Trends in Renewable Energy Adoption

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Introduction

Our project, "Trends in Renewable Energy Adoption", aims to analyze global renewable energy trends to provide actionable insights for stakeholders in the transition to sustainable energy. Renewable energy adoption has become a critical focus area for policymakers, businesses, and environmental advocates as the world strives to reduce its reliance on fossil fuels. By leveraging data visualization techniques, this project seeks to uncover patterns in renewable energy adoption across regions and technologies.

Through interactive dashboards and storytelling, our analysis will explore energy production, capacity, and trends, aiding decision-makers in formulating effective strategies for sustainable development. The visualizations intend to offer a comprehensive understanding of the dynamics driving renewable energy adoption globally. This project seeks to present nuanced insights that can inform policy development, drive investment decisions, and support the global shift toward cleaner energy sources.

Data Description

The dataset, *Renewable energy statistics 2024,* used in this project is sourced from the International Renewable Energy Agency (IRENA) and provides comprehensive information on renewable and non-renewable energy adoption globally. It provides insights into the adoption of renewable energy technologies, including production capacity, generation levels, and the type of technology used. The data reflects global trends and supports the analysis of country-level adoption patterns, offering a comprehensive view of energy production across various regions and energy types. There are 90,553 rows with each row representing a data point for a specific country categorized by energy type, technology, and year. The primary columns included in the dataset for our project are as follows:

- **Region** – VarChar/Categorical: Specifies the geographical region.
- **Sub-region** – VarChar/Categorical: Further divides the region into sub-regions.
- **Country** – VarChar/Categorical: Name of the country.
- **ISO3 code** – VarChar/Qualitative: ISO3 country code.
- **M49 code** – Integer/Quantitative: UN M49 area code for countries or regions.
- **RE or Non-RE** – VarChar/Categorical: Indicates if the data pertains to renewable energy (RE) or nonrenewable.
- **Group Technology** – VarChar/Categorical: General category of energy technology.
- **Technology** – VarChar/Categorical: Specifies the type of energy technology (e.g., solar, wind).
- **Sub-Technology** – VarChar/Categorical: More detailed classification of the technology.
- **Producer Type** – VarChar/Categorical: Type of energy producer.
- **Year** – Integer/Time Series: The year of the data record.
- **Electricity Generation (GWh)** – Numeric (Float)/Quantitative: Electricity generation in gigawatt hours.
- **Electricity Installed Capacity (MW)** – Numeric (Float)/Quantitative: Installed capacity in megawatts.

The dataset has been submitted in Excel format with the filename Group5-Data-RenewableEnergyTrends.xlsx.

In the International Renewable Energy Agency (IRENA) dataset, missing values in columns such as **Electricity Generation (GWh)** or **Electricity Installed Capacity (MW)** largely occur because specific energy technologies were not operational or present in certain countries during particular years. These blanks represent an absence of activity rather than errors or omissions, reflecting IRENA's meticulous tracking of global energy trends through sources like questionnaires, national statistics, industry reports, and news articles. For instance, developing countries or regions without advanced infrastructure may lack solar or wind energy generation in earlier years, while fossil fuel-reliant countries might not report renewable electricity generation at all. IRENA's metadata and reports emphasize that these gaps mirror genuine differences in energy adoption rather than inconsistencies, and imputing values would misrepresent the dataset's intent and distort analysis. Instead, treating these blanks as zero values offers an honest and realistic depiction of global energy systems' evolution, preserving data integrity and enabling meaningful insights for policymakers and stakeholders.

In addition to addressing missing values, the dataset required the removal of the "Heat Generated" column due to inconsistencies in data reporting. This column was primarily populated by a small subset of highly participating countries, leading to unintentional skewing of the dataset and making the data unsuitable for meaningful global analysis. Since only a fraction of countries consistently uploaded this data, it failed to represent broader trends in energy generation. IRENA will have to continuously improve the volume and accuracy of data it collects to make meaningful insights.

Project Goals and Purpose

The primary goal of this project is to analyze and visualize trends in global renewable energy adoption, providing actionable insights for policymakers, businesses, and stakeholders to support the global transition to sustainable energy.

The project will highlight leading countries in renewable energy adoption and examine the strategies driving their success, focusing on renewable energy generation capacity, technology preferences, and electricity output. By analyzing trends in energy generation and fossil fuel reliance, the project aims to uncover significant patterns across regions, technologies, and time periods. This analysis will reveal opportunities for transitioning away from fossil fuels and strategies to accelerate renewable energy adoption.

