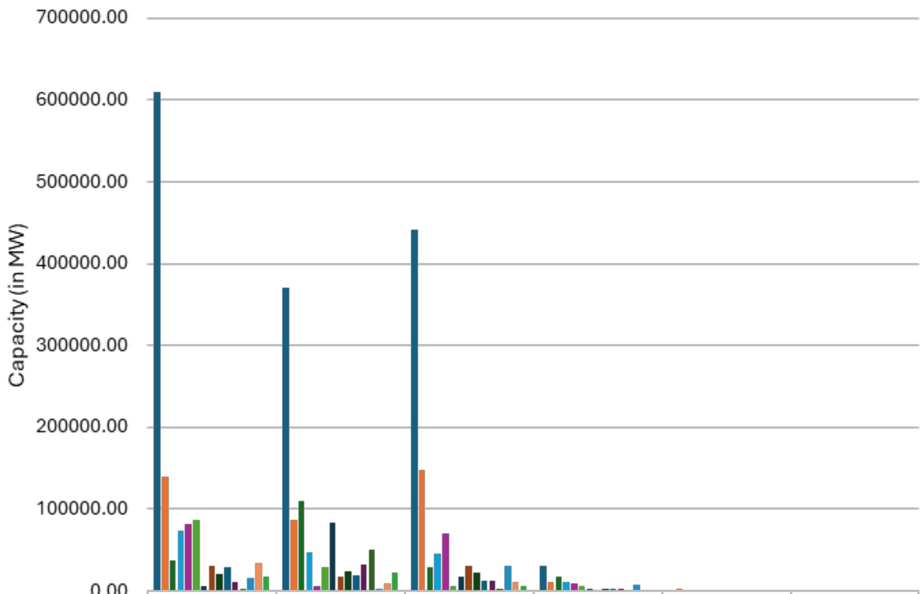
Figure 4. Top 15 players in global renewable energy in 2023.

4.2. Results on primary renewable energy sources

This research identifies six primary types of renewable energy sources used globally: bioenergy, geothermal, hydropower, marine, solar, and wind (see Table 1). The geography-dependent nature of these sources makes the choice of technology and energy type crucial for country-specific use (see Figure 5).

Table 1. Electricity installed capacity with the primary renewable energy sources.

Energy Sources	Capacity (in MW)	Percentage
Solar energy	1418968.98	36.67%
Hydropower	1267902.92	32.76%
Wind energy	1017198.79	26.29%
Bioenergy	150261.17	3.88%
Geothermal energy	14845.94	0.38%
Marine energy	526.92	0.01%



	Solar	Hydro	Wind	Bio	Geothermal	Marine
China	609920.80	370600.00	441894.95	31255.00	25.75	4.75
USA	139205.28	86660.35	148019.86	10989.50	2673.60	0.00
Brazil	37449.21	109903.35	29135.12	17596.94	0.00	0.05
India	73109.34	47331.00	44736.24	10752.41	0.00	0.00
Germany	81739.00	5741.00	69459.00	9950.00	50.00	0.00
Japan	87068.00	28216.00	5232.00	6383.50	428.00	0.00
Canada	5757.33	83307.20	16989.42	2682.36	6.00	21.40
Spain	31016.27	16808.69	31027.76	1278.63	0.00	4.80
France	20551.29	24139.01	22195.58	2187.25	16.15	212.07
Italy	29795.32	18847.79	12307.51	3434.46	771.79	0.21
Türkiye	11292.63	31779.49	11697.16	2001.07	1691.34	0.00
Russia	2170.12	50571.00	2517.75	1372.50	74.00	2.70
UK	15656.50	2190.43	30215.17	7476.98	0.00	22.40
Australia	33683.00	8439.96	11327.00	877.94	0.10	0.00
Vietnam	17077.41	22638.80	5888.00	407.74	0.00	0.00

China USA Brazil India Germany Japan Canada Spain
France Italy Türkiye Russia UK Australia Vietnam

Figure 5. Top 15 countries by renewable energy sources for electricity production.

4.3. Discussion

Renewable energy is utilized by over a hundred countries globally, but its consumption is highly concentrated [42]. The research highlights significant disparities in the distribution and concentration of installed renewable electricity capacity, with 15 countries accounting for over 80% (3,099,959 MW) of the global total (see Figure 4). In 2023, China leads with 1,453,701.25 MW, followed by the United States with 387,548.59 MW, and Brazil with 194,084.66 MW. These three countries alone represent a substantial share of global capacity.

