PriMera Scientific Engineering
Volume 7 Issue 4 October 2025
ISSN: 2834-2550

GHG Web Portal Dashboard: A Scalable and Flexible Digital Platform for Efficient Environmental Monitoring

Type: Research Article
Received: March 20, 2025
Published: September 29, 2025

Citation:
Goncalo Bastos., et al. "GHG Web Portal Dashboard: A Scalable and Flexible Digital Platform for Efficient Environmental Monitoring". PriMera Scientific Engineering 7.4 (2025): 44-55.

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Abstract

The importance of efficient digital platforms for monitoring greenhouse gas (GHG) indicators cannot be overstated in contemporary environmental management and sustainability efforts. Such platforms are crucial for accurate, real-time data collection and integration, facilitating regulatory compliance, and enabling strategic decision-making. However, developing a usable digital platform for GHG monitoring is challenging due to the complexity of integrating diverse data sources, ensuring data accuracy and reliability, and providing user-friendly interfaces for varied stakeholders.

Despite the availability of multiple official data sources on GHG emissions, no specific digital platform exists to comprehensively aggregate and manage this data. Existing systems often lack the flexibility to incorporate new indicators and adapt to evolving regulatory requirements. This paper presents a digital platform capable of seamlessly integrating data from various sources and offering robust usability, to enhance the effectiveness of GHG emission monitoring. The platform can be valuable to stakeholders, including regulatory bodies, industry leaders, environmental organizations, and the general public to address the complexities of environmental data and advancing global sustainability efforts.

Keywords: Data Visualization; Greenhouse gas (GHG) emissions; Interactive Dashboard; Usability

Introduction

In recent years, the levels of Greenhouse gas (GHG) emissions into the atmosphere have become a critical indicator for metering of global warming and climate change, thus creating the need to efficiently monitor and analyze them. Efficient GHG monitoring is critical due to the increasing severity of global warming, which has led to extreme weather events, rising sea levels, and significant impacts on biodiversity and human health. Furthermore, international agreements like the Paris Agreement [1] and national policies mandate strict monitoring and reporting of GHG emissions to meet reduction targets and mitigate climate change impacts. This has, in fact, become imperative and a reference for environmental policies and emerging response strategies [2]. As such and considering the wide-ranging and disperse public access to relevant GHG emissions data, the existence of digital platforms that combine selected indicators to allow a more facilitated and detailed analysis for a more comprehensive understanding of emerging problems becomes essential.

Similarly, digital platforms have been shown to enhance data management in community-based monitoring, effectively supporting larger-scale environmental pattern analysis and interlinking with other platforms, although they also introduce challenges related to data control and program sustainability [3].

There are already several initiatives, platforms, and tools as United Nations Framework on Climate Change (UNFCCC) [4] whose goal is to serve as a database, but there is still a significant gap in terms of their ability to gather several data sources, or even the use of data visualization techniques to provide an easier comprehension of GHG-related indicators. However, these platforms often face significant limitations, including fragmented data sources, lack of interoperability between different datasets, and difficulty in interpreting complex data due to inadequate data visualization techniques. Additionally, the complexity of some of these platforms poses additional usability challenges in accessing data either by specific stakeholders or by general public.

Furthermore, as more and more public and disperse data sources on GHG emissions are emerging online, it becomes harder to track, gather and correlate this information.

It is in this context, we propose in this paper the CO2 Web Portal Dashboard, which focuses on the aggregation and uniformized visualization of different GHG emissions data in a single website. Improved data visualization is crucial for making complex GHG emissions data more accessible and understandable, thereby facilitating better decision-making for policymakers and increasing awareness among the general public. The platform takes advantage of a flexible software architecture, in which several types of data sources can be combined (such as the well-recognized ones in [4], [5] or [6]), as well as their associated Key Performance Indicators (KPI) and their visualization properties, such as type of graph, scales and updating times.

The platform was developed in conjunction with researchers from a university and from a company, where key user profiles were identified. Most importantly, the platform allows for the company's key users to be able to update and configure data sources with several types of integration technologies, and to setup KPI indicators without requiring programming skills. We also apply direct observation usability testing [7] and Process Mining techniques to gather and analyze user-interaction information of the platform, to further optimize its use.

