VIZION: Global Solar Production Tracker

Leama Tah and Adam Anwar

Abstract— Global solar energy production has been increasing steadily every year, and the ability to track this growth on a global scale is crucial for making informed decisions. To address this, we introduce “VIZION,” a web-based visualization dashboard that integrates spatio-temporal data on solar photovoltaic (PV) capacity from countries worldwide between 2016 to 2021. Using D3.js and Python (Streamlit), we created dynamic and interactive visualizations such as choropleth maps, trend charts, stream graphs, and treemaps to reveal global and regional patterns over time. This dashboard can reveal continental variations and link solar capacity to economic and demographic factors such as population, demographics, wealth (Gross Domestic Product), and education. Through collaborative data processing, design, and evaluation, we identified both effective and inadequate visualization approaches to guide future refinement. Our results show the utility of combining interactive charts with geospatial and temporal data to better support energy policy assessments and future management for sustainable development.

Index Terms— solar energy, spatio-temporal, global trends

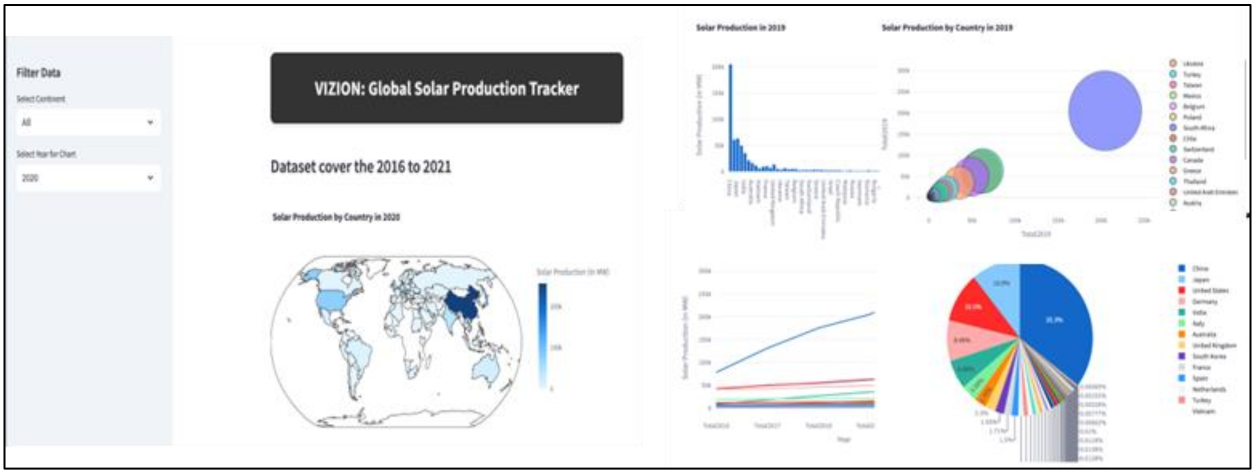

Fig.1. Initial view of VIZION: Global Solar Production Tracker.

1 Introduction

The global transition to renewable energy sources has increased in recent decades, with solar photovoltaic (PV) power leading as a key contributor to sustainable electricity generation. Complex repositories of energy data–from annual PV capacity to hourly geospatial datasets mapping solar installations–now confront researchers, analysts, and policymakers with a wealth of information. However, the volume and complexity of this data presents challenges. Regular spreadsheet applications and basic charts cannot easily reveal subtle patterns needed for evidence-based policymaking, forecasts, or sustainable development planning. Instead, stakeholders could find themselves struggling to figure out which countries are leading in solar adoption or how production capacity evolve over time.

Contributions: We frame this work as a visualization design study that addresses a complex energy analytics domain. Our main contributions include VIZION itself, its underlying data abstractions, and a detailed discussion of how users might interact with the tool to uncover information. Through several design phases and data exploration sessions, we refined our system to meet the needs of domain users. Ultimately, this experience led us to develop generalizable lessons for visualization design in sustainable energy context.

Outline: We start by reviewing related work on energy visualization and interactive analysis in Section 2. Section 3 then describes our end-to-end process in creating VIZION, and in Section 4, we present the core design elements of our application. We discuss future directions in Section 5 and conclude in section 6 by summarizing our contributions and the lessons learned from our experience.

