Interactive Visualization Report

In this GitLab repository, the dashboard code can be found in *ivi_dashboard.ipynb*. To explore the final dashboard, view the last section of the file. For full interactivity, please execute the entire notebook.

1. Performance

As datasets grow larger and include more variables, the need for interactive visualizations becomes increasingly important. Interactive tools allow users to dynamically explore complex data, uncover patterns, and gain insights that static charts cannot provide. At the same time, advancements in technology such as touch-enabled screens, faster hardware capabilities, and the widespread use of devices like phones, tablets, and laptops have greatly enhanced the potential for delivering seamless and optimized user experiences through these visualizations [1].

However, maintaining good performance presents significant challenges. Issues such as slow loading times, delayed responses, and difficulties in handling large datasets can disrupt the usability of visualizations, making it harder for users to interact with data efficiently. One of the main reasons interactive visualizations may become slow is large volume of data with millions of rows or high-dimensional variables can overwhelm memory and computational resources, causing noticeable delays. Additionally, performance depends on factors such as hardware capabilities, including CPU speed, GPU power, and available RAM, as well as network bandwidth for web-based visualizations [2]. To address these challenges and ensure smooth performance, it is essential to optimize data size, leverage hardware acceleration like GPUs, and adopt efficient data management techniques such as tiling and level-of-detail (LOD) rendering which means breaking data into manageable chunks (tiles) for optimized processing and dynamically adjusting the level of detail displayed based on factors like zoom level or user interaction to balance performance and visual clarity.

To evaluate how computational performance is influenced by input data size and varying CPU capabilities, I used a dataset on electricity generation in France spanning eight years. The original dataset consisted of 794,899 hourly data points, which I reduced to 33,139 daily data points and further to 1,112 monthly data points. These reductions represent large, medium, and small datasets, respectively. To simulate a real-world dashboard scenario, I created a dashboard containing four identical interactive graphs and recorded rendering times and memory usage for each dataset. Each test was repeated 20 times to ensure consistent results. The performance tests were conducted on two different CPUs: a two-year-old Apple M2 and an eight-year-old Intel Core i5, which is considered below average in modern computational power.

From the left two boxplots in Figure 1, we can see that, for the large dataset, rendering the dashboard took approximately 26 seconds (M2) and 131 seconds (i5), which are too long for most users. Delays of this magnitude can lead to frustration and reduced engagement. For the medium and small datasets, the rendering time dropped significantly to under 1.34 seconds and under 6.61 seconds, which is generally acceptable for most users. While there is a slight delay, it is manageable for moderately complex visualizations.

