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Exploring the Impact of GDP, Population, and Area on Renewable Energy Capacity Across Countries

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Abstract

As fossil fuels become scarcer and concerns about pollution grow, renewables offer a practical solution by cutting greenhouse gas emissions and supporting sustainable growth. In line with Sustainable Development Goal 7 (SDG 7), this study looks at factors that affect renewable energy capacity across 193 countries, focusing on how renewable capacity relates to a country's Gross Domestic Product (GDP), population size, and area. Using a quantitative correlational approach, data were gathered from the World Bank, International Renewable Energy Agency (IRENA), and Worldometer to ensure reliability. The dataset was prepared through extensive data cleaning, transformation, and integration processes using Python, with the Pearson correlation coefficient applied for statistical analysis. Choropleth maps illustrating different descriptive statistics provided a visual dimension to the analysis, showcasing patterns across countries. Findings indicate strong correlations between GDP and population size with renewable energy capacity ($r = 0.76$, $p < 0.0001$ for both), suggesting that higher economic resources and population-driven demand significantly influence renewable capacity. Total area showed a moderate correlation ($r = 0.50$, $p < 0.0001$), reflecting that larger countries may have some advantage in hosting renewable infrastructure, though less so than GDP and population size. This study is novel in its detailed look at how economic, population, and land factors together affect renewable energy capacity. These findings offer helpful guidance for policymakers in countries with lower capacity, encouraging smart investments and decisions to improve fair access to renewable energy and support global sustainability goals.

Keywords: Renewable energy, Gross domestic product, Population, Area, Pearson correlation coefficient.

1 | Introduction

Renewable energy plays an increasingly vital role in achieving global sustainability, with projections indicating it will contribute 50% of global power capacity growth by 2030 [1]. As fossil fuel reserves decline, their continued use exacerbates environmental and geopolitical crises. For instance, coal combustion accounts for approximately 30% of global CO_2 emissions, intensifying climate change [2]. Similarly, reliance on oil has

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historically fueled regional conflicts in resource-rich areas. In contrast, renewable energy offers a sustainable alternative by reducing greenhouse gas emissions and enhancing global energy security. Sustainable Development Goal 7 (SDG 7) aligns with this transition, advocating for universal access to affordable, reliable, and sustainable energy [3]. As part of the United Nations' 2030 Agenda, SDG 7 emphasizes expanding renewable energy infrastructure to reduce fossil fuel dependence and mitigate emissions. This goal promotes supportive policies and investments, particularly in under-resourced regions, to ensure equitable access to clean energy. By promoting universal energy access, SDG 7 links environmental sustainability with economic development [4].

Despite the critical role of renewable energy, significant disparities in capacity persist across nations, driven by factors such as economic strength, population size, and geographic area. Existing studies often examine these factors individually, but there is limited research exploring their combined effects, creating a gap in understanding the dynamics behind equitable renewable energy growth. The global distribution of renewable energy capacity remains uneven, shaped by economic strength, geographic advantages, and policy support [5]. Wealthier nations lead in renewable installations due to robust investments in technology, infrastructure, and supportive policies for large-scale solar, wind, and hydropower projects. Geographic factors also play a role; for example, regions with high sunlight exposure or consistent coastal winds are more favorable for renewable energy generation [6]. Conversely, limited resources, weak infrastructure, and inadequate policy support hinder renewable development in many countries, exacerbating disparities. Recent studies highlight these inequalities, showing that over 80% of the world's renewable energy installed capacity is concentrated in 15 countries, including China, the United States, Brazil, India, Germany, and Japan [7]. These nations often exhibit high GDP, substantial populations, and large land areas, factors that likely contribute to their leadership in renewable energy. Analyzing the interplay between GDP, population size, area, and renewable capacity can provide actionable insights for countries with lower capacity, enabling them to enhance infrastructure and adopt best practices for sustainable energy growth.

Accordingly, this study has two primary objectives:

RO1: to investigate the relationship between GDP, population size, area, and renewable energy capacity across different countries.

RO2: to provide insights and recommendations for countries with lower renewable capacity by analyzing factors contributing to high renewable capacity in leading nations.

To address these objectives, the following hypotheses are tested:

H01: there is no correlation between population and total electricity from renewables.

H02: there is no correlation between GDP and total electricity from renewables.

H03: there is no correlation between total area and total electricity from renewables.

A quantitative approach is applied to assess these relationships. Pearson correlation analysis evaluates the strength and direction of associations between renewable energy capacity and the selected variables. Data from reputable sources such as the World Bank, International Renewable Energy Agency (IRENA), and Worldometer support this comprehensive, data-driven exploration of factors influencing renewable energy capacity globally [8–11].