The concentration of capacity in a few countries indicates disparities in the adoption and investment in renewable technologies. China's leadership is driven by substantial investments and policy support, serving as a model for other nations [43]. The USA and Brazil also show significant capacities due to their vast resources, while European countries like Germany, Spain, and France benefit from strong policy frameworks.

The study also examines the global distribution of key renewable energy sources—solar, hydropower, wind, bioenergy, geothermal, and marine energy (see Table 1). Solar energy leads with 36.67% of the global capacity, followed by hydropower at 32.76% and wind energy at 26.29%. Bioenergy, geothermal, and marine energy contribute 3.88%, 0.38%, and 0.01%, respectively. The dominance of solar, hydropower, and wind highlights their critical roles in the current renewable energy landscape, driven by technological advancements and supportive policies [5], [10].

From the study, China leads globally in renewable energy capacity, with a remarkable 609,920.80 MW in solar power, 441,894.95 MW in wind power, and 370,600.00 MW in hydroelectric power. These figures underscore China's aggressive investment in renewable energy to reduce its carbon footprint and reliance on fossil fuels. Additionally, China has a modest capacity in biomass (31,255 MW) and geothermal energy (25.75 MW), showing a comprehensive approach to energy diversification. The United States follows China with significant capacities in wind (148,019.861 MW) and solar (139,205.277 MW) energy. The hydroelectric capacity stands at 86,660.353 MW, while biomass energy contributes 10,989.5 MW. The geothermal capacity is noteworthy at 2,673.6 MW, reflecting the country's utilization of diverse renewable resources. This diverse energy mix aligns with the US's strategic goals of energy security and environmental sustainability. Brazil's energy landscape is dominated by hydroelectric power, with a capacity of 109,903.346 MW, leveraging its vast river systems. The country also invests in wind energy (29,135.122 MW) and biomass (17,596.939 MW), contributing to its renewable energy matrix. The solar capacity, however, is relatively lower at 37,449.205 MW, indicating potential growth areas. India's renewable energy capacity is notable in solar (73,109.342 MW) and wind (44,736.240 MW) power, reflecting its significant strides in these sectors. The hydroelectric capacity is 47,330.995 MW, while biomass energy stands at 10,752.414 MW. India lacks marine energy capacity, highlighting an area for potential development. Germany showcases a balanced approach with substantial capacities in solar (81,739 MW) and wind (69,459 MW) energy. The hydroelectric capacity is relatively low at 5,741 MW, and biomass energy is 9,950 MW. Germany's negligible geothermal capacity (50 MW) suggests a focus on more established renewable technologies. Japan has significant capacities in solar (87,068 MW) and hydroelectric power (28,216 MW), alongside a smaller wind capacity (5,232 MW). Biomass energy is 6,383.5 MW, and geothermal capacity is 428 MW. Japan's energy strategy emphasizes solar and hydroelectric power, reflecting its geographical constraints and resource availability. Canada's energy capacity is led by hydroelectric power (83,307.2 MW), reflecting its abundant water resources. The country also invests in wind (16,989.418 MW) and solar (5,757.33 MW) energy. Biomass energy is 2,682.357 MW, with minimal geothermal capacity (6 MW), indicating a strong focus on hydroelectric power.

Spain excels in solar (31,016.274 MW) and wind (31,027.764 MW) energy capacities, highlighting its commitment to renewable energy. The hydroelectric capacity is 16,808.693 MW, while biomass energy is 1,278.63 MW. Spain lacks geothermal capacity, focusing primarily on solar and wind. France's energy mix includes solar (20,551.293 MW), wind (22,195.575 MW), and hydroelectric power (24,139.006 MW). Biomass energy is 2,187.252 MW, and geothermal capacity is minimal (16.15 MW), reflecting a balanced approach with room for growth in geothermal energy. Italy invests significantly in solar (29,795.318 MW) and hydroelectric power (18,847.79 MW), alongside wind energy (12,307.508 MW). Biomass energy stands at 3,434.457 MW, and geothermal capacity is 771.79 MW, indicating a diverse renewable energy portfolio.

Türkiye's energy capacity is diverse, with significant investments in solar (11,292.63 MW), hydroelectric power (31,779.49 MW), and wind energy (11,697.16 MW). Biomass energy is 2,001.067 MW, and geothermal capacity is 1,691.338 MW, reflecting a comprehensive renewable energy strategy. Russia's energy capacity is notable in hydroelectric power (50,571 MW), with smaller investments in solar (2,170.12 MW), wind (2,517.75 MW), and biomass (1,372.5 MW) energy. Geothermal capacity is minimal (74 MW), indicating a reliance on hydroelectric power. The UK demonstrates significant capacities in wind (30,215.173 MW) and solar (15,656.5 MW) energy. Hydroelectric capacity is low at 2,190.434 MW, with biomass energy at 7,476.977 MW. The absence of geothermal capacity suggests a focus on wind and solar energy.