To show how VIZION can be used, consider an analyst tasked with making decisions about solar energy management in Africa. After loading the global dataset into VIZION, the analyst begins with the choropleth map, viewing worldwide solar PV production trends from 2016 to 2021. By adjusting filters to focus on Africa, the map updates to highlight solar capacity data for countries within the continent. Hovering over specific countries reveals annual production values, making it clear, for example that South Africa leads regional solar adoption. Shifting to the trend section, the analyst examines a line chart and pie chart to confirm this data, while also observing how other African nations compare in both absolute and proportional terms. The analyst can receive information into geographic patterns, growth, and relative contributions by analyzing these linked visualizations. This example demonstrates how VIZION enable users to move smoothly from global overviews to focused regional assessments, extracting meaningful results from large datasets.

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2 Related Work

Energy-related data often lack complexity, but the core questions are similar: how can we identify hidden trends and correlation in large data collections. Researchers have studied this problem before, focusing on techniques for representing complex data, helping intuitive exploration, and helping users find meaningful conclusions.

Eco-visualization studies show that clear, interactive representations of energy usage can inform public awareness and influence decision-making. Holmes [1] discusses how dynamic visualization systems can increase user engagement with energy information, and Pahl et al. [2] confirms that well designed visual interfaces encourage users to understand and act upon energy consumption trends. In the solar domain, Hu et al. [3] and Solomon et al. [4] link energy transitions to broader climate impacts, showing that we need visualization tools that reveal temporal patterns and spatial distributions simultaneously. Kabir et al. [5] and Kannan & Vakeesan [6] discusses solar energy's evolving role in global electricity generation, calling for visualization frameworks that make global comparisons, historical change, and economic context readily apparent.

Prior work on energy data visualization frequently uses maps, line graphs, and treemaps to integrate temporal progression and geographic distribution. For example, tools that combine geographical encodings with interactive charts offer users the ability to navigate, zoom, filter, and annotate their explorations. This interactivity is important to uncover unexpected patterns and refining hypotheses. Studies like Murugesan et al. [7] review design criteria for visualizing complex energy consumption data, insisting on user-centric solutions that then focus on analysis tasks. This approach aligns with broader renewable energy visualization frameworks, such as immersive tools that leverage advanced interfaces to improve decision-making [8].

3 Process

For our analysis, we selected a comprehensive solar dataset from Kaggle, which provided detailed information on solar energy production across 94 countries. To explore and visualize the data, we used Tableau for an interactive visual exploration, which allowed us to uncover key trends and patterns in the dataset. The approach we took was to combine our knowledge in both Python and JavaScript. We built a custom dashboard using D3.js. It enabled us to design and implement a variety of advanced chart types, including interactive tree map and choropleth maps, which were essential for visualizing the solar energy production trends over time. To integrate our visualizations and make them accessible to users, we used the Streamlit framework, a popular Python library that simplifies the development of interactive web applications. By combining the power of D3.js and Streamlit, we created an intuitive, user-friendly app that allows users to interact with the data, explore various visualizations, and analyze solar energy production trends across different countries. This combination helps us build an accurate and flexible platform for analyzing and presenting the solar energy data in a comprehensive and visually appealing way.

4 Detailed Results

This section provides an in-depth examination of VIZION's features, design, implementation, usage requirements, and evaluation outcomes. The application uses a range of visualization techniques that together form a cohesive environment for analyzing global solar data. VIZION's features center on five primary visualization categories. The choropleth map provides a global spatial overview, allowing users to identify high-performing countries and continental clusters at a glance. Hovering over individual countries allows users to access detailed numerical data on solar production, reinforcing the details-on-demand task, a well-established interactive analysis principle [9]. The trend zone includes line, bar, pie, and bubble charts, each offering a distinct perspective on the underlying data. The line chart highlights temporal change, showing changes in solar production over time and revealing leading and lagging countries. The pie chart shows the proportional contributions of each country to a region's total production, supporting a clearer understanding of dominance and relative balance. The bar and bubble charts show comparative magnitude and distribution. These charts, used together, can guide analysts toward detailed interpretations of the data, though some users note that having so many perspectives in one section can initially feel overwhelming. To alleviate confusion, carefully chosen color schemes, interactive legends, and textual explanations can help users navigate these rich visual environments.