The remainder of this paper is organized as follows: Section 2 presents the background and related work, exploring existing technologies and their limitations. Section 3 describes the research and development methodology used to create the CO2 Web Portal Dashboard. Section 4 discusses the implementation of the platform, followed by Section 5, which details its software features, including the recording of user interactions for further usability studies and statistics through Process Mining. Finally, Section 6 summarizes the outcomes of the development and the research conducted, outlining future directions for enhancing the platform, including potential improvements and areas for further research.

Background and related work

With the constant technological evolution, various digital platforms [7, 4] have been developed to collect and process data for GHG emissions indicators, thereby addressing the growing recognition of the need for this information concerning climate dynamics to be increasingly accessible not only to researchers but also to people outside the field. For instance, the data platform of the UNFCCC [4] provides detailed national green-house gas inventory data submitted by parties to the convention, facilitating transparency and tracking of their evolution towards the climate commitments.

Our World in Data [5] provides comprehensive data visualizations and research on global challenges, including climate change, to help understand long-term trends and inform policymaking.

NASA's Climate Change website [6] provides comprehensive information on the latest climate data, research, and news. It features interactive tools, visuals, and resources to help understand the impact of climate change on our planet.

Eurostat [8] offers statistical information on various European Union policy areas, including detailed environmental data and GHG emissions metrics, to support evidence-based decision-making.

Climate Watch [9] provides accessible data on global greenhouse gas emissions, climate policies, and the progress of countries towards their climate goals, aiding in climate action planning.

The International Monetary Fund (IMF) Climate Change Indicators Dashboard [10] offers economic and financial data related to climate change, helping analyze the impact of climate policies on economic performance.

Carbon Monitor [11] offers near-real-time estimates of CO2 emissions at global, national, and sectoral levels, providing timely insights into emission trends and policy impacts.

The World Resources Institute (WRI) [12] is a global research organization that focuses on sustainable natural resource management, climate change, energy, and urban development. WRI provides data-driven solutions and policy recommendations to promote environmental sustainability and economic opportunity worldwide.

Regarding non-regulatory research efforts, we could also find several works in the literature. In [13] the authors propose an integrative approach to reconcile city-scale GHG emission inventories with global datasets, highlighting significant regional variations and the necessity for localized emission factors to improve data accuracy.

The authors of [14] propose an advanced digital solution that combines innovative CO2 monitoring stations and big data to deliver high-quality emission data in less than a month. This approach, initially implemented in Paris and now expanded to Italy, aims to support policy decisions and accelerate urban low-carbon transitions by providing precise and timely climate data.

In [15] the authors introduce a comprehensive system designed to monitor and manage GHG emissions in mixed farming operations. This platform aims to enhance sustainability by integrating various data sources and providing actionable insights for farmers to reduce their environmental impact.

In [16] the authors outline a strategy to help governments reduce GHG emissions through four key levers: increasing carbon sequestration, improving agricultural emission efficiency, incentivizing dietary changes, and utilizing bioenergy. This framework aims to balance environmental goals with sustainable development, ensuring food security, biodiversity preservation, poverty alleviation, and job creation.

The thesis in [17] focuses on creating a web application that integrates diverse sustainability data sources to help users visualize CO2 emissions calculations effectively. The study, part of the WISER project, addresses challenges in calculating and tracing greenhouse gas emissions, aiming to improve transparency and reliability by connecting different data formats and sources. The implementation and findings are demonstrated, with future improvements discussed.

The work in [18] focuses on analyzing building energy efficiency in New York through the lens of environmental justice. It evaluates the distribution of Energy Star Scores and their relation to socio-economic factors, such as low-income and non-white populations. The study uses statistical methods, regression analysis, and Multi-Criteria Decision Analysis (MCDA) to assess energy efficiency and develop a Building Energy Efficiency Justice (BEEJ) index. The primary output is an interactive dashboard that visualizes this data, combining spatial and statistical information to aid decision-making for various stakeholders. The dashboard, built with HTML, CSS, JavaScript, Python, PostgreSQL, and Tableau technologies, allows users to explore energy efficiency scores and their intersection with environmental justice indicators. The full database is publicly accessible for future research purposes.

In [19], the authors describe a platform that utilizes data from sensors and IoT devices to assist farmers in optimizing resource use, reducing costs, and minimizing environmental impacts. It integrates advanced technologies such as Artificial Intelligence (AI) and big data analytics to enhance farm management and promote sustainable agricultural practices.