Australia's energy capacity is led by solar (33,683 MW), reflecting its abundant sunlight. Wind energy capacity is 11,327 MW, while hydroelectric capacity is 8,439.96 MW. Biomass energy is minimal at 877.94 MW, and geothermal capacity is negligible (0.1 MW), highlighting a strong focus on solar energy. Vietnam invests in solar (17,077.41 MW) and hydroelectric power (22,638.8 MW), with smaller capacities in wind (5,888 MW) and biomass (407.735 MW) energy. The absence of geothermal capacity indicates potential areas for future development.

The global distribution of installed electricity capacity highlights the diverse approaches to renewable energy adoption. China and the United States lead in overall capacities, with other countries like Brazil, Germany, and India showing strengths in specific areas. This diversity underscores the importance of tailored energy strategies that leverage local resources and technological advancements to meet national energy demands and environmental goals.

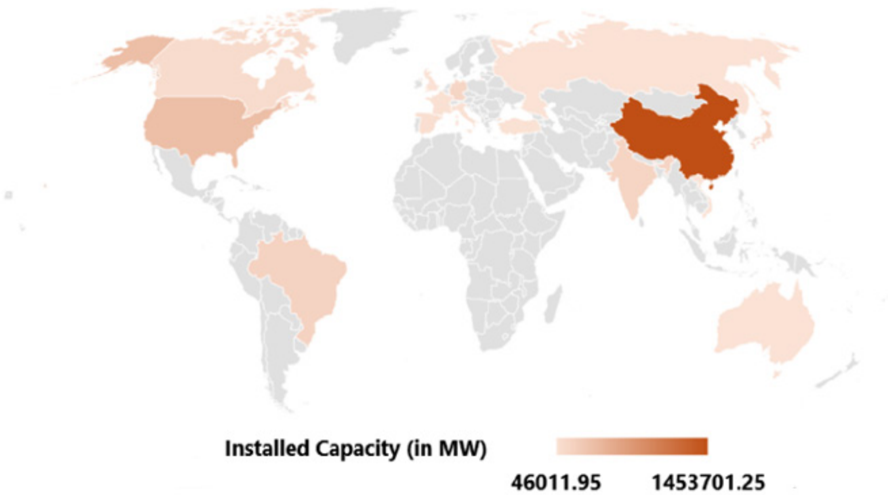


Figure 6. Concentration of renewable energy throughout the world.

From Figure 6, it can be observed that renewable energy is less installed in the African region, the Central and South Asian regions, and, excluding Brazil, also in the South American region. A significant portion of the global population lives in these regions. Without their active participation in a carbon-neutral world through energy transition, sustainable development goals cannot be achieved. Developing, lower-middle-income, and underdeveloped countries need to be prioritized in global policy for installing and developing renewable energy [7]. Global policymakers should focus on these regions and identify the forces driving energy development in the 15 leading countries identified by this research.

According to Osman et al. [44], climate change could reduce wind and hydropower production by up to 40% in certain regions, while solar energy remains relatively unaffected. Additionally, climate change can alter biomass productivity, growth, chemical composition, and soil microbial communities. Among renewable energy sources, hydroelectric power plants cause the most environmental damage, whereas solar photovoltaics need careful installation to minimize their impact. In contrast, wind turbines and biomass power plants have minimal environmental impact and should be widely implemented. This research strongly supports the claim on the need for tailored policymaking for various countries and renewable sources in this era of devastating global warming and climate change.

4.4. Implications on global energy politics

80% of the global renewable energy capacity is concentrated in just 15 countries, significantly impacting global energy politics and potential conflicts. This concentration may shift geopolitical power, raise energy security concerns, and spark conflicts over resources.

China, now the largest producer of solar and wind energy, has gained a strategic advantage in global energy policies. Through initiatives like the Belt and Road Initiative (BRI), China has invested heavily in renewable energy projects worldwide, enhancing its geopolitical influence [45]. By exporting renewable energy technologies and investing in infrastructure, China positions itself as a leader in the global energy transition, creating dependencies that can be leveraged in international negotiations. Similarly, the USA's resources and technological advancements enable it to exert substantial influence in the global renewable energy landscape, potentially reshaping international relations.