Data visualizations, including line charts, heatmaps, and comparative analyses, will be used to identify regional and global patterns in renewable energy adoption. These visualizations will illuminate disparities and opportunities across countries and regions, providing stakeholders with actionable insights. By presenting trends and interdependencies through clear and impactful visuals, the project will guide investments and policy decisions to maximize the effectiveness of renewable energy initiatives and support sustainable energy transitions globally.

Business Questions

1. **Energy Generation Analysis:**
   - **a.** How do renewable (RE) and non-renewable (non-RE) energy sources contribute to electricity generation across countries and regions over time?
   - **b.** What are the trends in electricity generation by technology type (e.g., solar, wind, fossil fuels) from 2000 to 2024?
2. **Fossil Fuel Dependency:**
   - **a.** How does dependency on specific types of energy production (e.g., fossil fuels, solar, wind) vary across regions, and what trends emerge over time?
   - **b.** How does the reliance on fossil fuels vary by energy technology, producer type, or sub-technology?

Related Work

The project builds on the extensive research and reporting conducted by the International Renewable Energy Agency (IRENA) on renewable energy trends and statistics. IRENA's reports highlight significant advancements in renewable electricity generation, including a steady growth of renewables at an annual rate of 6.1% since 2011 and a notable rise in variable renewables such as solar and wind, which accounted for 40.2% of renewable generation by 2022. Previous studies have explored how renewable technologies like solar and wind are outpacing traditional hydropower in growth, reflecting a global transition towards variable renewable energy sources. IRENA's data also examines regional contributions to renewable electricity generation, with Asia leading globally, followed by North America and Europe. Other researchers and policymakers have utilized these datasets to evaluate the effectiveness of renewable energy policies, analyze regional disparities, and forecast global energy transitions.

This project differs from previous work by offering a comprehensive analysis of global and regional energy trends, focusing on how renewable and non-renewable energy sources contribute to electricity generation over time. Unlike studies that primarily aggregate regional data, our work delves into granular trends, such as technology-specific contributions and year-by-year growth, using interactive visualizations to enable dynamic exploration of the data. Additionally, while IRENA's reports often emphasize high-level trends and aggregated statistics, this project highlights the intersection of regional, technological, and temporal dimensions to uncover nuanced insights, such as the relative efficiency of renewable adoption across different regions. By leveraging Tableau's interactive capabilities, the project bridges the gap between static analysis and dynamic stakeholder engagement, providing actionable insights for energy policymakers and investors.

