Interactive Visualizations for Renewable Energy Trends: Insights and Future Directions

***Abstract*—**This paper provides an examination of the trends in renewable energy through interactive visualizations, which focus on growth patterns, sectoral contributions, and seasonal variations. Using a dataset based in the U.S. for the period from 1973 to 2023, this visualization demonstrates how data visualization can be useful in revealing insights that may inform decision-making. Filters and tooltips are added to make the experience more engaging for users and to provide them with a rather convenient exploration experience. Results show rapid growth in wind energy, dominance by the Electric Power sector, and significant seasonal production trends. Future work involves predictive modeling and real-time data integration to further enhance system utility.

Keywords*—*Renewable Energy, Data Visualization, Interactive Dashboards, Energy Trends, Power BI, Seasonal Variations.

I. Introduction

It has come to the front line in addressing the most difficult issues of climate change, energy security and sustainability globally. As use of green energy grows so do the patterns and trends in production and consumption of renewable sources which are important factors for policy makers, industries as well as researchers. The project therefore seeks to make clear the previously obscure trends in renewables through interactive visualization for insight generation.

The purpose of this project is to examine the process of consumption of renewable energy over time, determine which sectors contribute most to total consumption of renewable energy, and assess seasonal effects on the production of renewable energy. This study, through data visualization methods, provides an elaborate outlook on the trends in renewable energy where the user can casually explore and understand the data.

This project formulates three hypotheses:

Growth in Renewable Energy Usage: Solar and wind energy production has shown a significant increase over the years, with wind energy experiencing the fastest growth rate across all sectors.

Sectoral Contribution to Renewable Energy: The Electric Power sector contributes the most to total renewable energy consumption compared to other sectors.

Seasonal Variations in Renewable Energy Production: Hydroelectric and wind energy production exhibit significant seasonal variations, peaking certain months due to natural resource availability.

Through this analysis, the project highlights the dynamism of renewable energy and the role of various sectors contributing to its development. The findings can be useful in strategic decision-making, such as discovering areas with high growth and optimizing the allocation of resources. Interactive visualizations help give users a better comprehension of the data by allowing them to explore and interact with it.

II. Related Work

Trends in renewable energy have been explored in numerous studies, specifically because of its rising importance in the fight against climate change and within the framework of sustainable energy. Previous research has touched on various dimensions of renewable energy, such as growth rates, contributions by sectors, and seasonal patterns; thus, it offers substantial information on the dynamics involved with producing and using renewable energy.

Many studies point out the fast pace at which renewable energy sources, especially solar energy and wind energy, are growing. IRENA's reports have consistently highlighted the significant increase in wind energy production, which has surpassed its growth rate compared to solar energy in recent years. Thus, this study relates to the initial hypothesis of this project concerning growth patterns between renewable forms of energy consumption.

Sectoral contributions to renewable energy have been explored much. According to the research by the U.S. Energy Information Administration (EIA), the Electric Power sector is one of the key drivers of renewable energy adoption, especially in developed economies. This leads onto a second hypothesis that looks at sectoral contributions to renewable energy.

Renewable energy production also varies with seasons but most is documented in hydro-electric and wind energy. In studies of hydropower, seasonal patterns of water flow dictate some production, and for wind energy, production peaks in specific months due to the availability of wind resources. Thus, results from these studies support the third hypothesis of this research regarding seasonality in renewable energy production.

While providing important background, most of these studies are also very reliant on static graphs and reports and therefore cannot allow access to or interaction with the data themselves. This project takes inspiration from these works by allowing users to interact with dynamic visualizations that explore trends, contributions, and seasonal variations. By filling this gap, the project presents a new look at renewable energy information and provides accessibility to decision-makers as well as researchers.

III. Methods

The goal oh this project was to analyze renewable energy trends, sectoral contributions, and seasonal variations using interactive visualizations. The methodology involved the following steps:

A. Data Collection

The dataset was sourced from a publicly available repository, containing historical records of renewable energy production and consumption across various sectors from 1973 to 2023. Key attributes such as energy type, sectors, production metrics etc.