The authors of [20], present a novel system leveraging blockchain technology to enhance the transparency and accuracy of GHG emissions tracking. This innovative system ensures secure and tamper-proof recording, verification, and disclosure of emissions data, improving reliability and supporting informed climate policy decisions.

In [21], the authors present a 4D interactive carbon emissions dashboard designed to visualize and assess the environmental impact of urban buildings. This innovative tool integrates time-based data, offering a comprehensive view of carbon emissions and enabling detailed analysis over time. It aids in evaluating and improving building sustainability practices by providing actionable insights into emissions trends and patterns.

Despite all the above-mentioned initiatives, and to the best of our knowledge, none of these digital platforms address flexibility, scalability and usability challenges posed mainly by the growing number of data sources and correlated GHG emissions-based KPIs. Additionally, the combination of these disperse data sources brings challenges regarding their integration within a single platform, the configuring of suitable data visualization properties, and the platform's usability considering the amount of data hierarchies and filtering options to provide. Our platform provides special attention to these challenges, by proposing a suitable software architecture and adequate usability testing, supporting detailed and dynamic data analysis across various fields.

Method

Throughout the development of this project and the digital platform itself, the methodology employed was characterized by a hybrid approach that effectively merged elements of rapid prototyping with Scrum principles [22], [23]. This approach ensured a dynamic and flexible development process. Regular meetings were conducted, where the partner team provided various prototypes that served as visual and functional blueprints for the platform's expected capabilities. These prototypes detailed necessary data functionalities and the user interface, setting clear expectations and goals for each development cycle.

Each prototype underwent rigorous evaluation and refinement, incorporating extensive adjustments, enhancements, and the introduction of new features. This iterative process was crucial for the progressive evolution and continuous improvement of the platform, ensuring that each version advanced closer to the final vision. By iteratively refining the prototypes, the team could enhance usability and functionality, addressing emerging challenges and user feedback promptly.

To support the development process, we predominantly utilized the Jira platform for its robust project management capabilities. Jira's backlog feature and timeline tools were instrumental in managing the project's scope and scheduling. Establishing a comprehensive task registry and defining the duration and dependencies of each task allowed the team to plan and execute the project effectively within the allocated timelines. This structured approach facilitated clear communication and coordination among team members, ensuring that all tasks were aligned with the project's overall objectives.

For usability testing, we developed user-interaction tracking features that enabled Process Mining of navigating data provided by beta testers. These features recorded all user interactions with the platform, offering valuable insights into user behavior and platform performance. The auxiliary testing component supported this process, providing a robust framework for analyzing and improving user experience. This method of collecting and analyzing user interaction data was vital for identifying usability issues and making data-driven improvements to the platform.

CO2 Web Portal Dashboard development

The implementation of the project commenced with data regarding the country of Portugal, aiming to consolidate diverse data on specific Portuguese indicators into a single platform. Key users of this platform included researchers, general public and, most importantly, a company partner team responsible for updating and configuring GHG emissions data in the platform, without requiring programming skills.

Software architecture

Aiming for the scalability and flexibility requirements of the platform, as well as the ability for key users to update its datasets and configure KPI visualizations, we propose in Fig. 1 the CO2 Web Portal Dashboard software architecture, using the C4 model[1] nomenclature.

The architecture is divided into several interconnected components that handle different aspects of the application, from user management to data visualization and administration.

The architecture serves two main types of users: the general public and administrators. The general public users access the system through a frontend web application. This application is built using Vue 3, a progressive JavaScript framework known for its efficiency and flexible structure. The frontend provides a user-interface, allowing users to visualize CO2 data through various interactive elements. Users can filter and select data based on specific parameters such as geographical regions or specific time frames. The ability to choose data from maps enhances the interactivity, providing a spatial understanding of the data. Users of type administrators have a different interaction with the system. They utilize the same frontend interface but are provided with additional software features to update and manage data sources and KPIs. This role is crucial for maintaining the accuracy and relevance of the data presented to the general public users.

The core of the application's functionality lies within the API and Backend Application, which is developed using Laravel 10. Laravel's robust features and Model-View-Controller architecture allows for the handling of complex business logic and data management. The backend is responsible for all server-side logic, including data import, processing, and API management. It communicates with the frontend via JSON over HTTP, facilitating a seamless data flow that supports the application's dynamic features.