Results

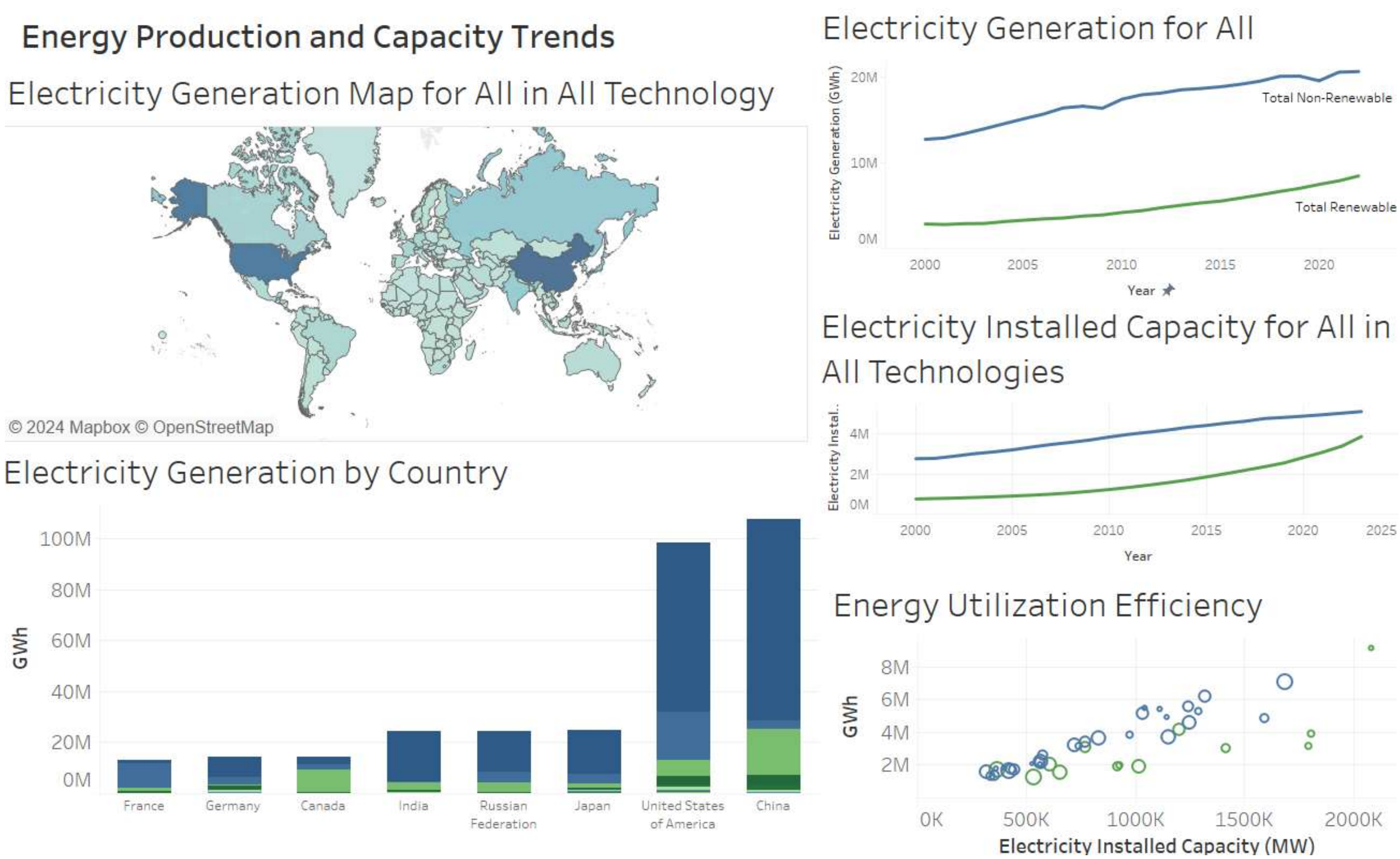

Figure 1: Dashboard of Overall Energy Production and Capacity (Non-Renewable Vs. Renewable) Trends

The "Overall Energy Production and Capacity" dashboard provides a general overview of global electricity generation, capacity, and energy efficiency. It highlights regional and country-level variations in electricity production while showcasing trends in capacity growth and utilization efficiency. The data emphasizes the scale of energy generation across countries, trends in renewable energy adoption, and differences in efficiency, offering a comprehensive snapshot of the global energy landscape from 2000-2024. Users can further interact and explore at various levels of granularity, enabling detailed insights. Filters allow for selection of regions, countries, energy technologies (fossil fuels, nuclear, hydropower, solar, etc.), and sub-technologies (coal vs natural gas) to analyze localized electricity generation, installed capacity, and efficiency metrics. This level of customization provides flexibility for users to uncover detailed patterns, compare trends across countries or technologies, and make data-driven decisions.