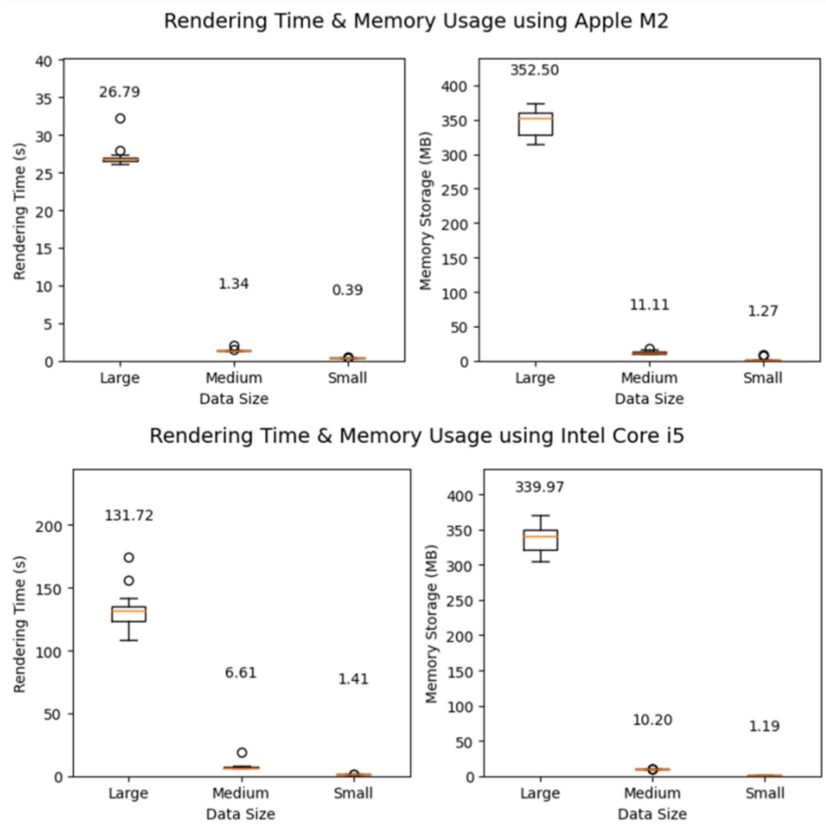

Figure 1 Performance evaluated with Rendering Time (left two plots) and System Memory Usage (right two plots) by different data size (large, medium, small) and different CPU (upper: two-year old Apple M2; bottom: eight-year old Intel Core i5). The numbers on top of each box indicate the median values.

The boxplots on the right illustrate similar memory usage. For the large dataset, memory usage was approximately 350 MB on both CPUs. While this is manageable on high-performance devices, it could strain older or multitasking systems with limited RAM. In contrast, the medium and small datasets reduced memory usage to under 12 MB, ensuring a lightweight footprint suitable for systems with limited resources.

When comparing the two CPUs, the Apple M2 performed faster rendering times across all dataset sizes, particularly for large datasets where it was nearly five times faster than the Intel Core i5. This highlights the advantage of modern hardware in handling interactive visualizations more efficiently.

These optimizations ensure the dashboard remains responsive and accessible on a range of devices, including those with average or older hardware. By adopting daily precision in future designs, performance and usability can be balanced, enabling interactive dashboards to deliver meaningful insights efficiently.

2. *Dashboard Design Principles*

Good dashboard design follows some key principles to make it easy and interactive for users. One well-known principle is Shneiderman's mantra [3]: "Overview first, zoom and filter, details on demand." This means starting with a broad summary of the data, letting users zoom into specific areas, apply filters to focus on what matters, and see detailed information when they need it. This approach helps users understand the big picture while still being able to explore the details without feeling overwhelmed. Two important techniques for this are brushing and linking. Brushing lets users select or highlight data points in one graph and see the related data reflected in other graphs. Linking connects multiple graphs, so when you zoom in or filter one, the others are updated to match the same context.

In this session, I created an interactive dashboard with four graphs to analyze Switzerland's electricity import status using Plotly Dash. My main goal was to make it easy for users to explore the data, starting with a high-level overview and then diving into the details as needed.

Overview

The initial page of dashboard shows the overviews of all four graphs (fig. 2a). The first graph is a time-series plot that displays the amount of electricity Switzerland imported from neighboring countries over the past years. It provides a clear overview of trends in electricity imports. On the second row, the left graph is a pie chart showing the proportion of electricity imports by source, highlighting key factors like CO_2 emissions and environmental impact within the selected time range. This is particularly relevant given the importance of sustainability in energy discussions. Next to the pie chart is a static reference plot that presents the CO_2 intensity associated with different energy sources, serving as a reference for users to understand emissions data in context. Finally, dual line plots display electricity generation quantity and quality in neighboring countries over the years. This visualization helps users understand how Switzerland might collaborate with its neighbors to optimize energy strategies and mutual benefits in the future.

Zoom and Filter

To support user navigation, I enabled intuitive controls via a toolbar on each graph. Clicking on empty spaces or hovering over a graph reveals the toolbar, making these tools easily accessible. Users can zoom, pan, or reset the view using the toolbar at the top-right corner of each visualization (fig. 2c).