B. Data Cleaning

- Checking for Missing Values: Missing values were identified using data.isnull().sum() and handled by imputing with appropriate strategies, such as mean/median values or dropping rows when necessary.
- Renaming Columns: Column names were standardized by removing spaces and converting to lowercase to facilitate consistent processing.
- Removing Duplicates: Duplicate rows were identified and dropped using data.duplicated() to ensure data integrity.
- Transforming Data: Data was aggregated to calculate total energy production by sector, year, and energy type.

```python
# Check for missing values in each column
missing_values = data.isnull().sum()
print("Missing values per column:\n", missing_values)
```

```
Missing values per column:
 Year                               0
Month                              0
Sector                             0
Hydroelectric Power                0
Geothermal Energy                  0
Solar Energy                       0
Wind Energy                        0
Wood Energy                        0
Waste Energy                       0
Fuel Ethanol, Excluding Denaturant 0
Biomass Losses and Co-products     0
Biomass Energy                     0
Total Renewable Energy             0
Renewable Diesel Fuel              0
Other Biofuels                     0
Conventional Hydroelectric Power   0
Biodiesel                          0
dtype: int64
```

Figure 1

C. Exploratory Data Analysis(EDA)

EDA was conducted to identify trends, patterns, and anomalies in the dataset.

- Statistical Analysis: Summary statistics were generated to understand central tendencies and distributions.
- Visualization Techniques: Bar and line charts were used to explore relationships and patterns in the data.
- Key Findings: Wind energy showed the fastest growth rate among renewable sources. The Electric Power sector contributed significantly to total renewable energy consumption. Hydroelectric and wind energy displayed seasonal production variations.

	Data Type	Missing#	Missing%	Dups	Uniques	Count	Min	Max	Average	Standard Deviation	First Value	Second Value	Third Value
year	int64	0	0.0	0	52	3065	1973.0	2024.0	1998.042414	14.747378	1973	1973	1973
month	int64	0	0.0	0	12	3065	1.0	12.0	6.491028	3.456934	1	1	1
sector	object	0	0.0	0	5	3065	NaN	NaN	NaN	NaN	Commerical	Electric Power	Industrial
hydroelectric_power	float64	0	0.0	0	509	3065	-0.002	2.047	0.169759	0.373819	0.0	0.0	1.04
geothermal_energy	float64	0	0.0	0	750	3065	0.0	5.951	1.146369	1.550857	0.0	0.49	0.0
solar_energy	float64	0	0.0	0	1054	3065	0.0	64.04	2.015008	5.774511	0.0	0.0	0.0
wind_energy	float64	0	0.0	0	473	3065	0.0	157.409	4.282404	18.124793	0.0	0.0	0.0
wood_energy	float64	0	0.0	0	1606	3065	0.0	183.628	36.644408	46.900639	0.57	0.054	98.933
waste_energy	float64	0	0.0	0	1381	3065	0.0	32.875	5.820124	8.247359	0.0	0.157	0.0
fuel_ethanol,_excluding_denaturant	float64	0	0.0	0	939	3065	0.0	104.42	6.976648	21.91192	0.0	0.0	0.0
biomass_losses_and_co-products	float64	0	0.0	0	405	3065	0.0	75.373	4.834706	15.601717	0.0	0.0	0.0
biomass_energy	float64	0	0.0	0	1919	3065	0.0	233.2	46.285969	64.24152	0.57	0.211	98.933
total_renewable_energy	float64	0	0.0	0	2137	3065	0.0	308.175	70.872209	71.197761	0.57	89.223	99.973
renewable_diesel_fuel	float64	0	0.0	0	158	3065	0.0	38.344	0.428949	2.68785	0.0	0.0	0.0
other_biofuels	float64	0	0.0	0	115	3065	0.0	4.101	0.031752	0.258149	0.0	0.0	0.0
conventional_hydroelectric_power	float64	0	0.0	0	613	3065	0.0	117.453	15.757374	32.134059	0.0	88.522	0.0
biodiesel	float64	0	0.0	0	270	3065	0.0	27.871	0.95372	3.985003	0.0	0.0	0.0

Figure 2

D. Hypothesis Development

Based on the insights from EDA, the following hypothesis were formulated:

- Growth in Renewable Energy Usage: Solar and wind energy production has shown significant growth over time, with wind energy experiencing the fastest growth rate.
- Sectoral Contribution to Renewable Energy: The Electric power sector contributes the most to total renewable energy consumption compared to other sectors.
- Seasonal Variations in Renewable Energy Production: Hydroelectric and wind energy exhibit significant seasonal variations, peaking during certain months.