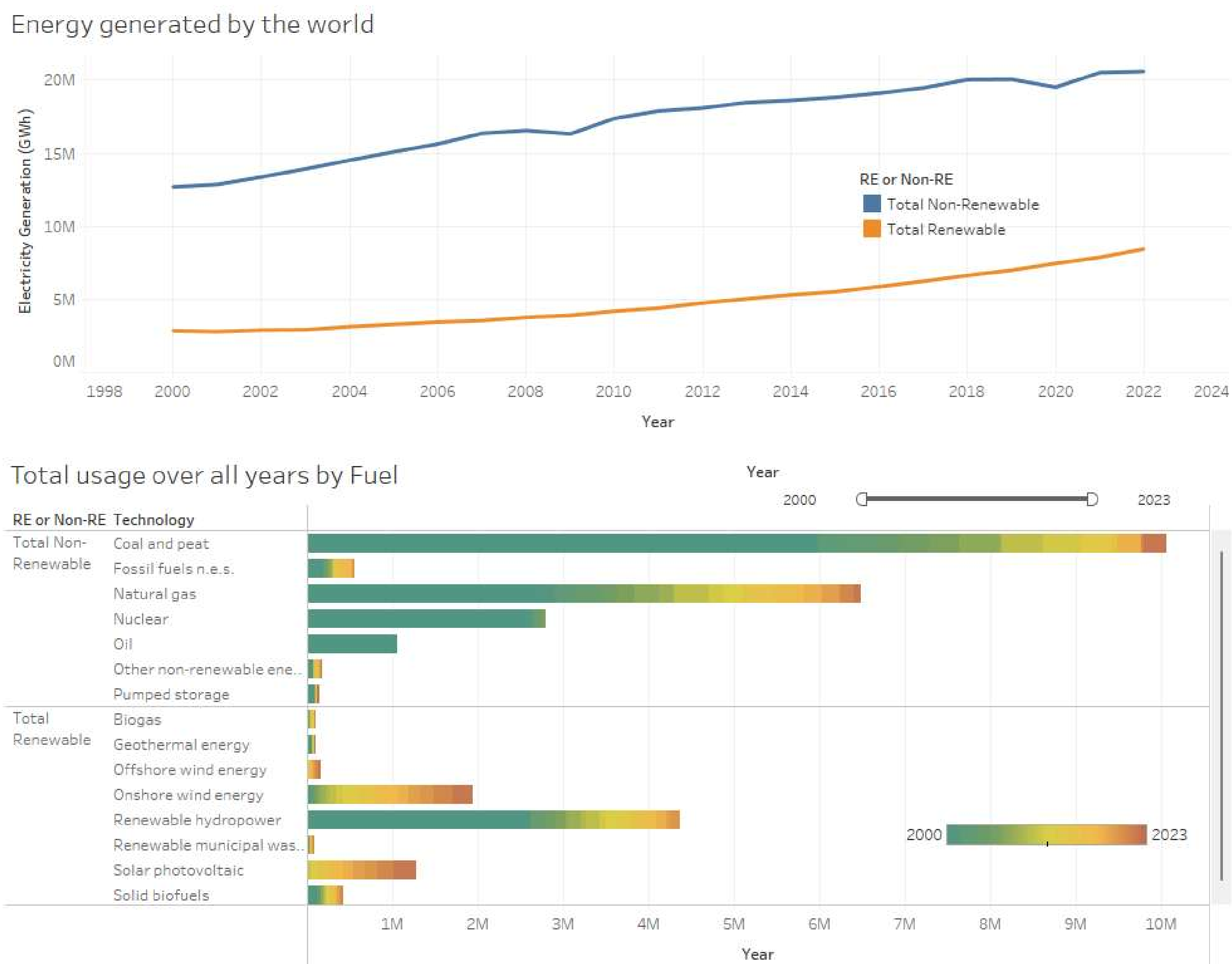

Figure 2 - Energy Generated by the World and Total Usage by Fuel.

The visualization captures global electricity generation trends from 1998 to 2023 and provides a detailed breakdown of energy usage by fuel type. The line chart highlights the steady growth of renewable energy (RE), shown by the orange line, driven by advancements in hydropower, solar, and wind. Despite this, non-renewable energy (Non-RE), represented by the blue line, continues to dominate, with fossil fuels and nuclear remaining critical contributors. While the renewable sector shows accelerated growth, the significant gap between RE and Non-RE underscores the global reliance on non-renewables to meet energy demand.

The bar chart further dissects energy usage by fuel type, revealing the dominance of fossil fuels, particularly natural gas, followed by coal and oil. Nuclear energy, while non-renewable, remains a key contributor with less environmental impact compared to fossil fuels. Within renewables, hydropower is the largest contributor, reflecting its established infrastructure, while onshore wind and solar energy exhibit strong growth trends, highlighting their pivotal role in the energy transition. Other renewables like biogas, geothermal, and offshore wind contribute modestly but remain essential for diversifying energy portfolios.

The gradient in the bar chart indicates increasing contributions from solar and wind technologies over the years, showcasing progress in renewable adoption. Overall, the visualization provides critical insights into the global energy landscape, illustrating both advancements in renewable energy and the persistent challenges of reducing dependency on fossil fuels to achieve a sustainable and decarbonized energy future.

The interactive dashboard can help quickly identify countries leading or falling behind in many categories, such as identifying leading polluters by filtering by fossil fuel consumption (Question 2a). Columns used include region, country, group technology, sub-technology, and electricity generated (GWh).