This study's novelty lies in its integrative examination of GDP, population size, and area as determinants of renewable energy capacity. While prior research often considers these factors in isolation, this study combines them to provide a comprehensive analysis of their collective impact [12], [13]. The findings hold significant implications for policymakers and stakeholders, offering actionable insights for expanding renewable energy capacity. By identifying key enablers and constraints, this research guides strategic policy and investment decisions, promoting equitable renewable energy growth and advancing global sustainability goals.

The paper is structured as follows. Section 2 conceptualizes the impact of GDP, population, and area on renewable energy capacity. Section 3 outlines the methodology, including hypotheses, data collection, and analysis methods. Section 4 presents results and discusses limitations. Section 5 provides insights and recommendations for boosting renewable capacity. Finally, Section 6 concludes and suggests directions for future research.

2 | Literature Review

Total installed renewable energy capacity serves as a key indicator of a country's energy consumption patterns and broader developmental progress [14]. Analyzing this capacity in relation to GDP, population size, and geographic area enables a more nuanced understanding of the factors that drive renewable energy adoption globally. Gross Domestic Product (GDP) represents the total monetary value of all goods and services produced within a country over a specific time period. GDP reflects the economic health and productivity of a nation, often serving as a strong predictor of energy consumption. Higher GDP levels typically correlate with increased energy demand due to expanded industrial activity, infrastructure development, and household energy usage [15]. Economic growth is thus closely tied to energy needs, including renewables. Recent studies underscore the complex relationship between GDP and renewable energy capacity. For instance, Chica-Olmo et al. [16] demonstrated that renewable energy use in one European country positively affects the GDP of neighboring countries, with a 1% increase in renewables boosting GDP by up to 0.054%. Karaaslan and Çamkaya [15] analyzed Turkey's energy landscape, revealing that while GDP growth drives CO_2 emissions, integrating renewables mitigates these effects. Similarly, Magazzino et al. [17] observed that renewable energy consumption in China and the U.S. correlates with reduced emissions, supporting sustainable economic growth.

In contrast, India's heavy reliance on coal alongside economic growth forecasts rising CO_2 emissions, highlighting the need for a renewable shift. Dong et al. [13] further found that renewable energy intensity reduces emissions globally, with significant impacts in regions like South America and Europe. These studies indicate that while economic growth typically raises CO_2 emissions, integrating renewables can support sustainable growth, though the effect varies by region. While these studies emphasize the influence of renewable energy on GDP and emissions, few focus on how GDP levels determine installed renewable capacity. This study aims to address this gap by analyzing GDP's role as a predictor of renewable energy capacity. A country's population is the total number of people living within its borders at a given time. Population size influences energy demand through increased residential, industrial, and public service needs [18]. Larger populations typically require more energy to sustain economic and social activities, underscoring the importance of scaling renewable energy infrastructure. Research illustrates that population growth amplifies energy needs while emphasizing clean energy's role in mitigating environmental impact. For instance, Rahman and Alam [19] highlighted Bangladesh's population-driven energy challenges, emphasizing the need for renewable investments. Minh et al. [20] demonstrated how urban population growth in Vietnam intensifies CO_2 emissions, necessitating renewable integration.

Globally, Dong et al. [13] identified population growth as a key driver of emissions, mitigated effectively by renewable energy intensity, particularly in regions with high renewable adoption. Vo & Vo [21] showed that ASEAN countries must balance population growth with renewable energy expansion to achieve sustainability. Despite these insights, most studies explore the population's indirect effects on emissions or renewable adoption without directly analyzing its correlation with installed renewable capacity. By examining this relationship, this study contributes to bridging this critical research gap. A country's area is its total land size, measured in square kilometers or miles, encompassing all territories within its borders. Larger countries often benefit from diverse geographic features that enable renewable diversification, such as coastal winds, solar exposure, or hydropower opportunities [5]. Moreover, geographic diversity within a large area, such as coastal, mountainous, or sunny regions, enables a country to diversify its renewable energy sources effectively. Conversely, smaller or densely populated nations may face spatial constraints, necessitating innovative, space-efficient renewable solutions. Studies have explored geographic areas' influence on renewable energy [22–24].