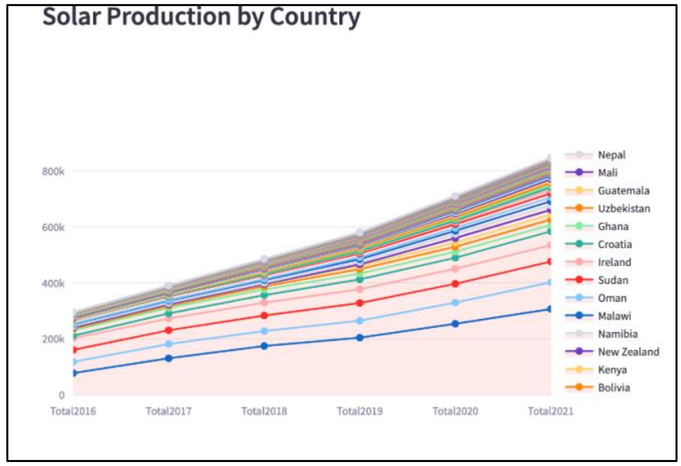

Fig. 2. Stream graph with stacked individual country data presented as over time.

The stream graph (Fig. 2) presents cumulative changes and highlights how the collective contribution of various countries shifts over time. Although it can effectively identify standout entities, the layered approach introduces challenges because the stacked format makes it difficult to precisely interpret individual components [10]. The treemap focuses on hierarchical relationships, allowing analysts to filter regions and examine relative values in nested structures [11]. This visualization reveals patterns that may be obscured in more traditional charts and provides another way for regional analysis. We initially created an animated treemap in D3 but failed to incorporate it into our python application. Therefore, we had to recreate our treemap using Streamlink. A comparison between the two is seen in Figure 3.

Lastly, the comparative view linking solar production to GDP per capita and population introduces a socioeconomic dimension (Fig. 4). This multivariate method can inform strategic decisions by showing how solar adoption correlates with wealth, demographics, or other factors that we can include, although proper labeling and guidance are necessary for non-expert users to understand these relationships. The clarity of legends, instructions, and interactive tooltips is essential for users to interpret multivariate charts without prior specialized knowledge.

From a design standpoint, VIZION uses a minimalist visual aesthetic that emphasizes clarity and accessibility. High-contrast color palettes and careful use of shape and scale support diverse user needs, including those with color-vision deficiencies [12]. Interactivity is achieved through responsive hovering, filtering, and coordinated views that update simultaneously to maintain a coherent context. Smooth animations and transitions help users maintain a sense of continuity when the display changes [13]. The interface is organized into logical sections, allowing users to begin with broad overviews and then apply filters and selections to narrow their focus. Coordinated filters ensure that all visualizations remain in sync, so when an analyst selects a particular continent on the map, the corresponding time-series and hierarchical charts simultaneously update to reflect the chosen subset.