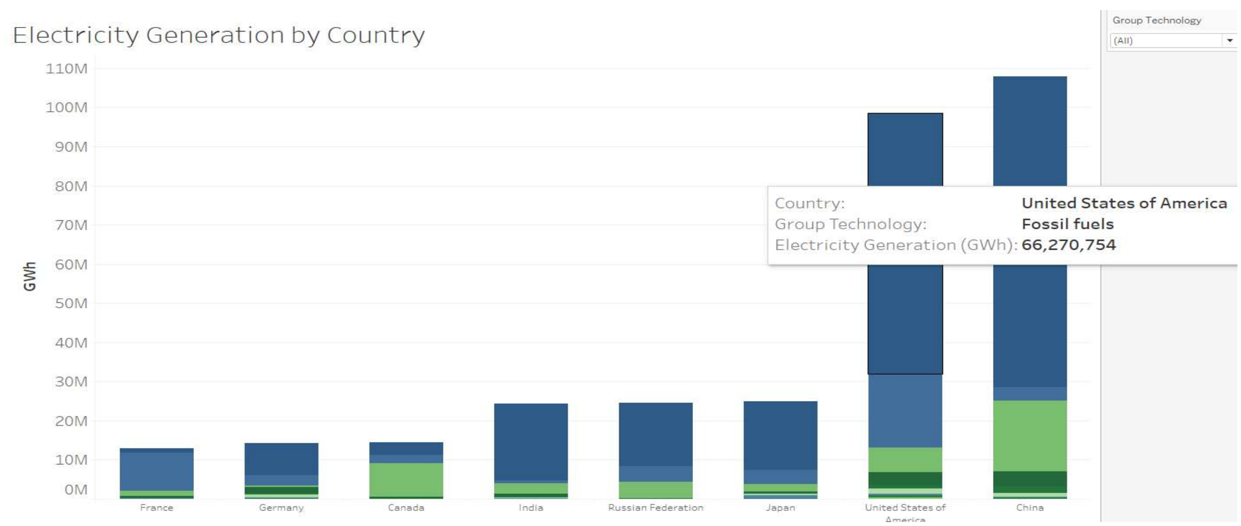

Figure 3 - Electricity Generation Bar Graph for Country by Technology

The Electricity Generation Bar Graph by Country and Technology is an interactive visualization that displays the total electricity generation (GWh) for the top electricity-producing countries, segmented by group technology (e.g., fossil fuels, solar, wind). The stacked bar design allows users to clearly see both the overall generation for each country and the specific contribution of each technology. With interactive filters, users can focus on specific technologies or countries to better understand energy production patterns. In the figure shown, countries like the United States and China stand out as top producers, with a significant portion of their energy generated from fossil fuels, while other countries show varying contributions from renewable technologies. Users can also further filter by sub-technology, allowing for further analysis into large countries' reliance on certain types of energy such as fossil fuels and the leading sub-technologies (coal/natural gas).

This bar graph aligns with the project's objective of analyzing global electricity generation by breaking it down at the country level and by group technology. Stakeholders can use the visualization to identify which countries dominate in total energy production and to compare their reliance on different energy sources. For example, the graph can reveal trends such as which countries are transitioning toward renewable technologies and which remain heavily reliant on non-renewable sources (Question 2a/2b). Columns used in the visualization include country, group technology, sub-technology, and electricity generation (GWh), ensuring a detailed and actionable view of energy production.