Szyba [22] examined the role of spatial distribution in wind farm efficiency, while Neupane et al. [23] highlighted the impact of land area on solar and wind energy potential in Nepal. Igliński et al. [24] analyzed the geographic determinants of renewable energy adoption in Poland, emphasizing area as a critical factor. However, these studies often focus on specific regions or technologies, leaving gaps in understanding the broader relationship between geographic area and total renewable energy capacity. This study addresses these gaps by conducting a cross-national correlation analysis of area and renewable energy capacity. Such analysis provides actionable insights for countries with varying spatial characteristics to optimize renewable deployment. While extensive research examines renewable energy's role in mitigating emissions and supporting economic growth, few studies investigate GDP, population, and area as combined predictors of installed renewable capacity. Additionally, existing studies often adopt regional or technology-specific perspectives, limiting their applicability to global contexts. This research seeks to fill these gaps by integrating these three variables into a comprehensive analysis, offering novel insights to inform policies and investments aimed at equitable renewable energy expansion.

3 | Methodology

This study employs a quantitative correlational approach to investigate the relationship between independent variables such as GDP, population, and area of a country, and the dependent variable, total renewable energy installed capacity. The analysis encompasses 193 countries globally, considering those for which complete data is available for all variables. Data were gathered from sources such as the World Bank, Worldometer, and IRENA reports. A methodological framework for this study is depicted in *Fig. 1*.

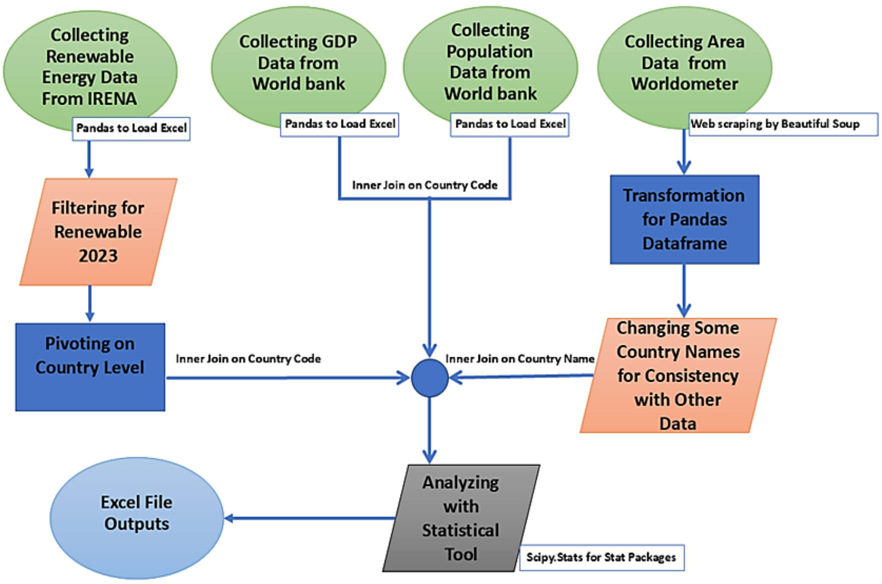

Fig. 1. Methodological framework.

Python code for this study can be found in appendix A to ensure reproducibility of the study.

3.1 | Data Preparation

The entire dataset for this study was prepared using Python, employing several libraries to manage data extraction, cleaning, transformation, and integration processes.

3.1.1 | Data acquisition

Data for GDP (current US$) and total population for the year 2022 were obtained from the World Bank's publicly available datasets:

GDP data: API_NY.GDP.MKTP.CD_DS2_en_excel_v2_10034.xls.

Population data: API_SP.POP.TOTL_DS2_en_excel_v2_9992.xls.

Both datasets were loaded into Python as data frames, extracting columns for Country Name, Country Code, and the 2022 values.

Land area data were scraped from Worldometers' webpage listing the largest countries by total area. The extracted information included country name and total area (Sq km).

Renewable electricity installed capacity (in MW) for 2023 was sourced from the IRENA dataset (IRENA_Stats_Extract_2024_H1_V1.xlsx). The data was filtered for the "total renewable" category under the "RE or Non-RE" column.

3.1.2 | Data cleaning and transformation

Records with missing values in any column in the GDP and Population tables were removed, as these indicated missing data in the World Bank records for specific countries. Standardization of country names was performed using predefined dictionaries to harmonize naming conventions across datasets. For example, “Russia” was converted to “Russian Federation,” “Vietnam” to “Viet Nam,” and “South Korea” to “Korea, Rep.” Data integration and exclusion procedures were conducted through inner joins, ensuring that only countries with complete information across all datasets were retained. Specifically, the GDP and population tables were merged using the common key country code. Land area data were then merged with the GDP–Population dataset based on country name. Renewable energy data from the IRENA database were integrated using the ISO3 country code aligned with the country code in the merged dataset. Filtering and aggregation steps were subsequently applied. The IRENA dataset was filtered to include only 2023 records with “Total Renewable” capacity. Renewable electricity capacity values were aggregated at the country level to compute each country’s total installed renewable capacity. The final aggregated table contained Country Name, ISO3 Code, GDP, Population, total area, and total renewable installed capacity for each included country (see *Table 1*). Zero or null values were checked again for quality assurance, and any remaining incomplete records were removed.