After viewing the overview, users can zoom into time-series graphs to discover more details. To enhance user interaction and ensure data consistency across the dashboard, I implemented linking between visualizations. This makes it easier to focus on specific periods without losing context across the dashboard.

Additionally, I incorporated two filters to enhance precision. On the top left is a Date Range Sliding Filter. It Enables users to select specific start and end dates for focused exploration. Next to it is a Country Filter which allows users to select one or more countries (fig. 2b), tailoring the visualizations to their interests.

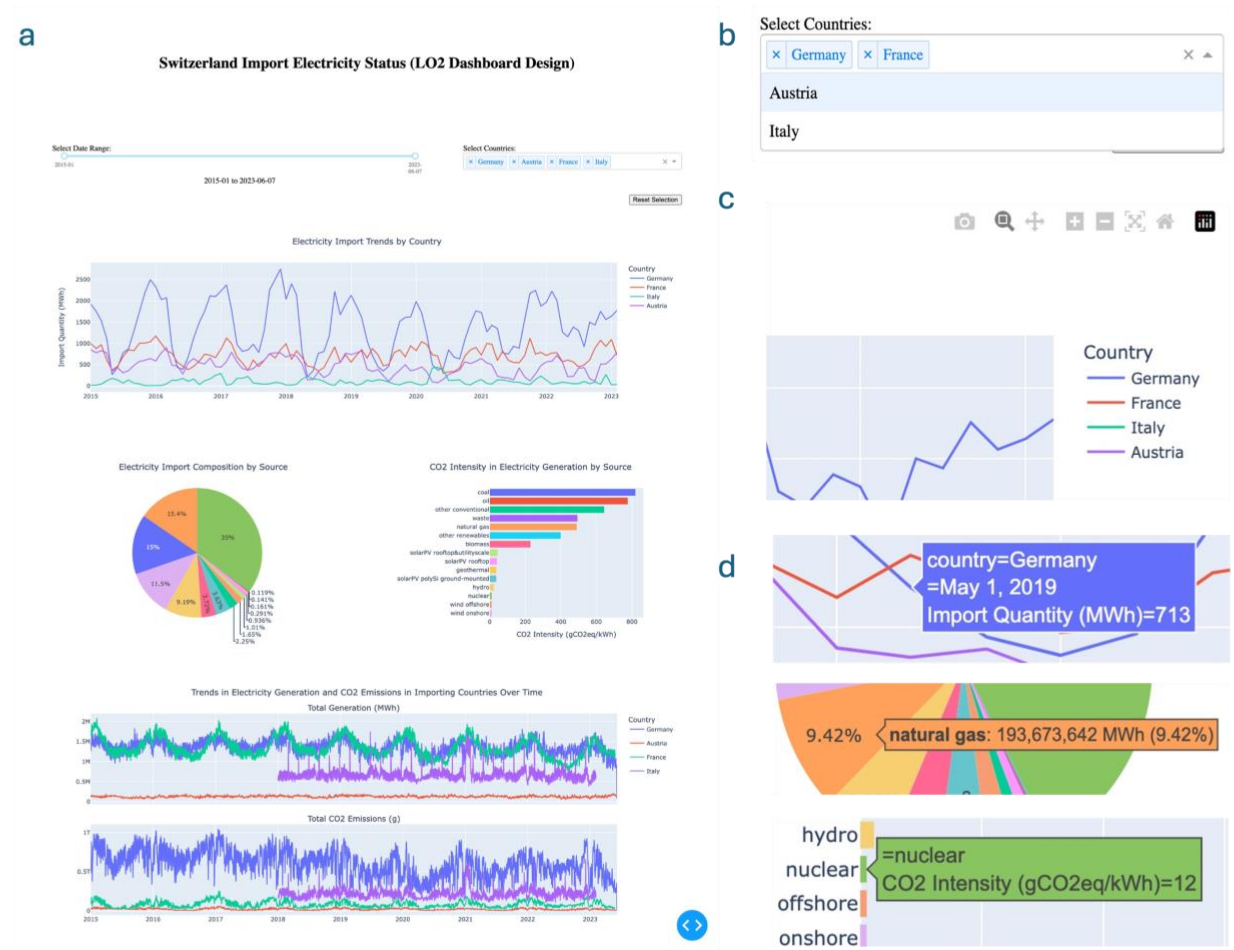

Figure 2 Dashboard design Overview and partial details. a) The initial page of the interactive dashboard; b) Multi optional country filter; c) Toolbar; d) Details accessible by hovering.