Countries with lower renewable energy capacities face significant energy security concerns, becoming dependent on leading producers for technology, expertise, and energy imports. This dependency increases their vulnerability to supply disruptions and price fluctuations, undermining their energy security. For example, many African nations, despite abundant renewable resources, struggle to develop their renewable energy sectors due to financial and technical constraints [46]. As a result, they rely heavily on imported technologies, primarily from China and Europe, making them susceptible to geopolitical tensions and supply chain disruptions.

Disparities in renewable energy capacities also heighten tensions over access to technologies and resources. In South America, the conflict over lithium resources in the Lithium Triangle (Bolivia, Chile, Argentina), which holds the world's largest lithium reserves, illustrates these tensions [47]. The global demand for lithium, crucial for renewable energy systems, has led to geopolitical strife, with nations and corporations vying for control. In Bolivia, political instability and nationalization policies have further complicated international investments in the lithium sector.

4.5. Implications considering socio-economic and geopolitical factors

The adoption of renewable energy is shaped by a complex mix of socio-economic and geopolitical factors, including economic development, social acceptance, access to natural resources, industrial structure, financial resources, geopolitical strategy, and international relations.

Germany has led in renewable energy adoption due to its strong economy and the Renewable Energy Sources Act (EEG) of 2000, which provided feed-in tariffs that boosted solar and wind capacity [48]. In the United States, varying social acceptance has resulted in state-level policies, with California and Texas leading in renewable energy production thanks to robust public and political support [49]. Brazil's vast hydropower resources have made it a leader in renewable energy, with hydropower contributing significantly to its electricity generation [50]. Following the Fukushima nuclear disaster, Japan has strategically increased its renewable energy capacity to enhance energy security and reduce reliance on imported fossil fuels [51].

Countries like Denmark and the UAE have made significant strides by focusing on specific energy sources. Denmark's emphasis on innovation has propelled it to a leadership position in wind energy [52], while the UAE has leveraged its financial resources, through projects like Masdar City, to become a hub for renewable energy research and development [53]. The EU's Horizon 2020 program exemplifies international cooperation, funding renewable energy projects and promoting innovation across member states [54].

However, some countries face challenges despite their renewable energy ambitions. India, while advancing in solar and wind energy, struggles with socio-economic issues like financial constraints and grid infrastructure challenges, hindering widespread adoption [55]. South Africa, despite its potential for solar and wind energy, has been slowed by political instability, regulatory uncertainty, and financial difficulties. Achieving broader adoption in these countries requires stable governance, clear regulations, and improved financing [56].

4.6. Implications on society

Farghali et al. [57] emphasize that addressing the social implications of transitioning to renewable energy requires consideration of societal acceptance, employment changes, and equity issues. Renewable energy can have significant social impacts, such as poverty reduction, climate change mitigation, and health improvements by reducing pollution from gas emissions. Investments in renewable energy can alleviate poverty by creating jobs, particularly in rural areas. For example, a 1-gigawatt hour (GWh) increase in electricity generation from renewable sources can create 3.5 jobs. In 2016, renewable energy technologies generated 9.8 million jobs globally, with solar energy contributing 43% of employment in the USA's electrical sector, compared to 22% from fossil fuels. Future job projections include 4.18 million jobs in solar photovoltaic by 2050, 894 thousand in battery storage by 2050, 504 thousand in wind energy by 2030, 297 thousand in hydropower by 2020, and 523 thousand in bioenergy by 2025.

While renewable energy projects can create jobs and reduce poverty in rural areas, careful planning is essential to ensure benefits are equitably distributed and do not exacerbate existing inequalities. Countries like China, Brazil, and India have seen significant job creation and economic benefits from increased renewable energy investments.

4.7. Implications on achieving SDG 7

The research findings closely align with the Sustainable Development Goals (SDGs), particularly SDG 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all. The concentration of renewable energy capacity in a small number of countries highlights the disparities in global energy access and underscores the need for tailored policy interventions. For example, Germany's success in renewable energy adoption, driven by the German Renewable Energy Sources Act (EEG), demonstrates how robust policy frameworks can significantly boost renewable energy capacities, aligning with SDG 7.2, which focuses on increasing the share of renewable energy in the global energy mix [58]. Similarly, Brazil's extensive use of hydropower aligns with SDG 7.1, which aims to ensure universal access to affordable, reliable, and modern energy services [58]. By leveraging its vast river systems, significant strides have been made by Brazil in providing sustainable energy to its population, showcasing how resource availability can be effectively utilized to meet SDG targets.