Table 1. Integrated data for analysis [8–11].

Country	ISO3 Code	Installed Capacity (MW)	GDP Current US$ (Billion)	Population (Total)	Total Area (Sq km)
Afghanistan	AFG	492.781	14.50 B	41128771	652230
Albania	ALB	2657.425	18.92 B	2777689	28748
Algeria	DZA	589.7	225.56 B	44903225	2381741
American Samoa	ASM	4.81	0.87 B	44273	199
Andorra	AND	55.352	3.38 B	79824	468
Angola	AGO	4090.739	104.40 B	35588987	1246700
Antigua and Barbuda	ATG	15.584	1.87 B	93763	442
Argentina	ARG	15886.46	631.13 B	46234830	2780400
Armenia	ARM	1762.4	19.51 B	2780469	29743
Aruba	ABW	46.804	3.54 B	106445	180
Australia	AUS	54328	1,692.96 B	26014399	7692024
Austria	AUT	26712.417	470.94 B	9041851	83871
Azerbaijan	AZE	1687.8	78.81 B	10141756	86600
Bahrain	BHR	59.298	44.38 B	1472233	765
Bangladesh	BGD	1005.693	460.13 B	171186372	147570
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Table 1. Continued [8–11].

Country	ISO3 Code	Installed Capacity (MW)	GDP Current US$ (Billion)	Population (Total)	Total Area (Sq km)
Viet Nam	VNM	46011.945	410.32 B	98186856	331212
Zambia	ZMB	3332.12	29.16 B	20017675	752612
Zimbabwe	ZWE	1220.964	27.37 B	16320537	390757

3.1.3 | Software and programming tools

Data preparation was executed in Python (version 3.9.12), primarily using the pandas library for data extraction, cleaning, and manipulation; requests and BeautifulSoup for web scraping; scipy.stats for statistical analysis; and Jupyter Notebook (version 6.4.8) as the development environment.

3.1.4 | Choropleth maps

The choropleth maps visually represent global distributions of key metrics, providing valuable insights into geographic variations. Choropleth maps of electricity installed capacity from renewables, GDP, population, and total area were prepared based on the prepared dataset and are presented in *Figs. 1-4*.

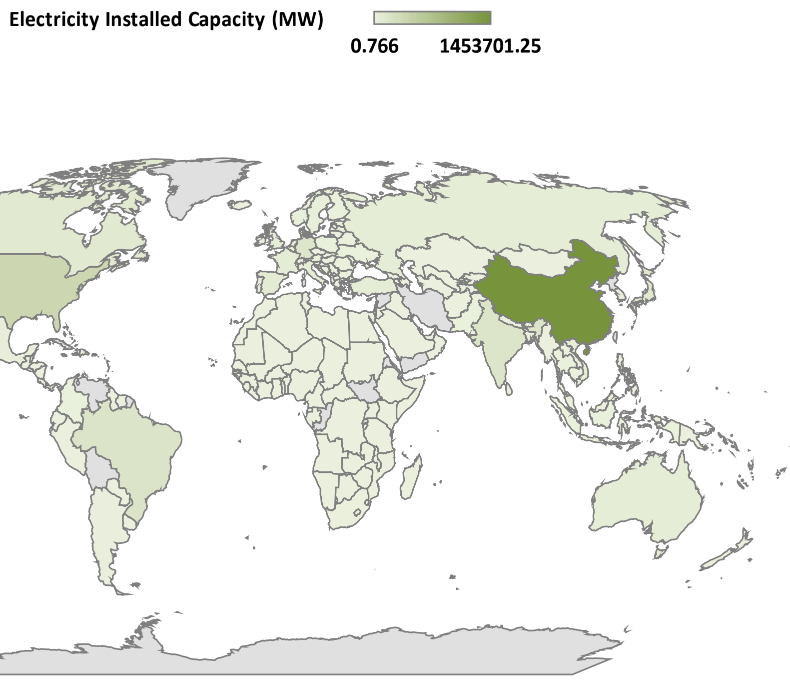

Fig. 2. Electricity installed capacity from renewables across the world.

Fig. 2 highlights electricity installed capacity from renewables, showcasing the global adoption of sustainable energy sources. The concentration in some regions, like China and the USA, shows their dominating position in electricity generation from renewable sources.