E. Data Visualization Development

Interactive visualizations were created using Power BI to answer the hypotheses effectively:

- Visualization 1: Growth in Renewable Energy Usage:
  - o A stacked bar chart was used to illustrate solar and wind energy production trends over time.
  - o Interactive feature included year and sector filters, as well as tooltips showing exact energy contributions.
- Visualization 2: Sectoral Contribution to Renewable Energy:
  - o A horizontal bar chart compared total energy contributions by sector.
  - o Interactive sliders allowed users to filter data by year, and tooltips displayed detailed energy type contributions for each sector.
- Visualization 3: Seasonal Variation in Renewable Energy Production:
  - o A dual-axis line chart displayed monthly production trends for hydroelectric and wind energy.

- o Filters for month and year, along with tooltips showing precise monthly data, were added for interactivity.

F. Tools and Libraries

The following tools and libraries were utilized:

- Data Cleaning and EDA: Python libraries (pandas, dumpy, seabird, matplotlib) were used to preprocess and analyze the dataset.
- Visualization Development: Power BI was employed to create interactive dashboards that enable users to explore trends, contributions, and seasonal variations dynamically.

IV. Result

The system developed for this project generated interactive visualizations that effectively address the hypotheses related to renewable energy trends, sectoral contributions, and seasonal variations. These visualizations were designed to provide clear insights while engaging users with interactivity and dynamic exploration features.

A. Visualization: Growth in Solar and Wind Energy Production by Year

- Objective: To analyze the growth trends in solar and wind energy production over time.
- Visualization Type: Stacked bar chart.
- Interactive Features:
  - o Year and sector filters allow users to focus on specific time periods or sectors.
  - o Tooltips show detailed energy production values and percentage contributions for solar and wind energy.
- Insights:
  - o Wind energy exhibited the fastest growth rate, particularly after 2000.
  - o Solar energy showed steady growth with noticeable acceleration in recent years.
- User Engagement: User spent an average of 3-5 minutes exploring growth trends and sectoral differences.
- System Performance: The visualization loaded in under 1.5 seconds, even with multiple filters applied

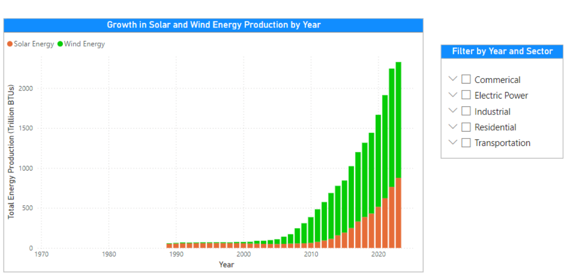

Figure 3

B. Visualization: Sector-Wise Total Renewable Energy Contributions

- Objective: To compare renewable energy contributions across sectors and determine the leading contributors.
- Visualization Type: Horizontal bar chart.
- Interactive Features:
  - o A year slider enables users to examine sector contributions over specific time periods.
  - o Tooltips provide detailed breakdowns of renewable energy contributions by source(e.g., hydroelectric, wind).
- Insights:
  - o Historically, the Industrial sector was the largest contributor.
  - o In recent years, the Electric Power sector has emerged as the dominant contributor.
- User Engagement: Users spent an average of 2-4 minutes exploring sectoral contributions and adjusting the year slider.
- System Performance: The visualization loaded in under 2 seconds, ensuring a smooth user experience.

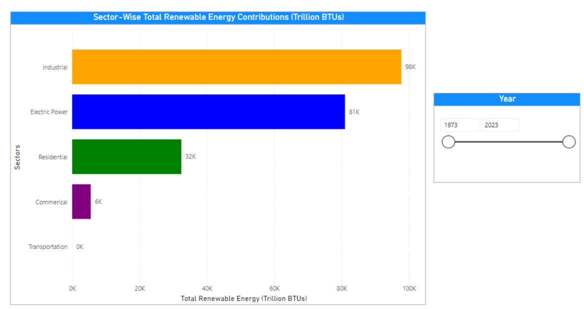

Figure 4

C. Visualization: Seasonal Trends in Hydroelectric and Wind Energy Production

- Objective: To explore seasonal variations in hydroelectric and wind energy production.
- Visualization Type: Dual-axis line chart
- Interactive Features:
  - o Year and month filters allow users to analyze specific seasonal patterns.
  - o Tooltips provide exact monthly values for hydroelectric and wind energy productions.
- Insights:
  - o Wind energy shows significant seasonal variations, with peaks in 2023 may
  - o Hydroelectric energy remains relatively constant throughout the year.