To achieve SDG 7, it is crucial to address the renewable energy capacity gaps in developing and lower-middle-income countries [4]. For instance, notable progress has been made by India in solar and wind energy, supported by government initiatives like the National Solar Mission, which aligns with SDG 7.A, aimed at enhancing international cooperation to facilitate access to clean energy research and technologies [59]. However, the persistent challenges of financial constraints and grid infrastructure issues highlight the need for continued support and investment. Another practical example is Kenya, where the deployment of off-grid solar energy solutions has significantly improved energy access in rural areas, aligning with SDG 7.B, which promotes expanding infrastructure and upgrading technology for supplying modern and sustainable energy services in developing countries [60]. These examples illustrate that achieving SDG 7 requires a comprehensive approach that combines policy support, financial investment, and international cooperation to ensure that all countries, particularly those with lower renewable energy capacities, can participate in the global transition to sustainable energy.

4.8. Limitations

Several limitations of this study should be acknowledged. Although a robust dataset from the IRENA was utilized, the analysis was primarily descriptive, aimed at providing a foundational understanding of the global renewable energy landscape. Descriptive statistics, while useful for initial data exploration, are limited in that they only summarize data from a specific sample without allowing for generalizations about a larger population. They do not enable inference, hypothesis testing, or establish causal relationships, making it difficult to determine statistical significance or predict future outcomes. Furthermore, descriptive analyses may oversimplify complex data, potentially masking important details, and their interpretation is often context dependent.

The dataset used was secondary data collected and prepared by IRENA, which was cleaned for the purposes of this study. However, it is important to note that this dataset provides only a preliminary estimate of global renewable energy employment and reveals significant data gaps for certain countries and technologies. These gaps are largely due to renewable energy being a relatively new and cross-cutting industry that is not distinctly classified in national economic or labor statistics. The absence of data on specific technologies or countries often reflects these data gaps rather than a lack of renewable energy implementation.

5. CONCLUDING REMARKS

This research provides a comprehensive analysis of the global landscape of renewable energy capacity, addressing key research questions and objectives. The study aimed to determine the major renewable energy-using countries (RQ1), identify the primary renewable energy sources (RQ2), and understand the global scenario for these sources (RQ3). By utilizing secondary data from IRENA, insights were gained into the distribution and utilization of renewable energy worldwide.

The findings reveal that a small group of countries, primarily China, the United States, and Brazil, dominate the global renewable energy capacity. Only 15 countries collectively account for over 80% of the total installed capacity. This concentration underscores significant disparities in the adoption and investment in renewable energy technologies across different regions. China leads with substantial investments in solar, wind, and hydroelectric power, setting a benchmark for other nations. The USA and Brazil follow with notable capacities, driven by their vast geographical areas and resource potentials. European countries like Germany, Spain, and France also show strong renewable energy adoption, supported by robust policy frameworks and incentives.

The analysis of major renewable energy sources highlights solar energy as the largest contributor to global renewable capacity, followed by hydropower and wind energy. These three sources collectively account for over 95% of the global renewable energy capacity, emphasizing their critical roles in the current energy landscape. Bioenergy, geothermal, and marine energy, though less prominent, offer significant potential for future growth, especially in regions with suitable resources.

To effectively address the disparities in renewable energy adoption, specific strategies tailored to the unique needs and capacities of different regions should be implemented by policymakers. Firstly, international funding mechanisms and investment incentives should be established to significantly enhance the renewable energy infrastructure in developing and lower-middle-income countries. Programs such as concessional loans, grants, and public-private partnerships can alleviate financial constraints and attract private sector investment in renewable energy projects. Additionally, a framework for technology transfer and capacity-building initiatives should be created to enable these countries to harness advanced renewable energy technologies and develop the necessary technical expertise locally. Moreover, the financing should be tailored to the specific socio-economic and geopolitical factors of each country and renewable energy source.

Integration of renewable energy sources into national energy grids through comprehensive grid modernization plans should also be a focus for policymakers. Enhancing grid infrastructure to accommodate variable renewable energy sources like solar and wind will improve reliability and efficiency. Furthermore, supportive regulatory frameworks and incentives, such as feed-in tariffs, tax credits, and renewable portfolio standards, should be adopted to stimulate domestic renewable energy markets. By fostering innovation and supporting research and development in emerging technologies like bioenergy, geothermal, and marine energy, countries can diversify their energy portfolios and reduce reliance on fossil fuels. Collaborative international efforts, including knowledge-sharing platforms and regional energy agreements, can further promote the equitable distribution of renewable energy benefits and contribute to achieving SDG 7 globally.