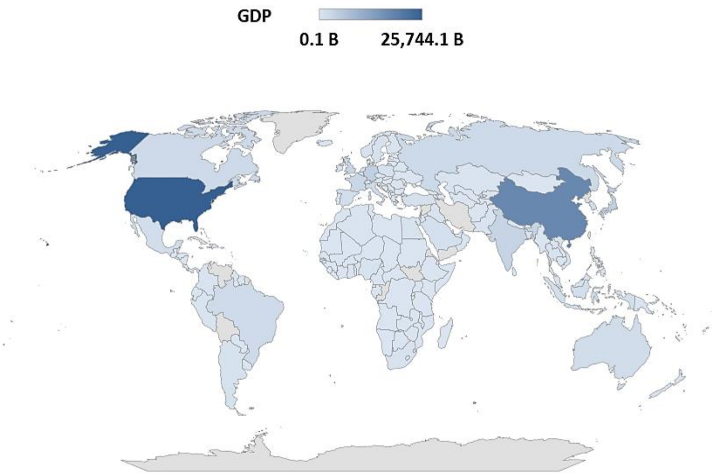

Fig. 3. GDP across the world.

Fig. 3 displays GDP across the world, illustrating the economic disparity and concentration of wealth among nations. The USA and China are again found to be the countries with the highest GDP among others.

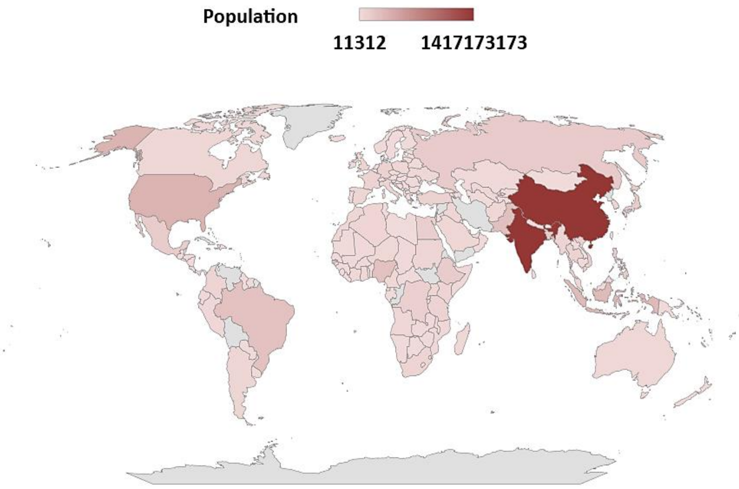

Fig. 4. Population across the world.

Fig. 4 focuses on population distribution, emphasizing regions with high and low population densities. In this map, China and India are identified as the most densely populated countries.

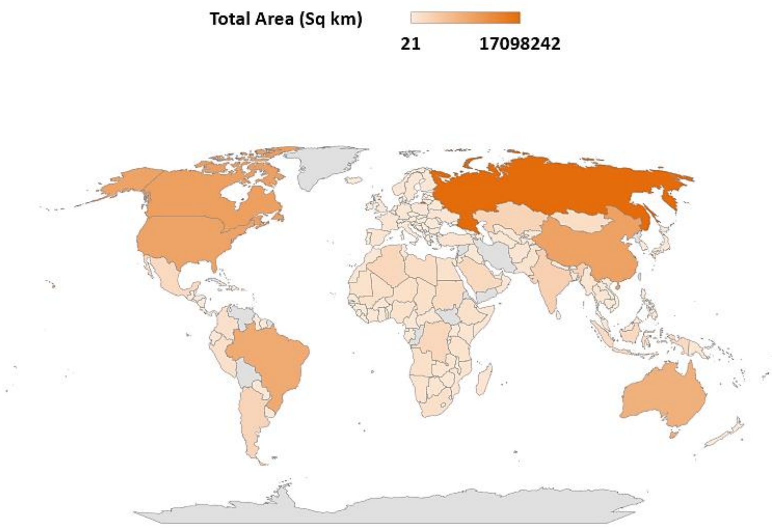

Fig. 5. Total area of different countries.

Fig. 5 presents the total land area of countries, offering a perspective on geographic size and spatial resources across the globe. Russia, the USA, China, and Brazil are identified as the most prominent countries on this map.

3.1.5 | Descriptive statistics

After the integration and validation processes, a summary table with descriptive statistics was exported to an Excel file (see *Table 2*), alongside the final table in a separate file. The final table ensured that all variables were standardized and complete for the study's correlational analysis.

Table 2. Summary of descriptive statistics of the prepared data for analysis.