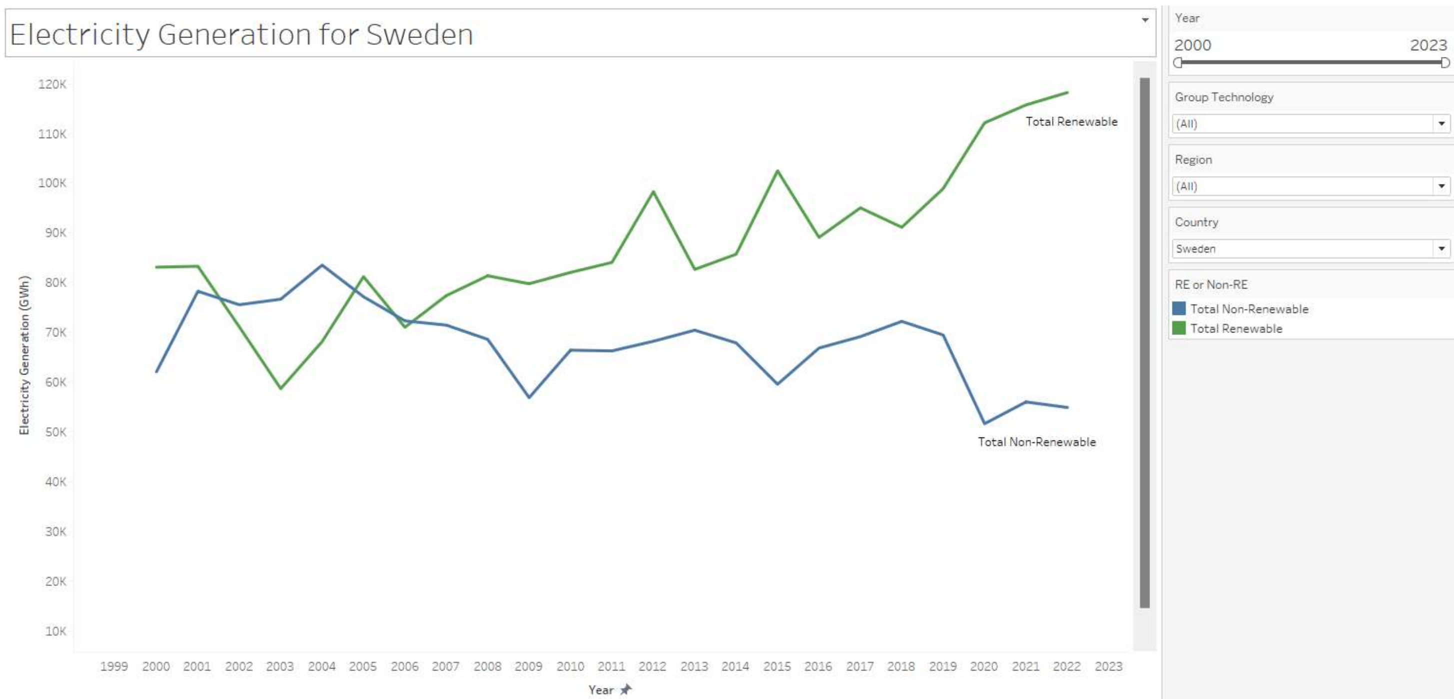

Figure 4 - Electricity Generation Line Graph for Country

This line graph provides a comprehensive view of electricity generation trends over time, distinguishing between renewable and non-renewable energy sources. By displaying the total electricity generation (GWh) on the Y-axis and year on the X-axis, the graph enables users to observe long-term patterns and shifts in energy production. The interactive filters allow users to analyze specific countries, regions, or energy types, making it a versatile tool for examining energy transitions across different contexts. The separation of renewable and non-renewable totals via distinct lines highlights how these categories compare over the years, offering insights into the pace of renewable adoption and the decline or stability of non-renewables.

Sweden serves as a compelling case study within this global framework because renewable energy has surpassed non-renewable energy in total electricity generation. This shift demonstrates the effectiveness of renewable energy policies and technological advancements. As seen in the graph, the steady rise of renewables and the relative decline of non-renewables make Sweden a model for countries aiming to transition toward cleaner energy sources. This example underscores the broader importance of understanding how such transitions occur and what factors enable countries to achieve sustainable energy dominance (Question 1a/1b). By examining Sweden's trajectory, stakeholders can identify best practices and apply lessons to other regions striving for energy sustainability. Columns used include Year, Country, Group Technology, Sub-Technology, and Electricity Generated (GWh).