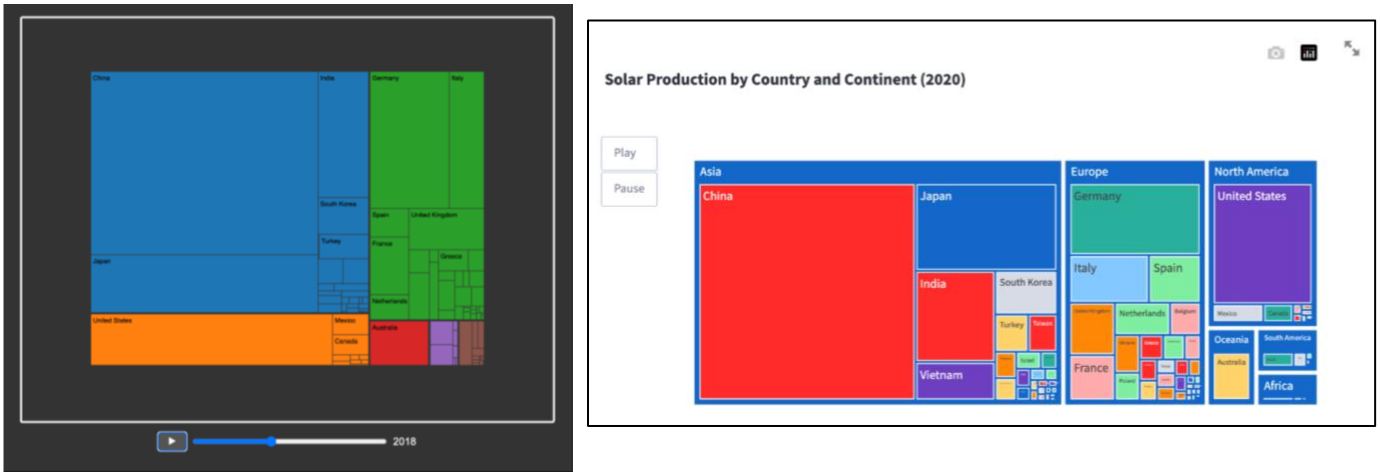

Fig 3. Animated treemap produced in D3 (left) vs python (right).

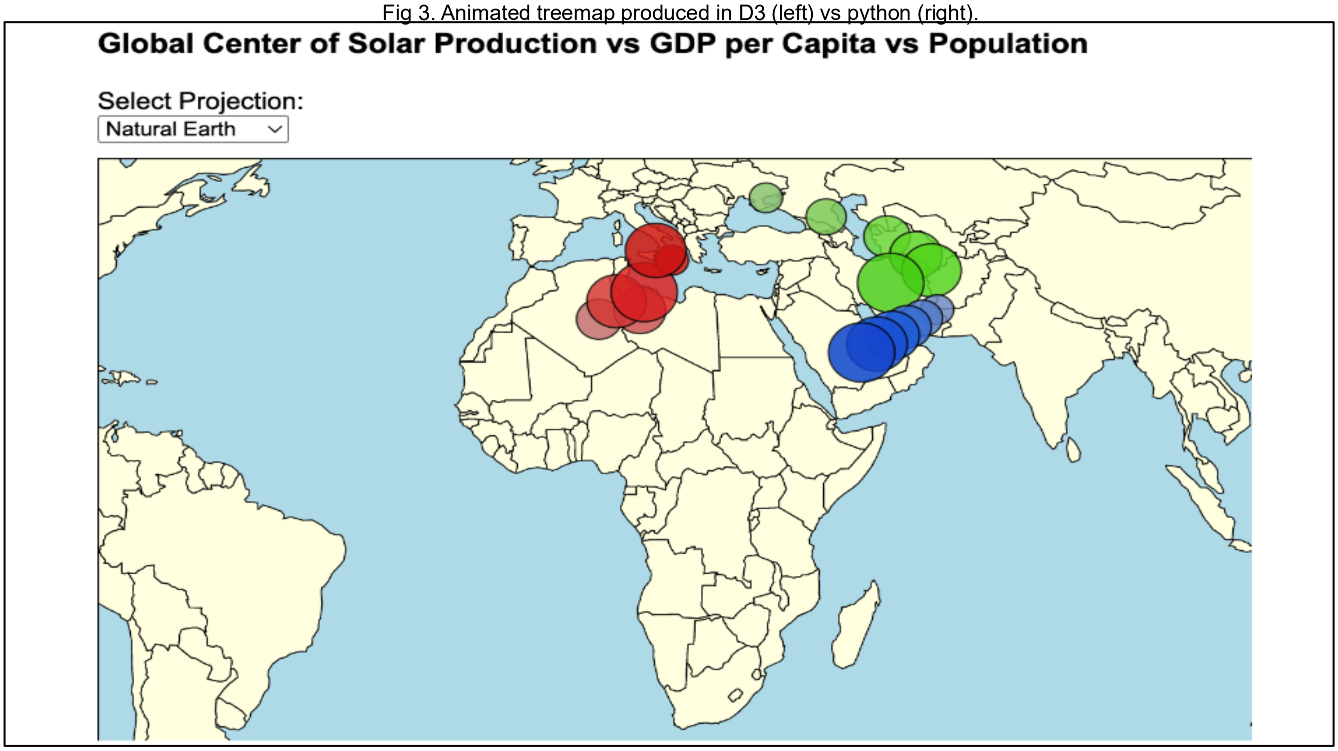

Fig 4. Global center for three different variables: solar production (green), population (blue), and red (GDP per capita).