Details on demand

To avoid clutter and maintain a clean design, I used hover interactions to provide additional details on demand. Hovering over a region in the pie chart displays detailed information about the proportion and source of electricity. This avoids overcrowding the chart with labels and keeps the layout clean while providing the necessary details when needed. Hovering over data points in the time-series plot will reveal precise information, such as exact electricity production or CO2 emissions of this data point (fig. 2d). This approach allows users to access detailed insights without overwhelming the dashboard with too much text or data at once.

By following dashboard design principles, I ensured that the most critical insights are highlighted in the initial overview. The interactive features make the dashboard highly responsive, seamlessly adapting to user preferences. Users can drill down further using zoom, filters, and hover interactions to explore specific details on demand. For instance, by zooming in or hovering over a data point, users can access exact production or CO2 emission data for a particular day.

3. Human-Computer Interaction (HCI) Basics

Creating a user-friendly interface is essential for effective dashboard interaction. Human-Computer Interaction (HCI) principles focus on making systems accessible, responsive, and efficient for users. For this dashboard, I applied several foundational HCI concepts to enhance usability, navigation, and interactivity.

Hardware and Input Modality

My dashboards focus on environmental sustainability and the transition to renewable energy. The target users are people who interested in politics, environmental issues, and global technologies, who value data-driven insights but may not use statistics or graphs daily. Computers or tablets with touch boards or mice are ideal for viewing, as larger screens suit the detailed visualizations, and precise interactions like zooming and hovering are easier. To accommodate users without high-performance hardware, the dashboard is optimized to respond quickly even on average-performing devices, ensuring accessibility and usability.

Figure 3 Screenshot of the final dashboard (not including the arrows). The green arrows indicating the main improvements in this session, including 1) Overall layout; 2) Fix the title and filters; 3) Simplify toolbar; 4) Reduce data resolution to one record per month; 5) Change date range filter type.

User Interface Design

I designed my user interface using the cognitive walkthrough approach, a method traditionally used for usability testing to evaluate how easily users can accomplish tasks [4]. However, it is also effective for UI design, as it helps anticipate user behavior and identify usability issues early. When opening the dashboard, users typically glance at the title to understand its purpose and then scroll through the graphs to assess the content and length and decide whether to continue reading. Initially, I noticed the plots were poorly arranged, wasting space and requiring significant scrolling on a 13.3-inch screen. This layout made it inconvenient to reference earlier graphs while reviewing later ones. Using the cognitive walkthrough, I refined the layout from three rows to two rows, reduced plot sizes, and minimized vertical spacing (fig. 3 arrow 1). After these changes, 70% of all plots became visible on one page. For users who prefer larger text, increasing the zoom to 125% still maintain manageable scrolling. These changes reduced the need for excessive scrolling, helping users retain an overview and easily track correlations between graphs.

Data Simplification for Improved Responsiveness

Next, I evaluated the graphs for quality and usability. The last one displayed very detailed daily trends spanning eight years. For users without a related background, such fine-grained data could be overwhelming. Reducing the data resolution to a monthly level made the long-term trends in the last graph easier to follow, and also improved the dashboard responsiveness (fig. 3 arrow 4). Additionally, maintaining the same resolution across all graphs improved the dashboard's visual consistency.