Future research should extend beyond basic descriptive statistics by incorporating more advanced analytical techniques. For instance, correlations between variables such as GDP, population, and electricity installed capacity should be determined, regression analyses should be performed to understand relationships between variables, and clustering algorithms should be used to group countries with similar characteristics. These approaches could help identify trends and patterns in the data, guiding future policymaking. Moreover, pathways to renewable energy adoption should continue to be explored in future studies, with a focus on overcoming the practical challenges faced by lower-income economies and ensuring a just transition for all regions.

Author Contributions: S.S.S.: Conceptualization, methodology, formal analysis, review and editing; M.T.S.: writing original draft, project administration, validation. All authors agreed to publish the current version of the manuscript.

Data Availability Statement: Data will be available upon request.

Funding: This work did not receive any external funding.

Conflicts of Interest: The authors declare that they have no conflict of interest.

Acknowledgement: Authors would like to thank the Department of Statistics and Data Science at Jahangirnagar University, Bangladesh, for providing the academic foundation that greatly contributed to the completion of this research.

REFERENCES

[1] H. Shreif, W. El-Osta, and A. Yagub, 'Wind resource assessment for southern part of Libya: Case study of Hun', Solar Energy and Sustainable Development Journal, vol. 8, no. 1, pp. 12-33, 2019.

[2] X. Yuan, C. W. Su, M. Umar, X. Shao, and O. R. LobonŢ, 'The race to zero emissions: Can renewable energy be the path to carbon neutrality?', Journal of Environmental Management, vol. 308, p. 114648, 2022.

[3] C. McMichael, S. Dasgupta, S. Ayeb-Karlsson, and I. Kelman, 'A review of estimating population exposure to sea-level rise and the relevance for migration', Environmental Research Letters, vol. 15, no. 12, p. 123005, 2020.

[4] M. T. Siraj et al., 'Towards sustainable energy transitions: ranking lower-middle-income economies on the accessibility to affordable and clean energy', Environmental Engineering and Management Journal, vol. 23, no. 3, pp. 487-501, 2024.

[5] B. Debnath, M. S. Shakur, M. T. Siraj, A. M. Bari, and A. R. M. T. Islam, 'Analyzing the factors influencing the wind energy adoption in Bangladesh: A pathway to sustainability for emerging economies', Energy Strategy Reviews, vol. 50, p. 101265, 2023.

[6] S. B. Payel, S. F. Ahmed, M. Z. Anam, and M. T. Siraj, '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, Mar. 2023, pp. 7-9.

[7] M. T. Siraj, M. T. Hossain, S. F. Ahmed, and S. B. Payel, '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, Dec. 2022, pp. 20-21.

[8] IRENA, 'Renewable capacity statistics 2024', International Renewable Energy Agency, Abu Dhabi, 2024. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Mar/IRENA_RE_Capacity_Statistics_2024.pdf?rev=a587503ac9a2435c8d13e40081d2ec34

[9] J. Yang, H. Fang, and F. Jing, 'Renewable energy pathways toward carbon neutrality in BRICS nations: A panel data analysis', Economic Change and Restructuring, vol. 57, no. 2, p. 26, 2024.

[10] Q. Hassan et al., 'The renewable energy role in the global energy Transformations', Renewable Energy Focus, vol. 48, p. 100545, 2024.

[11] L. Qing, J. Abbas, H. Najam, and X. Ma, 'Investment in renewable energy and green financing and their role in achieving carbon-neutrality and economic sustainability: Insights from Asian region', Renewable Energy, vol. 221, p. 119830, 2024.

[12] Y. Zhou, 'Worldwide carbon neutrality transition? Energy efficiency, renewable, carbon trading and advanced energy policies', Energy Reviews, p. 100026, 2023.

[13] S. Erdogan, U. K. Pata, and S. A. Solarin, 'Towards carbon-neutral world: The effect of renewable energy investments and technologies in G7 countries', Renewable and Sustainable Energy Reviews, vol. 186, p. 113683, 2023.

[14] P. A. Owusu, J. K. Borkloe, and Y. Mahamud, 'Challenges towards Sustainable Energy as a Substitute for Fossil Fuels for the Case of Municipal Waste Management', Journal of Earth Energy Science, Engineering, and Technology, vol. 7, no. 1, 2024.

[15] S. Majumder, S. B. Payel, M. T. Siraj, M. Rahaman, and M. K. H. Chowdhury, '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, 2023. doi: 10.46254/BA06.20230153.

[16] A. M. Bari, M. T. Siraj, S. K. Paul, and S. A. Khan, 'A Hybrid Multi-Criteria Decision-Making approach for analysing operational hazards in heavy fuel oil-based power plants', Decision Analytics Journal, vol. 3, p. 100069, 2022.