VIZION's implementation relies on using standard tools and libraries through a website. Data preprocessing is performed in Python and R, where raw data is cleaned, aggregated, and transformed. Resulting datasets are stored in formats such as CSV or JSON/GEOJSON. The visualization components are built primarily with D3.js [14], a well-known JavaScript library for interactive and dynamic data visualizations. Modular code organization separates each chart type into its own module, simplifying maintenance and future enhancements.

The usage requirements for VIZION are relatively minimal. Any modern web browser can run the application without specialized hardware or software. Although the interface is most effective on desktop displays due to the complexity and density of information, it can be accessed on tablets or high-resolution monitors as well. A stable internet connection is recommended for remote data access, but the application can be deployed locally if necessary. Users with a background in energy policy, sustainability, or data analysis will likely find VIZION most intuitive. Non-experts benefit from introductory tutorials, embedded tooltips, and reference materials that explain the meaning of visual encodings, interactive controls, and domain-specific terms.

Internal evaluation of our work highlights both strengths and limitations. The choropleth map's immediate details-on-demand feature proves valuable for quick identification of top performers, while the trend zone's variety of charts is praised for providing a multi-perspective understanding of solar capacity changes over time [15]. We found that the density of information in the trend zone is challenging but note that with practice and occasional reference to legends, navigation becomes smoother. The stream graph raises discussion about whether alternative layouts or adding annotations could improve interpretability. The treemap's hierarchical filtering capabilities and animations was successful, but countries with smaller values can be overshadowed unless users interact with filtering tools. The comparative view linking solar production to GDP per capita and population shows the potential for more contextualization, but newcomers may need more explicit guidance, such as a carefully designed legend, or on-demand explanations to facilitate interpretation [16].

While certain visualization techniques may require incremental refinements and additions to the user interface, the tool as a whole effectively supports analysts who need to find insights from global trends. Through ongoing refinements, VIZION can evolve into an even more effective platform that guides users toward better-informed strategies in global solar energy development.

5 Future Directions

Although our current visualization tool, VIZION, allows users to analyze global solar capacity data with spatial, temporal, and socioeconomic dimensions, several limitations remain. One key limitation is the focus on a single data source and a relatively fixed set of metrics. Future research should explore integrating more diverse datasets, such as complementary renewable sources (e.g., wind, hydro) or energy policy, to provide a deeper context for comparative analyses. Another limitation is that the system currently focuses on descriptive analytics, allowing users to identify historical trends rather than predict future trends. As solar energy production continues to increase, the ability to predict future patterns such as the impact of emerging countries could be invaluable. Integrating forecasting and machine learning models could provide scenario-based information that can be used to guide policy and investment decisions [17]. Recent studies suggest that probabilistic forecasting and ensemble methods can capture uncertainties and guide proactive energy planning [18].

6 Conclusion

In this project, we addressed the growing need of analyzing global solar photovoltaic (PV) capacity data by developing VIZION, an interactive visualization tool that integrates spatial, temporal, and socioeconomic dimensions. Through design and evaluation, VIZION has demonstrated its ability to provide users with dynamic, multi-perspective analyses of solar energy trends. By combining interactive maps, temporal charts, hierarchical representations, and multivariate views, the platform allows analysts to uncover patterns, identify key contributors, and contextualize solar adoption within broader economic and demographic frameworks.

VIZION's strengths lie in its flexible, user-friendly interface, which supports a wide range of analysis tasks. From details-on-demand choropleth maps to coordinated trend zones and treemaps, the tool successfully bridges high-level overviews and fine-grained explorations. Our implementation leveraged standard web technologies, including D3.js, Python, and Streamlit, to create an accessible and responsive platform capable of supporting diverse user needs. While evaluations have highlighted certain limitations, such as the complexity of the stream graph and the need for clearer legends in multivariate analyses, the tool's overall design effectively meets its objectives and provides a strong foundation for future enhancements.

Through this work, we have contributed to the broader domain of sustainable energy analytics by providing information into effective visualization design for large-scale datasets. VIZION offers a replicable framework for integrating geospatial and temporal data, and the lessons learned from its development and evaluation provide a roadmap for future visualization tools. As solar energy continues to grow worldwide leading renewable energy strategies, tools like VIZION will play a critical role in guiding evidence-based decisions and promoting more sustainable energy systems. Moving forward, the incorporation of forecasting capabilities, expanded datasets, and enhanced user support will ensure that VIZION remains an invaluable resource for analysts, policymakers, and researchers worldwide.

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