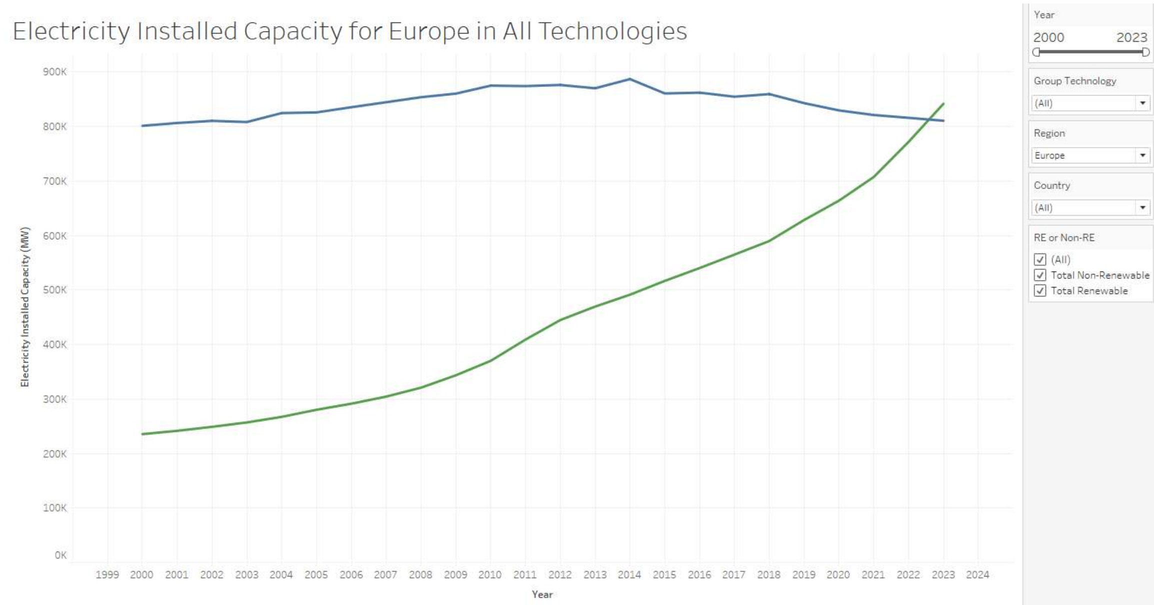

Figure 5 - Electricity Installed Capacity for Region in Technology

The Electricity Installed Capacity figure provides an overview of electricity installed capacity trends, which represent a country's growing potential to produce electricity in a category over time. The Y-axis displays installed capacity in megawatts (MW), while the X-axis spans from 2000 to 2023. The graph highlights the global shift toward renewables, with a sharp and consistent increase in renewable capacity, contrasting with the stable or slightly declining trends in non-renewables. The granularity of the data allows users to drill down into specific countries or technologies, enabling detailed insights into the growth of energy infrastructure and its alignment with long-term sustainability goals.

In the European context, the graph showcases how renewable installed capacity has surpassed non-renewable capacity in recent years, emphasizing the region's leadership in adopting clean energy technologies. Stakeholders can filter the data to explore specific countries or technology types, such as wind, solar, or fossil fuels, to understand their contribution to Europe's overall energy transition. They can also further explore the trends in sub-technologies such as solar grids vs privately owned panels. This visualization not only supports regional and global comparisons but also informs policy and investment decisions, highlighting key areas for growth and opportunities to replicate Europe's renewable energy success in other regions (Question 1a/1b). Columns used include Year, Country, Group Technology, and Electricity Installed Capacity (MW).