Variables	N	Min	Max	Mean	Standard Deviation
Electricity installed capacity (MW)	193	0.766	1453701	19820	110475
GDP	193	59065982	25744108000000	517182919380	2314691178436
Population	193	11312	1417173173	40355961	148739665
Total area (Sq km)	193	21	17098242	678102	1914315

3.2 | Pearson Correlation Coefficient

The Pearson Correlation Coefficient, denoted by r, is a statistical measure used to evaluate the strength and direction of the linear relationship between two continuous variables [25]. The coefficient ranges between -1 and 1, where values close to 1 indicate a strong positive correlation, values near -1 signify a strong negative correlation, and values around 0 indicate no linear correlation. Mathematically, the Pearson Correlation Coefficient between two variables, X and Y, is calculated as *Eq. (1)*.

$$r = \frac{\sum(X-\bar{X})(X-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2 \sum(Y-\bar{Y})^2}}, \quad (1)$$

where X and Y represent the values of the two variables, $\bar{X}$ and $\bar{Y}$ are the mean values of X and Y, respectively. In this study, the dependent variable is consistently the installed capacity of electricity from renewable energy, while GDP, population, and total area of a country were individually considered as independent variables. For each variable, the Pearson correlation coefficient (r-value) was calculated to assess the strength and direction of the relationship. Subsequently, two-tailed hypothesis tests were conducted to determine the statistical significance, with the two-tailed significance level (p-value) evaluated in each case. The analyses were performed using the scipy.stats library in Python.

The use of Pearson correlation in this study is justified due to its simplicity and direct applicability in assessing the linear relationships between pairs of continuous variables, which aligns with the hypotheses being tested. Unlike regression analysis or Structural Equation Modeling (SEM), Pearson correlation is specifically designed to quantify the strength and direction of a linear association without requiring assumptions about causality or the need to model predictor-outcome relationships [26], [27]. Additionally, regression and SEM introduce complexities such as model specification, multicollinearity management, and parameter estimation, which are unnecessary when the sole objective is to evaluate bivariate linear associations. Pearson correlation is computationally efficient, well-suited for exploratory analysis, and provides clear, interpretable results directly relevant to testing the null hypotheses stated in the study.

4 | Results Discussion

The high standard deviations for each variable highlight the diversity in country characteristics (see *Table 2*). The results of the Pearson Correlation Analysis in this study can be found in *Table 3*. For all tests, the p-value was less than 0.0001, leading to the rejection of the null hypothesis at a 99.9% confidence level.

Table 3. Result of correlation analysis.

Independent Variables	Correlation Coefficient (r)	P-value (p)
Population	0.76	<0.0001
GDP	0.76	<0.0001
Total area	0.50	<0.0001

The correlation coefficient ($r = 0.76$, $p < 0.0001$) for population shows a strong positive relationship with renewable electricity capacity, indicating that countries with larger populations generally have higher renewable capacities due to greater energy demand. It is visible in both populous and smaller countries. For example, China and India, with populations of over a billion, have installed renewable capacities of 1,453,701 MW and 175,929 MW, respectively. It aligns with the expectation that large populations create higher energy demands, prompting investments in renewable infrastructure. On the other hand, Finland, with a smaller population of around 5.5 million, has a renewable capacity of 14,093 MW. While modest compared to countries like China, Finland's renewable capacity aligns well with its population size, showing that smaller populations also follow the general trend, maintaining a proportional relationship. Some countries, however, deviate from this trend. Bangladesh serves as a good example of this type of exception. Despite a large population of approximately 170 million, Bangladesh has a relatively low renewable electricity capacity, especially compared to other highly populated nations. The installed renewable capacity in Bangladesh is around 1,000 MW. This capacity is low given the country's population size, showing that while population creates demand, factors like economic resources, policy focus, and infrastructure readiness also influence renewable capacity.

The correlation between GDP and renewable electricity capacity is also strong ($r = 0.76$, $p < 0.0001$), suggesting that economically strong countries tend to invest more heavily in renewable energy. Both high-GDP and low-GDP countries contribute to this positive trend. For example, the United States and China, with GDPs of around $25.74 trillion and $17.88 trillion, have significant renewable capacities of 387,549 MW and 1,453,701 MW, respectively. These examples show that wealthier nations are better positioned to fund large-scale renewable energy projects due to their economic resources. On the other hand, Nepal, with a GDP of around $41 billion, has a renewable capacity of about 2800 MW. Though smaller, Nepal's renewable energy infrastructure is proportionate to its economic size, supporting the positive correlation even at the lower end of the GDP spectrum. Certain countries, like Singapore and Hong Kong, illustrate deviations from the typical GDP-renewable capacity pattern. Despite having high GDPs of approximately $498 billion and $359 billion, respectively, Singapore's renewable capacity is around 1,020 MW, while Hong Kong's is only 250 MW. This discrepancy highlights how factors such as limited land area, high population density, and reliance on imported energy can affect a country's position in the global ranking of total installed renewable electricity capacity, even in economically strong nations.