[17] A. Farhan et al., 'Analyzing failure modes of turbochargers for engine-based power plants by combined SWARA-FMEA approach', in AIP Conference Proceedings, vol. 2825, no. 1, Nov. 2023, p. 1. AIP Publishing.

[18] A. H. Alami et al., 'Concentrating solar power (CSP) technologies: Status and analysis', International Journal of Thermofluids, vol. 18, p. 100340, 2023.

[19] K. Lovegrove and W. Stein, 'Introduction to concentrating solar power technology', in Concentrating Solar Power Technology, Woodhead Publishing, 2021, pp. 3-17.

[20] S. Mohammed et al., 'Carbon and energy life cycle analysis of wind energy industry in Libya', Journal of Solar Energy and Sustainable Development, vol. 12, no. 1, 2023.

[21] M. A. Al-Rawajfeh and M. R. Gomaa, 'Comparison between horizontal and vertical axis wind turbine', International Journal of Applied Power Engineering (IJAPE), vol. 12, no. 1, pp. 13-23, 2023.

[22] R. Siri, S. R. Mondal, and S. Das, 'Hydropower: A renewable energy resource for sustainability in terms of climate change and environmental protection', in Alternative Energy Resources: The Way to a Sustainable Modern Society, 2021, pp. 93-113.

[23] D. Tsuanyo et al., 'Design models for small run-of-river hydropower plants: a review', Sustainable Energy Research, vol. 10, no. 1, p. 3, 2023.

[24] J. F. Zhao et al., 'A review of world-wide advanced pumped storage hydropower technologies', IFAC-PapersOnLine, vol. 55, no. 9, pp. 170-174, 2022.

[25] M. C. Muteba, S. N. Foster, D. Raheem, and A. E. Agwu, 'Micro-hydropower systems for smallholder farmers in rural communities of Taraba state, Nigeria: Feasibility study, system analysis, design and performance evaluation (Part II)', Energy Nexus, vol. 11, p. 100228, 2023.

[26] M. R. Hasan et al., 'Converting biowaste into sustainable bioenergy through various processes', Bioresource Technology Reports, p. 101542, 2023.

[27] S. Sikiru et al., 'Technology projection in biofuel production using agricultural waste materials as a source of energy sustainability: A comprehensive review', Renewable and Sustainable Energy Reviews, vol. 200, p. 114535, 2024.

[28] J. Yazbeck and J. B. Rundle, 'A Fusion of Geothermal and InSAR Data with Machine Learning for Enhanced Deformation Forecasting at the Geysers', Land, vol. 12, no. 11, p. 1977, 2023.

[29] L. C. Gutiérrez-Negrín, 'Evolution of worldwide geothermal power 2020–2023', Geothermal Energy, vol. 12, no. 1, p. 14, 2024.

[30] W. Lin et al., 'Heat source model for Enhanced Geothermal Systems (EGS) under different geological conditions in China', Gondwana Research, vol. 122, pp. 243-259, 2023.

[31] S. Molloy, 'Tidal Power', in Wind, Water and Fire: The Other Renewable Energy Resources, 2021, pp. 233-264.

[32] N. Guillou, G. Lavidas, and G. Chapalain, 'Wave energy resource assessment for exploitation—a review', Journal of Marine Science and Engineering, vol. 8, no. 9, p. 705, 2020.

[33] D. Lennard, 'Ocean thermal energy conversion', in 2004 Survey of Energy Resources, Elsevier Science, 2004, pp. 419-432.

[34] J. M. Bane et al., 'Marine hydrokinetic energy from western boundary currents', Annual Review of Marine Science, vol. 9, pp. 105-123, 2017.

[35] C. W. Finkl and R. Charlier, 'Electrical power generation from ocean currents in the Straits of Florida: Some environmental considerations', Renewable and Sustainable Energy Reviews, vol. 13, no. 9, pp. 2597-2604, 2009.

[36] A. Rahman, O. Farrok, and M. M. Haque, 'Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic', Renewable and Sustainable Energy Reviews, vol. 161, p. 112279, 2022.

[37] M. G. M. Almihat and M. T. E. Kahn, 'Design and implementation of Hybrid Renewable energy (PV/Wind/Diesel/Battery) Microgrids for rural areas', Journal of Solar Energy and Sustainable Development, vol. 12, no. 1, 2023.

[38] S. A. Qadir, H. Al-Motairi, F. Tahir, and L. Al-Fagih, 'Incentives and strategies for financing the renewable energy transition: A review', Energy Reports, vol. 7, pp. 3590-3606, 2021.