Improved Filtering and Tool Options

During testing, I noticed a usability issue with the filters at the top of the dashboard: users had to scroll back up when analyzing the second row plots. To resolve this, I fixed the title and filters in a floating position, allowing users to adjust filters without losing focus on the current visualization(fig. 3 arrow 2). This enhances usability and maintains attention. The date slider filter was also difficult to use precisely, so I replaced it with a searchable calendar filter (fig. 3 arrow 5), enabling users to type or select exact dates, improving accuracy and convenience.

While zooming the line plot, I observed that the interactive controls included eight small tool buttons, which could overwhelm users unfamiliar with them. To improve both interactivity and performance, I retained only three essential tools: zoom, pan, and reset (fig. 3 arrow 3).

Practical Example of Interaction

In the first graph, I noticed the frequently appeared high peaks in the blue line representing Germany. By zooming on these peaks, I discovered they occur during winter, with a significant increase in onshore wind energy shown in pie chart. All linked graphs dynamically updated to reflect this time range, providing insights into seasonal patterns and energy sources, as well as when I panned the time range slightly to analyze valleys after the peaks.

By applying HCI principles, I designed a responsive and user-friendly dashboard tailored to my audience. Features like fixed filters, an optimized layout, and reduced data resolution ensure accessibility on slower devices. These enhancements allow users to explore complex energy data effortlessly and discover meaningful insights.

4. Evaluation

Evaluation is a critical step in assessing the usability and user experience of interactive visualizations. Feedback from users can help to identify strengths and weaknesses, refine the design, and ensure the dashboard meets its intended goals. This process involves selecting appropriate evaluation methods, such as surveys, interviews, or hypothesis testing, based on the nature of the visualization's scope and its target users group.

For this dashboard, the primary focus was to evaluate how effectively users interact with the visualizations, navigate the interface, and extract meaningful insights. To achieve this purpose, I have selected qualitative interviews combined with a cognitive walkthrough approch [4]. This method is particularly effective with a small sample size, as it provides detailed insights into user interactions and aligns with the needs of the target audience. The interviews were designed to identify usability issues and validate whether the dashboard supports seamless and intuitive interactions. An interview protocol was developed, consisting of five interactive tasks followed by 12 questions (Table S1 in the Appendices).

Table 1 Evaluation Result

Category	Average Score (1 – 5)
General Usability	4.33
Interaction Features	4.67
Navigation	4.17
Performance	4.83

The evaluation result (Table 1) from three user interviews showed us, the dashboard scored highest in performance (average of 4.83), indicating users found it fast and responsive, followed by interaction features, general usability, while navigation (average of 4.17) received slightly lower feedback, suggesting minor areas for improvement. The most valuable feedback highlighted the following:

Positive Feedback

Overall, users were highly satisfied with the dashboard especially the following key points:

- Layout: Users appreciated the clean and simple layout, which helped them focus quickly without feeling lost while exploring the dashboard.
- Performance: The dashboard loaded very quickly, and interactions like zooming and filtering were smooth and fast, with no noticeable delays.
- Linked Graphs: Users were impressed by the interactivity of linked graphs. Selecting an area of interest on one graph immediately updated all other graphs to reflect the same context, which they found intuitive and efficient.

- Hover Functionality: The hover feature, revealing additional details, was particularly helpful. It allowed users to extend their understanding and focus more concretely on specific parts of the dashboard.
- Content: Users found the graphs easy to understand, and the interconnected nature of the graphs deepened their engagement. They found the content interesting and were motivated to spend time exploring it.