Additionally, both Singapore and Hong Kong focus on optimizing energy efficiency and diversifying energy imports, which influences their renewable capacity development. The correlation between Total Area and renewable capacity ($r = 0.50$, $p < 0.0001$) is moderate, indicating that while larger geographic size can support renewable installations, it is less directly influential than Population and GDP. Both large and small countries show patterns supporting this moderate correlation. For instance, the United States and China, with extensive land areas (9,372,610 sq km and 9,706,961 sq km, respectively), have large installed capacities, partly due to the ample space available for renewable projects like solar and wind farms. In contrast, Singapore, with a very limited land area of about 710 sq km, has a renewable capacity of around 1020 MW.

Despite spatial limitations, Singapore has developed a renewable infrastructure that fits its available space, showing how smaller countries also support the correlation by optimizing their limited land resources. Exceptions also exist. Kazakhstan, with a vast area of 2,724,900 sq km, has a relatively low renewable capacity of around 5,663MW. It suggests that large land availability alone does not guarantee higher renewable capacity, as other factors like demand and economic focus play crucial roles. This analysis demonstrates that Population and GDP have strong positive correlations with renewable electricity capacity across countries, while Total Area has a more moderate influence. Both high and low values across these variables support the correlations, indicating proportional relationships in various contexts. Notable exceptions, such as Bangladesh (large population but low renewable capacity) and Kazakhstan (vast land area but relatively low renewable capacity), highlight the role of additional factors such as economic limitations, energy import reliance, and infrastructure priorities. These findings suggest that while larger populations, higher GDP, and extensive land availability generally encourage renewable capacity growth, each factor's impact may vary significantly based on a country's unique economic conditions, energy policies, and geographic constraints. This nuanced understanding underscores the importance of considering a country's specific characteristics and policy environment when analyzing renewable energy capacities.

The findings of this study align with and expand upon the literature concerning the relationships between renewable energy capacity and factors such as GDP, population, and land area. Consistent with prior research, the positive correlation between GDP and renewable energy capacity observed here supports the notion that economic growth typically accompanies greater renewable energy investment. It aligns with studies like those by Karaaslan and Çamkaya [15] and Magazzino et al. [17], which noted that high GDP often enables countries to fund large-scale renewable projects, particularly in economically strong nations such as the U.S. and China. Furthermore, the study's finding of a strong correlation between population and renewable capacity corroborates research by Khan et al. [18] and Vo & Vo [21], who highlighted that larger populations drive energy demand, necessitating substantial renewable infrastructure. However, while previous studies often examine the effects of population growth or high density on renewable needs, this study uniquely focuses on how absolute population size relates to renewable capacity, providing a broader, more inclusive view across countries with both high and low population levels.

Additionally, the moderate correlation observed between land area and renewable capacity aligns with Siraj et al. [5] and Neupane et al. [23], who found that larger areas can facilitate renewable installations but are not the sole determining factor, as other geographic and policy aspects also play roles. While prior research often focused regionally or emphasized individual impacts of renewables on emissions and GDP, this study's holistic analysis of installed capacity offers a more comprehensive perspective on the intrinsic relationship between these foundational variables and a country's renewable infrastructure. This approach fills gaps in the literature by comparing renewable capacity across diverse contexts, offering actionable insights for countries at various stages of economic and renewable energy development.

4.1|Study Limitations and Future Development Scopes

While the study demonstrates statistically significant correlations between population, GDP, total area, and total electricity from renewables, it is crucial to emphasize that correlation does not imply causation [28]. The observed relationships may be influenced by other confounding factors such as government policies, levels of investment in renewable energy, access to renewable technologies, or cultural attitudes toward sustainability. For example, countries with similar GDP levels may have vastly different renewable energy capacities due to differing policy frameworks or geographic advantages. Acknowledging these limitations helps ensure a nuanced interpretation of the findings and encourages further research to identify causal mechanisms.

To strengthen the study's statistical validity, additional metrics such as Confidence Intervals (CIs) for the correlation coefficients and further significance testing could be provided. For instance, the 95% CIs for the coefficients would offer insight into the range of plausible values for each relationship, enhancing the reliability of the results [29]. Furthermore, exploring advanced statistical methods like regression modeling or SEM can help isolate the impact of individual variables while accounting for potential confounders. For example, a multivariate analysis incorporating policy indices or renewable energy infrastructure data could yield deeper insights into the factors influencing renewable energy capacity across countries, offering more actionable conclusions for policymakers and researchers [30].