Data persistence is managed by a MySQL database, which stores all essential data such as user information, environmental indicators, and filters. MySQL was chosen for its reliability, performance, and widespread support. The database schema is designed to efficiently store and query large sets of environmental data, optimizing both retrieval and update operations.

An important element of this architectural design is the incorporation of Grafana[2], an open-source platform dedicated to monitoring and observability. In this case, Grafana is employed to allow administrators the power of configuring KPI visualizations that general public users will access to. Therefore, administrators can access their Grafana portal through a simple account and configure several KPI panels and data sources directly. These Grafana embedded panels are then incorporated into the frontend web application, providing general public users with advanced data visualization tools that include graphs, charts, and maps.

Overall, the architecture is designed with a focus on scalability and flexibility. By separating concerns among the frontend, backend, and database components, the system ensures that each component can evolve independently while maintaining overall system integrity. The use of containerization for both the Vue 3 frontend and Laravel 10 backend enhances the portability and scalability of the application, facilitating easy deployment and scaling across different environments.

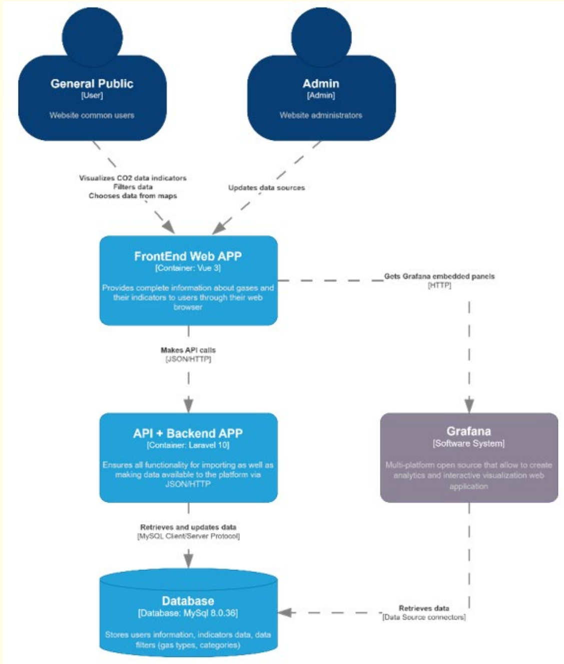

Figure 1: Platform architecture.

Implementation

Regarding the development of the platform, it started with the integration of technologies such as Grafana, Vue, and Laravel. The first prototype confirmed the feasibility of embedding Grafana charts directly into Vue, enabling basic interactions with the panels through URLs that transmitted variables for MySQL queries, and enabling access control to the panels by associating them with a specific organization.

Following the positive evaluation of the initial prototype, the project progressed to a second stage, where the user interface was significantly enhanced. The homepage visible at Fig. 2 was redesigned to categorize indicators, simplifying navigation and access to detailed information without the need for multiple clicks.

This restructuring provided a more fluid and intuitive user experience, enhancing efficiency in data visualization. To improve interaction with the platform, further enhancements were needed, constantly incorporating direct feedback from the company partner team. Consequently, a fixed sidebar was introduced, providing immediate access to recent aggregated data, and allowing users to view essential statistics without interrupting the main navigation. Additionally, the establishment of a development infrastructure on the Azure platform facilitated continuous access to project progress, utilizing a reverse proxy [24] architecture with Grafana to ensure security and efficiency.

Development then advanced to the next stage, which expanded data import functionalities to accommodate various sources and formats. Specific routines were created to handle complex data from different categories, such as emissions by gas type and sector, utilizing external libraries to assist in data importation and filtering. This version prepared the platform to support data from multiple national and international contexts, enhancing its adaptability and applicability. Subsequently, based on user feedback, improvements were primarily focused on refining the data import window, reorganizing it to enhance user interaction and optimize the import process visible (Fig. 3). The interface was also modified to improve filters and facilitate direct selection of categories or sectors, depending on the data being imported. Additionally, data was separated and reorganized into sections to enable better navigation and location of data required by users with the help of a top navigation bar.

Figure 2: Platform homepage.