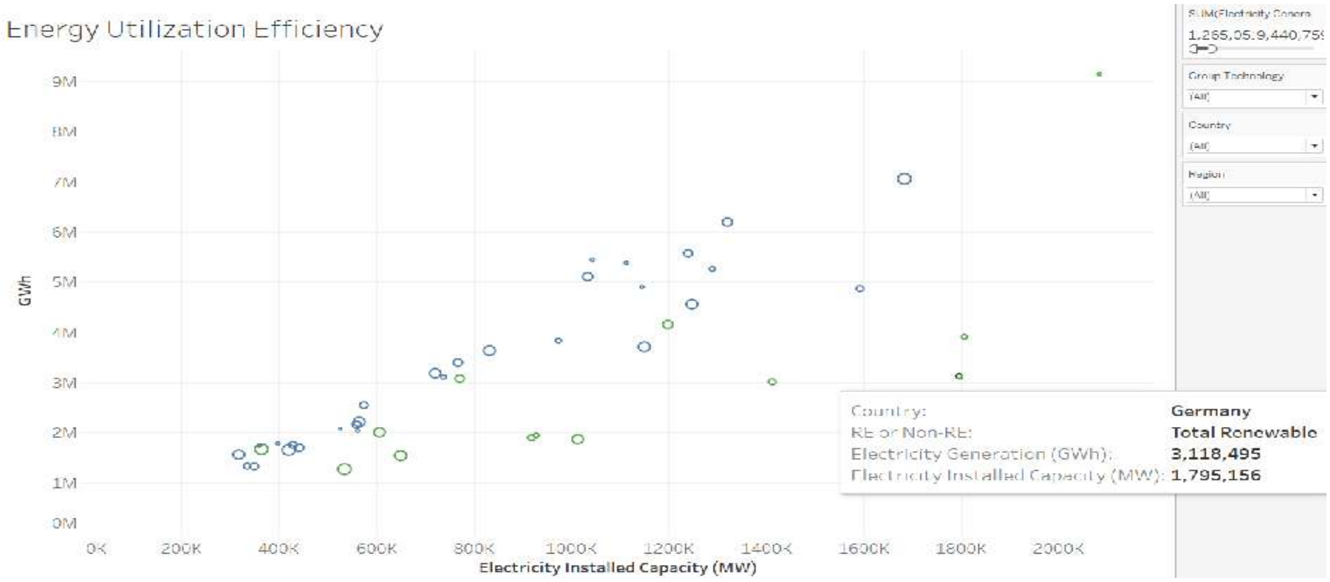

Figure 6 - Energy Utilization Efficiency Scatterplot

The Energy Utilization Efficiency Scatterplot visualizes energy utilization efficiency, comparing electricity installed capacity (MW) on the X-axis and electricity generation (GWh) on the Y-axis. Each point represents a country, with markers color-coded to distinguish between renewable and non-renewable sources. The plot highlights how efficiently countries convert their installed capacity into electricity generation, making it easy to identify outliers or trends in renewable versus non-renewable energy performance. Users can interact with the visualization by filtering for specific technologies or countries, enabling a granular analysis of energy efficiency across various energy types and regions.

The scatter plot offers valuable insights into the efficiency of newly created energy systems, such as Germany's renewable energy infrastructure, which combines high installed capacity with lower than average electricity generation. Countries should aim to have a high ratio of electricity generated to electric capacity. Beyond Europe, the plot can be used to benchmark energy efficiency globally, helping stakeholders identify areas for improvement in underperforming systems or study the strategies of high-performing countries. This visualization serves as a powerful tool for policymakers, energy analysts, and investors to evaluate the effectiveness of infrastructure investments and identify opportunities for sustainable energy improvements. Columns used include Country, Group Technology, Electricity Generated (GWh) and Electricity Installed Capacity (MW).

Conclusion

Our analysis of global renewable energy adoption reveals a clear and accelerating trend toward renewable energy sources, with substantial regional variations in adoption rates and technology preferences. For example, Europe was a leader in adoption rates of renewable energy resources with specific countries such as Germany and Sweden leading the adoption race. Fossil fuel dependency remains largely prevalent in the Americas and Asia, but is steadily declining as renewable technologies become more cost-effective, easy to use, and accessible. Additionally, there is a steady trend in nuclear energy adoption as a viable non-renewable source.

The Energy Production and Capacity Trend Dashboard effectively answers our business questions through its diverse range of interactive visualizations with specific drill-down capabilities to address the granularity of the data. To address trends in electricity generation by renewable (RE) and non-renewable (non-RE) sources, the line graph and stacked bar chart provide clear visualizations of contributions across regions, technologies, and time periods, highlighting key growth areas and declines. Fossil fuel dependency is examined through the choropleth map and bar chart, which allow users to identify regions most reliant on specific energy sources and compare their reliance to renewable technologies. The scatterplot adds depth by revealing energy utilization efficiency, helping to uncover disparities in how installed capacity translates to electricity generation across countries. Collectively, these tools enable users to explore granular details by filtering for specific years, countries, or technologies, making the dashboard a comprehensive solution for analyzing global energy trends and dependencies in alignment with the project's business questions. By providing a comprehensive, dynamic view of global energy trends, the dashboard equips stakeholders with the tools needed to develop effective strategies, inform investment decisions, and support the global shift toward sustainable energy systems.

Insights

1. Growth of Renewable Energy Sources: As a whole, renewable energy adoption has increased worldwide since 2000. Solar and wind energy have grown rapidly, outpacing other sources such as hydropower, likely due to advancements and lower costs/difficulty
2. Regional Leader: Europe has established itself as a leader in renewable adoption, while developing regions lag due to economic and infrastructural barriers
3. Technology Trends in Non-Renewable Energy: Natural gas and coal usage proportions are gradually decreasing, while other non-renewable sources such as nuclear have drastically increased indicating a more positive nuclear energy sentiment
4. Fossil Fuel Reliance: While other forms of energy have increased, oil and coal remain significant in all major countries
5. Policy Impacts: Countries that are typically associated with clean energy adoption such as Germany and Sweden are leaders in green energy adoption.
6. Data Challenges: Incomplete data, such as gaps in the original dataset's Heat Generated column underscore the need for better global reporting standards and participation in renewable energy

Our next step would be to expand the scope of the project and dataset, incorporating new information to provide deeper insights. Additional data can include socioeconomic indicators such as GDP and population growth and direct environmental impact such as CO2 Emissions to demonstrate the relationship between energy type and production and its impact/relationship with society. We can also conduct a deeper analysis of trends in energy following major policy changes, such as how energy production was affected/changed over the Covid-19 pandemic.

References

International Renewable Energy Agency. (2024, July 1). *Renewable energy statistics 2024*. IRENA. https://www.irena.org/Publications/2024/Jul/Renewable-energy-statistics-2024