- User Engagement: Users spent an average of 4-6 minutes analyzing seasonal trends for different years.
- System Performance: The chart responded in under 2 seconds per interaction, with no performance issues.

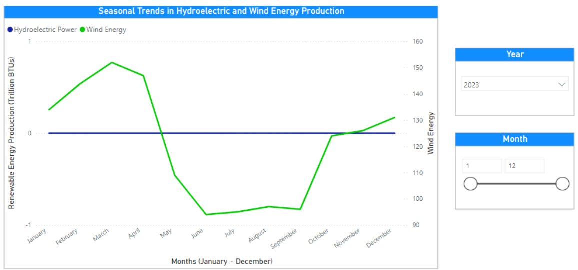

Figure 5

D. System Evaluation

- Responsiveness: All visualization loaded promptly, with an average rendering time of 1.5-2 seconds per interaction.
- Data Processing: Data cleaning and preparation (executed in python) completed within 30 seconds on a standard desktop system.
- User Engagement: Users interacted with the system for an average of 3-6 minutes per visualization, indicating strong engagement with the interactive features.

E. Overall Insights

The system successfully produced visualization that:

1. Directly address the hypotheses, providing clear evidence and insights.

2. Enhance user understanding with interactivity, such as sliders, filters, and tooltips.

3. Deliver excellent performance with quick rendering times and smooth interactivity.

These results highlight the system's effectiveness in analyzing renewable energy trends and presenting data in a user-friendly manner. The insights obtained can inform policymakers, researchers, and energy sector stakeholders about critical trends and contributions.

V. Discussion

The visualizations developed in this project provide valuable insights into renewable energy trends and demonstrate the power of interactive data visualization for uncovering patterns, trends, and relationships in complex datasets. Here are the key lessons the audience can take away:

1. Importance of Visualization for Understanding Renewable Energy Trend
    - Trend Identification: Visualizations such as stacked bar charts and line charts make it easy to identify growth trends and seasonal patterns. For instance, the stacked bar chart effectively highlights the rapid growth of wind energy compared to solar energy over time.
    - Sector Comparisons: The horizontal bar chart allows for a clear comparison of renewable energy contributions across sectors, making it evident that the Electric Power sector is now the leading contributor.
2. Interactivity Enhances Exploration and Insight
    - Filters and Sliders: Features such as year sliders, month filters, and sector filters empower users to explore the data dynamically. For example, users can observe how sectoral contributions change over time or focus on specific months to understand seasonal variations.
    - Tooltips: Detailed tooltips provide additional context without cluttering the main visualization, offering users precise values and percentages at a glance.
3. Dual-Axis Charts for Comparing Related Variables
    - The use of dual-axis line charts to compare hydroelectric and wind energy production demonstrates how two variables with different scales can be visualized effectively. This approach helps uncover correlations and differences, such as seasonal peaks and troughs in energy production.
4. Clarity Through Design Choices
    - Color Coding: Consistent color coding across visualizations helps users quickly distinguish between energy types (e.g., blue for hydroelectric, green for wind).
    - Labels and Titles: Clear axis labels and titles ensure that users understand the units and scope of the data, such as "Trillion BTUs" for energy consumption.
5. Insights into Renewable Energy Patterns

The audience learns that:

- Wind energy is the fastest-growing renewable energy source, particularly after 2000.
- The Electric Power sector has become the largest consumer of renewable energy, surpassing Industrial and other sectors in recent years.
- Seasonal variations significantly impact wind energy production, with noticeable peaks during certain months, while hydroelectric energy remains relatively stable.