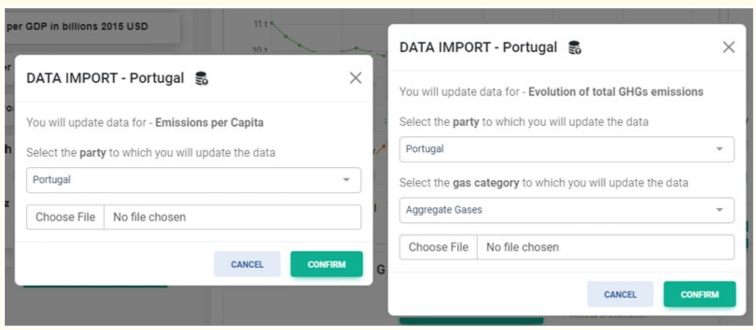

Figure 3: Import windows.

To enhance the platform and the regional indicator, a map facilitating the manipulation and visualization of geographic data was also developed. Due to the limitations of existing tools for integrating interactive maps, the adopted solution was to use a combination of bar charts in Grafana and vector maps (SVG) directly in Vue for more effective manipulation. This configuration allowed the region selected on a bar chart to automatically change the map visualization, thus improving user interaction with regional data. The regions on the map were colored according to the volume of gases emitted, with variations based on the selected year, which helped the visual interpretation of environmental data on a regional scale. This approach not only overcame the technical challenges of integration but also provided a more dynamic and informative tool for geographic data analysis on the platform visible at Fig. 4.

With this extensive implementation framework and following the testing phase, the development proceeded to create global (world) indicators, which essentially followed the same structure while only changing their data sources. Here, we were able to introduce real-time data fetching by using the NASA API [6]. This implementation also required the "export to image" feature of the charts, so that produced indicators could be exported and used in other data visualization scenarios.

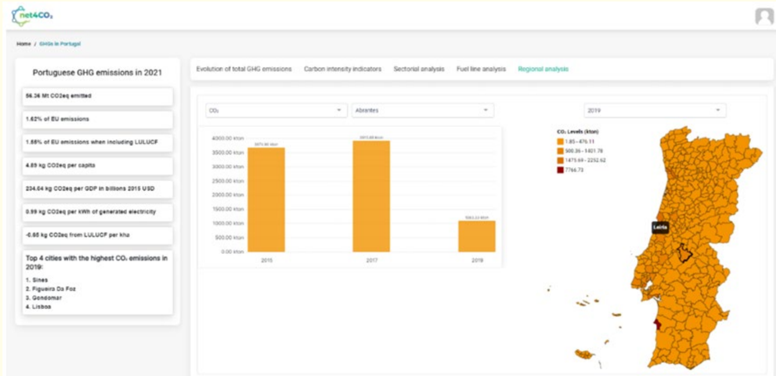

Figure 4: Geographic data analysis.

Usability testing

User-interaction tracking

The user-interaction component has been implemented primarily based on the recording of user gestures in the frontend web application. The component enables the generation of comprehensive event logs that detail all user activities within the platform, containing the user-interaction activity performed (e.g. *click on button A*), the actual origin place in navigation (e.g., *homepage*), time-stamps and, most importantly, an identifier for the feature being performed (e.g., *feature 23: visualizing GHGs for an industry sector of a country*).

This component is designed to be toggled on and off as needed (Fig. 5), serving as a wizard that guides users during testing phases. It provides explicit instructions on the tasks to be performed, marks the start and end timestamps for each task, and measures the total time spent on all testing activities. This extensive data collection is instrumental in conducting further process mining thorough analyses aimed at understanding and improving platform usability bottlenecks and deviations to a normal user interaction. The statistics produced are then crucial for identifying usability trends and pinpointing specific areas where the platform can be optimized to enhance user experience and operational efficiency.

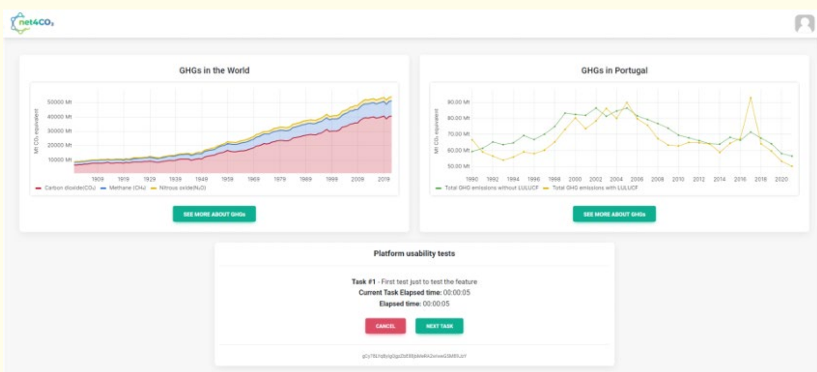

Figure 5: Wizard tests.