[39] C. Chatfield, 'The initial examination of data', Journal of the Royal Statistical Society: Series A (General), vol. 148, no. 3, pp. 214-231, 1985.

[40] M. Al Hazza, H. Attia, and K. Hossin, 'Solar Photovoltaic Power Prediction Using Statistical Approach-Based Analysis of Variance', Solar Energy and Sustainable Development Journal, vol. 13, no. 2, pp. 45-61, 2024.

[41] L. Chen et al., 'Artificial intelligence-based solutions for climate change: a review', Environmental Chemistry Letters, vol. 21, no. 5, pp. 2525-2557, 2023.

[42] O. O. Yolcan, 'World energy outlook and state of renewable energy: 10-Year evaluation', Innovation and Green Development, vol. 2, no. 4, p. 100070, 2023.

[43] G. Sun, G. Li, A. Dilanchiev, and A. Kazimova, 'Promotion of green financing: Role of renewable energy and energy transition in China', Renewable Energy, vol. 210, pp. 769-775, 2023.

[44] A. I. Osman et al., 'Cost, environmental impact, and resilience of renewable energy under a changing climate: a review', Environmental Chemistry Letters, vol. 21, no. 2, pp. 741-764, 2023.

[45] W. Hao et al., 'The impact of energy cooperation and the role of the one belt and road initiative in revolutionizing the geopolitics of energy among regional economic powers: an analysis of infrastructure development and project management', Complexity, vol. 2020, no. 1, p. 8820021, 2020.

[46] L. Pistelli, 'Addressing Africa's energy dilemma', in The Geopolitics of the Global Energy Transition, 2020, pp. 151-174.

[47] J. Barandiarán, 'Lithium and development imaginaries in Chile, Argentina and Bolivia', World Development, vol. 113, pp. 381-391, 2019.

[48] G. Soroush et al., 'Review of different national approaches to supporting renewable energy development', European University Institute, 2022.

[49] F. Mormann, D. Reicher, and V. Hanna, 'A tale of three markets: Comparing the Renewable energy experiences of California, Texas, and Germany', Stan. Envtl. LJ, vol. 35, p. 55, 2016.

[50] J. F. G. de Oliveira and T. C. G. Trindade, 'Sustainability performance evaluation of renewable energy sources: The case of Brazil', Springer International Publishing, 2018.

[51] B. A. Abin, 'Japan's Energy Security: Opportunities and Challenges of Renewables in post-Fukushima Energy Scenario', Journal of Polity & Society, vol. 13, pp. 23-47, 2021.

[52] A. Gallaher, M. Graziano, S. Axon, and A. Bertana, 'Breaking wind: A comparison between US and European approaches in offshore wind energy leadership in the North Atlantic region', Renewable and Sustainable Energy Reviews, vol. 187, p. 113766, 2023.

[53] P. Petratos, 'Sustainability and financing project: The UAE paradigm', in Sustainable Development and Social Responsibility—Volume 1: Proceedings of the 2nd American University in the Emirates International Research Conference, AUEIRC'18–Dubai, UAE 2018, Springer International Publishing, 2020, pp. 163-170.

[54] O. Husiev, O. U. Arrien, and M. Enciso-Santocildes, 'What does Horizon 2020 contribute to? Analysing and visualising the community practices of Europe's largest research and innovation programme', Energy Research & Social Science, vol. 95, p. 102879, 2023.

[55] S. Snigdhha, V. Patel, and V. S. K. V. Harish, 'A comprehensive study and assessment of electricity acts and power sector policies of India on social, technical, economic, and environmental fronts', Sustainable Energy Technologies and Assessments, vol. 57, p. 103299, 2023.

[56] I. Todd and D. McCauley, 'Assessing policy barriers to the energy transition in South Africa', Energy Policy, vol. 158, p. 112529, 2021.

[57] M. Farghali et al., 'Social, environmental, and economic consequences of integrating renewable energies in the electricity sector: a review', Environmental Chemistry Letters, vol. 21, no. 3, pp. 1381-1418, 2023.

[58] J. He et al., 'Linking SDG 7 to assess the renewable energy footprint of nations by 2030', Applied Energy, vol. 317, p. 119167, 2022.

[59] A. Sharma, K. Srivastava, and S. K. Kar, 'Jawaharlal Nehru national solar mission in India', in Energy sustainability through green energy, 2015, pp. 47-67.

[60] I. Pappis, 'Strategic low-cost energy investment opportunities and challenges towards achieving universal electricity access (SDG7) in forty-eight African nations', Environmental Research: Infrastructure and Sustainability, vol. 2, no. 3, p. 035005, 2022.