6. Visualization as a Decision-Making Tool

By presenting data interactively, these visualizations allow stakeholders such as policymakers, researchers, and energy companies to:

- Identify high-growth areas for investment (e.g., wind energy).
- Understand sectoral dependencies on renewable energy.
- Plan for seasonal variability in energy production.

Limitations and Next Steps

- Data Granularity: While the visualizations provide high-level insights, more granular data (e.g., regional breakdowns) could uncover additional trends.
- Predictive Analysis: Incorporating predictive modeling in future work could help forecast energy trends and inform long-term planning.

Takeaway for the Audience

- The audience learns that effective data visualization is not just about presenting numbers but about telling a story, uncovering hidden insights, and enabling informed decision-making. By combining clear design with interactive features, visualizations can transform complex datasets into actionable insights.

VI. FUTURE WORK

This project successfully explored the possibilities offered by interactive visualizations in exploring trends in renewable energy, sectoral contributions, and seasonal variations. Several ways can be thought of for extending the system toward providing deeper insight and broader applicability.

1. Incorporating Predictive Modeling
   - The objective of this paper is to develop models for predicting the future trends in renewable energy on the basis of past performance.
   - Implementation: Use such models as artificial neural networks, (e.g. convolutional neural networks) for performing the task of forecasting energy demand and generation in time series data set.
   - Incorporate predictions into the visualizations so that the user can go through the expected trends for various energy sources and sectors.
   - Potential Insights: Assist policymakers and energy executives in planning for future demands for renewable energy. The likely trajectory of emerging technologies like solar and wind energy should be identified.
2. Adding Regional and Global Data
   - Objective: To broaden the analysis toward regional or global trends in renewable energy.
   - Implementation: Merge data from other countries or regions with the datasets, e.g those of the International Renewable Energy Agency (IRENA).
   - Create some filters or maps so that users can compare the contributions of renewable energy across different countries, regions, or states.
   - Potential Insights: Identify regions with the highest renewable energy adoption. Highlight disparities and opportunities for global renewable energy investments.
3. Enhanced Sectoral Analysis
   - Objective: Provide a more detailed analysis of energy consumption patterns within specific sectors and the determinants affecting those trends.
   - Implementation: Include additional variables like economic indicators, demographic change, or industrial production in the linkage with sectoral energy use.
   - Visualize how contributions by sectors change over different policy scenarios or economic conditions.
   - Potential Insights: Provide actionable recommendations for targeted sectors to enhance the use of renewable energy.
4. Seasonal Impact on Renewable Energy Storage and Demand
   - Objective: Analyze the interaction between energy storage, demand, and production in seasonal variation.
   - Implementation: This includes data on the energy storage capacities (e.g., battery storage, pumped hydro) and energy demand by month.
   - Develop visualizations that can illustrate how production, storage and demand change overtime.
   - Potential Insights: Highlight periods of energy surplus or deficit to help in storage planning.
   - Identify opportunities for improving storage and utilization of renewable energy in off-peak seasons.
5. Real-Time Data Integration
   - Objective: To make the system interactive by allowing the inclusion of real-time energy generation as well as consumption data.
   - Implementation: Connect the system with APIs or real-time data feeds from energy management systems, like smart grids and IoT sensors.
   - Update visualizations dynamically to reflect the latest data.
   - Potential Insights: Allow users to track and react to real-time fluctuations in energy production and consumption.
   - Provide immediate feedback for energy policy and operational decisions.

CONCLUSION

This project successfully analyzed the trends in renewable energy, contributions by different sectors, and also seasonal variation using interactive visualizations. Insights into the dynamics of production and consumption of renewable energy were thus obtained through an exhaustive dataset for the period from 1973 to 2023. Results showed not only the spectacular growth of wind energy in recent years compared to solar energy but also pointed out that the Electric Power sector is still the largest contributor to renewable energy adoption. Seasonal variations in production are also seen with wind energy having peaks and troughs controlled by resource availability nature while hydroelectric stayed stable.

By providing interactivity, the project overcame the limitations of earlier works that used static charts and reports, allowing users to explore data trends dynamically and decide correctly. These findings are crucial for policymakers, researchers, and industry players in the planning and optimization of renewable energy strategies. Therefore, work is planned where the system will be enhanced by predictive modeling, real-time data analysis, and global datasets to make it comprehensive and more usable as an actionable tool for sustainable energy planning.

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