Direct observation tests

Following the completion of the initial version of the platform, with all indicators pertaining to Portugal implemented, direct observation tests were conducted, followed by the deployment of a Post-Study System Usability Questionnaire (PSSUQ) involving several volunteers, using the process mining data, and the wizard tool to conduct the tests.

The direct observation tests entailed users with different capabilities as visible in Table 1, performing a variety of tasks, covering as many application software features as possible. Tasks included identifying specific amounts of GHG emissions by area and by Portugal's gross domestic product, as well as specific emission data for certain years and locations, such as *N_2O emissions in Leiria district in 2017*. Additionally, users were instructed to execute standard operational procedures on the platform, such as logging in and out, and importing data for specific indicators, such as the overall evolution of GHGs for the transportation sector in Portugal. These tasks not only tested the user's ability to navigate and interpret data but also assessed the efficiency of the data import processes and interaction with various interfaces and panels on the platform.

	Age	***Gender***	***Professional Area***
User 1	26	Female	Chemical Engineering
User 2	34	Male	Economies and Environmental Management
User 3	25	Male	Chemical Engineering
User 4	28	Male	Chemical Engineering
User 5	38	Female	CO2 Utilization Team Leader
User 6	27	Female	Chemical Engineering
User 7	52	Female	Scientific Research
User 8	26	Male	Environmental Engineering

Table 1: Tests users' information.

These tasks Table 2 were meticulously planned, and the test results included metrics such as successful task completion, time taken for each task, number of incorrect clicks, and whether users followed the expected path without deviation. The analysis of these parameters revealed that, despite a somewhat slow start in adapting to the platform, the time required to complete tasks tended to decrease as users became more familiar with the application environment, visible at Fig. 6, except for task 6, where user 5 took a considerably long time to complete the task, and user 3 in task 7, both of whom can be considered outliers.

Task	***Description***
1	Identify the amount of emissions per area for Portugal in 2014.
2	Specify the amount of CO2 emissions including LULUCF for Portugal in 2019**.**
3	Specify the amount of N2O emissions in Leiria for 2017.
4	Using the main indicators, specifically the left sidebar, indicate the amount of emissions per GDP (Gross Domestic Product) in Portugal for the most recent available year.
5	Log in to the platform.
6	Import data for the Total GHGs (Greenhouse Gases) evolution in Portugal, and then for the European Union.
7	Import data for the transportation sector in Portugal.
8	Import data for CH4 (methane) emissions in Portugal.
9	Log out of the platform.

Table 2: User Tasks.

However, it was identified that the data import window required restructuring, especially because tasks related to this functionality showed prolonged completion times and a significant rate of incorrect clicks, suggesting that the integration and arrangement of elements on the interface could be optimized for easier use. Furthermore, the current structuring of the indicators was considered confusing by some users, implying the need for a different organization that facilitates access to information. The data import tasks particularly revealed that different import windows presented distinct challenges, with some facilitating interaction more than others.

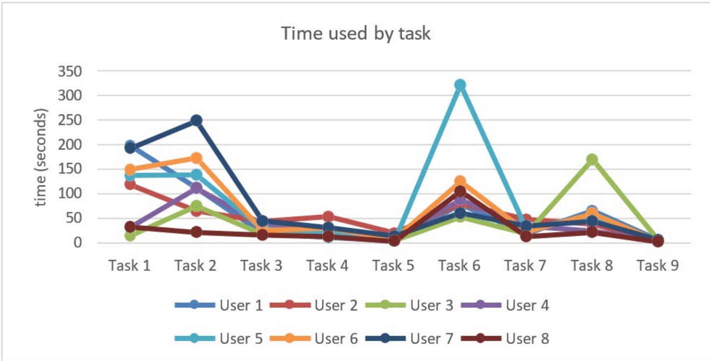

Figure 6: Time used by task in seconds.