Areas for Improvement

Users have also highlighted a few areas where improvements could enhance the user experience:

- Fixed Filter Bar and Title: Two users appreciated the fixed filter bar and title for allowing easy access to filter conditions and maintaining context. However, one user felt the fixed elements occupied too much space and suggested adding an option to hide or show the fixed filters and title, giving more room for viewing graphs.
- Reset Functionality: The reset function only worked for individual graphs, and users expected it to update all linked graphs and filters simultaneously.
- Help Float Box: Although users eventually found the filters and zoom functions intuitive, two users initially faced difficulties. One user didn’t realize that he could also type in numbers to select dates and assumed he could only use the calendar interface. Another user, unfamiliar with interactive dashboards, wished a help float box with brief instructions for first-time users.
- Brushing Filters on Country Legends: One user thought it would be interesting if the country legend could act as a brushing filter. However, he also showed concerns about this feature potentially being overwhelming, as the existing country filter was already easy to use.
- Graph Title Font: Two users felt the graph titles could be more prominent and suggested improving the font style and size to make them stand out.

Summary

The evaluation revealed strong user satisfaction with the dashboard's layout, performance, and interactivity. Users appreciated the clean design, smooth responsiveness, and intuitive features like linked graphs and hover functionality. However, some areas were identified for improvement, including adding an option to hide the filter bar and title for more viewing space, linking the reset function across all visualizations, providing floating help boxes for tools and filters, and enhancing the prominence of graph titles. Implementing these suggestions will further enhance usability and user experience.

5. *References*

[1] Analytics Insight, "How to visualize big data: Challenges and solutions," *Analytics Insight*. [Online]. Available: https://www.analyticsinsight.net/big-data-2/how-to-visualize-big-data-challenges-and-solutions

[2] J. Morgan, "Visualization software requirements," *Jeffrey Morgan Blog*. [Online]. Available: https://jeffreymorgan.io/articles/visualization-software-requirements/

[3] Hamp Data Visualization, " mantra," *Hamp Data Visualization Blog, Feb. 26, 2016*. [Online]. Available: https://hampdatavisualization.wordpress.com/2016/02/26/schneidermans-mantra/

[4] Interaction Design Foundation, "How to conduct a cognitive walkthrough," *Interaction Design Foundation*. [Online]. Available: https://www.interaction-design.org/literature/article/how-to-conduct-a-cognitive-walkthrough

6. Appendices

Table S1 Dashboard evaluation protocol

General Usability
Task: Ask users to review the dashboard title and layout. • Question 1: On a scale of 1 to 5, how clear is the purpose of the dashboard when you first see it? • Question 2: On a scale of 1 to 5, how intuitive is it to explore data across the dashboard without feeling lost? Task: Ask users to locate and use the filters, zoom and pan controls on a graph. • Question 3 : On a scale of 1 to 5, how easy is it to locate and use the filters, zoom and pan controls?
Interaction Features
Task: Ask users to adjust the filters, e.g. 2018.03 – 2019.12; country Germany and France. • Question 4: On a scale of 1 to 5, How clearly do the visualizations update when you adjust the filters? Task: Ask users to zoom on the first graph to a certain time range, then pan, reset. • Question 5: On a scale of 1 to 5, how well does linking meet your expectations for interactive exploration? Task: Ask users to hovor on a peak datapoint on graph 1 or 3, then on the largest proportion on piechart. • Question 6: On a scale of 1 to 5, how useful is the hover functionality for accessing detailed information?
Navigation
• Question 7: On a scale of 1 to 5, how well does the layout help you track relationships between graphs? • Question 8: On a scale of 1 to 5, is the fixed filter and title bar convenient when scrolling through the dashboard?
Performance
• Question 9: On a scale of 1 to 5, how quick do the visualizations load, or do you notice delays? • Question 10: On a scale of 1 to 5, how smoothly does the dashboard perform during interaction?
Improvements
• Question 11: Are there any features or information you feel are missing from the dashboard? • Question 12: Is there anything about the design or interactivity that you find frustrating or confusing?
Rating Scale 1. Strongly Disagree / Very Poor/ Very Slow; 2. Disagree / Poor / Slow; 3. Neutral; 4. Agree/Good / Fast; 5. Strongly Agree / Excellent / Very Fast **Follow-Up** For ratings <= 3 or in case of unsatisfied reactions, an open-ended question will be asked to understand the reasons behind the low rating and gather suggestions for improving the feature.