This study relies on cross-sectional data from 2022 and 2023, providing a snapshot that does not capture temporal trends or fluctuations in renewable energy capacity. Future research could adopt a longitudinal approach to observe how relationships between GDP, population, area, and renewable energy capacity evolve [31]. While this study focuses on total installed renewable capacity, future research could disaggregate data by energy type (e.g., wind, solar, hydro) to explore how different renewable sources uniquely contribute to these relationships. Such extensions could guide countries in optimizing their renewable energy infrastructure with more targeted strategies.

5 | Insights and Recommendations for Boosting Renewable Capacity

To support countries with lower renewable capacity, this section highlights strategies observed in leading nations, providing actionable insights for overcoming economic, spatial, and policy-related constraints. Wealthier countries, such as the United States and China, have utilized their strong economies to invest heavily in renewable energy infrastructure. Countries with lower GDPs, however, can bridge this gap by seeking international funding and implementing green finance initiatives. For instance, partnerships with development banks or international organizations could help Bangladesh attract investments, while offering tax incentives for private-sector involvement could further stimulate renewable energy projects [32]. In regions with high population density but limited land, innovative approaches to renewable installations have proven effective. Japan and Singapore have successfully promoted rooftop solar and community solar programs, optimizing renewable infrastructure in urban areas [33], [34]. Bangladesh, with similar spatial limitations, could adopt this model, encouraging residential and commercial buildings to install rooftop solar panels through subsidies or low-interest loans.

While geographic size has a moderate influence, efficient land use and advanced technologies can enable smaller countries to achieve significant renewable capacities. Countries like Nepal, for example, could capitalize on its natural resources by implementing vertical wind turbines or hydroelectric projects suited to mountainous terrains [35]. Additionally, investing in battery storage solutions can enhance the reliability of renewable sources like solar and wind, ensuring a more consistent energy supply despite land constraints. Leading renewable nations also benefit from robust regulatory frameworks that provide stability and attract investment. The European Union's Renewable Energy Directive, for example, has set binding targets that encourage member countries to expand their renewable portfolios [36]. Developing nations can follow a similar path by establishing clear renewable energy goals, simplifying project approval processes, and introducing favorable tariffs, creating a predictable policy environment that supports long-term investment. Community engagement and public awareness campaigns have proven essential in building public support for renewable projects. Denmark, for instance, has encouraged community-owned wind farms, increasing local involvement and acceptance [37]. Emerging economies could also benefit from incentivizing community-owned renewable projects, allowing residents to share in the benefits and boosting public enthusiasm for renewable initiatives. Finally, maintaining a diversified energy mix has helped many high-capacity countries build resilient energy systems. The United States and China both balance solar, wind, hydro, and other sources, enhancing grid stability and reducing dependency on any single resource. Nepal, for example, could complement its hydro resources with solar and wind projects, ensuring a more robust and reliable renewable portfolio.

6 | Conclusion

This study investigated the relationships between total renewable energy capacity and key national indicators—GDP, population size, and land area—across different countries. The Pearson correlation analysis revealed strong positive correlations between renewable energy capacity and both GDP ($r = 0.76$) and population size ($r = 0.76$), as well as a moderate correlation with land area ($r = 0.50$). These findings confirm that economic strength and population demand are significant drivers of renewable energy capacity. At the same time, land area alone plays a more nuanced role, likely mediated by other factors such as resource availability and policy priorities. By identifying these correlations, the study contributes to the growing body of literature on renewable energy development, offering a clearer understanding of how socioeconomic and spatial factors shape renewable infrastructure. Specifically, the findings provide actionable insights for countries with lower renewable capacity, emphasizing the importance of targeted investments in economic and social systems to enhance renewable energy adoption. Additionally, the study highlights the need for a holistic approach to renewable energy planning, integrating economic growth, efficient land use, and community engagement.

Future research should expand on this work by including additional variables, such as energy demand, grid infrastructure, and renewable energy resource distribution, to better understand the multifaceted drivers of renewable capacity. A longitudinal approach could also capture temporal trends and provide deeper insights into how these relationships evolve over time. Such extensions would support more tailored strategies for accelerating renewable energy transitions in both developing and developed countries.

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Author Contributions

S.I.A.: drafting manuscript; M.L.B.: drafting manuscript; S.S.S.: methodology, formal analysis; M.T.S.: conceptualization, project administration, validation. All authors agreed to publish the current version of the manuscript.

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Data Availability Statement

Data will be available upon request.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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