Regarding following the expected path, most users did not experience significant difficulties, except in initial tasks while they were still adapting to the platform. The challenge of importing data for the European Union was a particular obstacle, highlighting the need for a more intuitive and uniform import window.

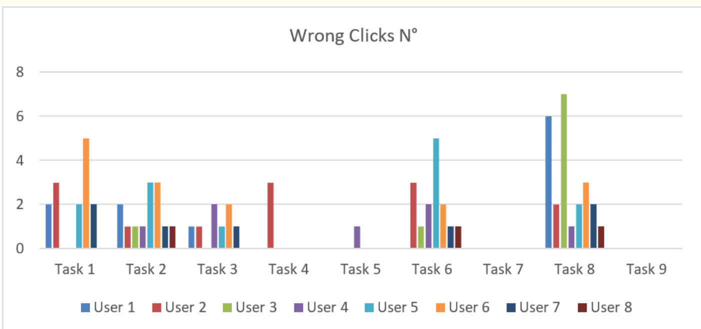

Figure 7: User's wrong clicks by tasks.

Regarding the number of incorrect clicks, visible in Fig. 7, practically all tasks have them. As mentioned earlier, this is due to users initially getting accustomed to the interface, misreading certain panels, and interacting with incorrect panels. This highlights the need to structure the platform differently so that a new user can achieve their reading objectives more quickly.

Furthermore, we observe that tasks 6 and 8, related to data importation, are the only ones with incorrect clicks, contrasting with task 7, which had no incorrect clicks. In task 6, the incorrect clicks were due to users having difficulty switching the import between the current party and the European Union, indicating a need for modification and the creation of a homogeneous import window. As for task 8, the number of incorrect clicks was primarily because the filters for the gas to be imported were outside the import window instead of within it, once again necessitating a change to make this window homogeneous.

Subsequently, users were given the opportunity to explore the platform freely, which allowed for the collection of additional feedback through the PSSUQ. Despite some positive comments, suggestions for improvement again indicated the need for a revision of the element layout on the interface, particularly the import window, whose filter placement outside the main window unnecessarily complicated interactions. These insights emphasize the importance of a clear and well-structured interface in optimizing user experience and suggest a thorough review of the platform layout to reduce visual clutter and facilitate access to desired information. The proposed restructuring aims to significantly enhance the usability and efficiency of the platform.

Conclusion and future work

The development of the CO2 Web Portal Dashboard as a scalable and flexible monitoring digital platform represents a significant contribution advancement in the visualization and management of environmental data and provides a comprehensive dashboard for tracking GHGs emissions. Utilizing cutting-edge technologies such as Grafana, Vue, Laravel and MySQL, the platform has been crafted to provide dynamic, real-time access to GHG data. This approach has not only streamlined the data visualization process but also enhanced accessibility and interactivity for the general public, experts and regulators, enabling more informed discussions and decisions on environmental issues.

The platform's architecture allows for the integration of disperse data sources, and for the configuration of KPIs by non-programmers, ensuring it maintains updated and useful through time. It also provides efficient handling of large datasets and complex user interactions. By integrating advanced visualization tools through Grafana, the application offers diverse data visualizations, which are essential for effective environmental monitoring and advocacy.

The broader implications of this research include potential impacts on policymaking, industry applications, and global sustainability efforts. By offering a reliable and accessible tool for GHG emissions tracking, the platform can support policymakers in developing informed strategies to meet international climate targets. Industries can leverage the platform to monitor and reduce their carbon footprints, contributing to broader sustainability goals.

Looking ahead, a near-future analysis will include the automatic collection of user-interaction data and the application of additional Process Mining techniques to further enhance the usability of the platform.

It is also foreseen the integration of predictive analytics using Machine Learning techniques that will transform the platform from a descriptive to a prescriptive tool, providing forecasts and actionable insights that could help preempt environmental issues.

In summary, the CO2 Web Portal Dashboard not only addresses current challenges in GHG emissions tracking but also lays the foundation for future innovations in environmental data management, contributing to global efforts in combating climate change.

Acknowledgements

The authors acknowledge the funding program under the Recovery and Resilience Plan (Missão Interface N.º 01/C05-i02/2022).

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Foot Notes

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