Visual representation of the internet consumption in the European Union*

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Abstract. The impact of internet usage on the environment is a contradictory topic. While it can help reduce carbon emissions, with smart grids or the automation of services and resources, it can also increase e-waste that end up affecting the environment. To draw attention to the impact of energy consumption on the environment, we proposed and developed a computational artifact that unites the areas of Data Aesthetics and Interaction Design. The artifact, displayed in an interactive installation, was divided into three panels: (i) the left panel, which represents the countries—from the European Union (EU)—with the lowest energy consumption impact on the environment; (ii) the central panel, which use swarming boids to represent the internet usage at the installation site and its impact; and (iii) the right panel, which represents the EU countries with the highest energy impact on the environment. The arrangement of the three panels in a single interactive installation aims to establish a visual connection between the energy consumption in the EU and the energy consumption in the installation's site and to promote awareness of its impact on the environment.

Keywords: Data Aesthetics · Swarming System · Environment · internet usage · Awareness.

1 Introduction

The impact of the increasing use of internet resources—and consequent increase in energy consumption—on the environment can be seen in two ways, through its positive and negative impacts [1]. On the positive side, there was an improvement of energy efficiency, with the optimization of energy resources and the use of renewable energies, and a reduction of unnecessary travel, through e-commerce and remote work. On the negative side, there was an increase of energy consumption and pollution related to the production of electronic infrastructures and devices.

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In recent years, there has been a growing interest in exploring data representations of environmental problems. Climate change harms the entire population and therefore there have been several ways of alerting, raising awareness, and emphasizing information on this topic [2,12,5]. Nonetheless, there is still data that needs to be correlated, explored, and represented, such as energy consumption, internet use, and their impact on the environment. To communicate such data in a more aesthetic way, one can resort to Data Aesthetics. Data Aesthetics is a sub-area of Information Visualization and its main focus is the visual exploration of data rather than functionality [6,7,9]. In this context, data is represented to draw the public's attention and communicate a message, regardless of its readability. However, and due to the effectiveness of visual mappings, in many cases they can still be understood by the viewer [6].

To promote awareness on the impacts of energy consumption and internet usage but also to highlight the adoption of positive measures in recent years by EU countries [4], we propose a computational artifact that combines Data Aesthetics and Interaction Design. Our artifact represents both the impacts of energy consumption and internet usage on the environment, such as the increase in greenhouse gas (ghg) and fossil fuels, and the application of positive actions, such as the increasing adoption of renewable energy by EU countries. More specifically, we visualize data regarding internet usage, energy consumption, energy sources, and impact on the environment for every EU country.

This project aims to analyze and visually represent the aforementioned data in an aesthetic way as well as to explore visual metaphors that highlight the impact of internet usage at the installation site. Through the visual representation of the energy consumption in the EU countries—left and right panels of the installation—our intent is to make the viewers aware of the high consumption values in different countries and the measures that each country is applying to reduce the impacts on the environment. Through the visual artifact based on swarming boids—central panel, which represents the impact of internet users logged in the installation site in multiple perspectives—we intend to draw the viewers' attention and make them conscious of the impacts of internet usage.

The remainder of this article is organized as follows. Section Related Work, presents other projects that use Data Aesthetics and Information Visualization to represent the energy's consumption impact on the environment. Section Impacts of Consumption on the Environment, presents the left and right panels—which show the countries with the lowest and highest impacts of energy consumption on the environment—the central panel—representing the ecosystem of internet networks—and the interaction mechanisms. The third Section (User Testing) presents the user tests regarding interaction and visual perception. In Section Discussion, we discuss the results obtained and possible improvements. Finally, in Section Conclusion, we present the conclusions and future work.

2 Related Work

The related work was chosen due to its relation to the theme and application of Information Visualization and Data Aesthetics.

"Earth Bits—Sensing the Planetary" is an installation developed by Dotdotdot that represents the carbon footprint of humanity [2]. The installation is divided into sub-projects, each one visualizing different data. Below, we present the sub-projects more related to ours.

The subproject "Power Rings—Energy Consumption in Portugal (2019-2020)" consists of a visualization of the changing patterns of daily electricity consumption in Portugal, between the years 2019 and 2020. In addition, other representations are made concerning specific Portuguese cities, such as Faro, Viana do Castelo, and Porto. The interactive console with multi-user capability, called "CO2 mixer—Identifying Human Impact", measures the individual ecological footprint, according to the users choices in categories such as nutrition, housing and mobility. "CO2 mixer" also features a sonification that reflects the measured data. Finally, the sub-project "Planet Calls—Imagining Climate Change", offers, through images and satellite data, a historical correlation between emissions and the increase of occurrences of environmental phenomena on Earth.

The "7000 Oaks and Counting" project, by Tiffany Holmes, reinterprets ecological data through new technological and artistic means with the aim of educating and changing consumer behaviors [5]. This visualization aims to explore the individual public commitment to carbon footprint reduction and consists of an animated sequence of images of trees representing carbon emissions. The data was collected from the NCSA building and refers to steam, chilled water, electricity flow, among others. Then, the carbon footprint is calculated in real time and is converted into the number of trees that would be needed to offset the carbon emitted. This project uses metaphor to facilitate the understanding of the concept and create a relationship between the viewer and the data.

"Waves to waves to waves" is an interactive audiovisual installation that uses visualization and sonification to represent the electromagnetic energy generated by humans that is imperceptible to the human senses [12]. This project aims to reflect on the growing dependency with technology. The changes detected in the environment by Wi-Fi devices, television, and mobile phones are converted into electrical signals that generate sounds and abstract shapes in real time.

The related works were chosen due to their focus on the impacts of energy and pollution on the environment and due to the variety of representations. The projects that best relate to the concept of our project is the "Earth Bits-Sensing the Planetary", specifically the subprojects "Power Rings-Energy Consumption in Portugal", that addresses the changing patterns of electricity consumption in Portugal, and the sub-project "Power Rings-Energy Consumption in Portugal", that represents the energy consumption in different cities. The project "Planet Calls-Imagining Climate Change" reveals an historical correlation between CO2 emissions and the increase in the occurrence of environmental phenomena on Earth. The visual metaphor is best applied in "7000 oaks and counting" project, as it creates a direct link between the way data is presented and the topic.

Fig. 1. Picture of the installation on the site.

3 Impacts of Consumption on the Environment

Our project consists of an interactive installation divided into three panels (figure 1). The installation was developed in Processing, which is an open-source tool developed by artists and designers that uses a simplified language built on the Java language. We chose this tool as its main focus is the creation of visual and interactive media. In the first and third panels, left and right sides of the installation, respectively, we represent the EU countries. This focus is due to the response of the 27 countries in the fight against climate change and environmental degradation.

In the second panel, central panel, we visually represent the energy consumption of the EU countries and data from the internet networks at the installation site through an ecosystem. This ecosystem aims to explore the creation of a narrative of boids that evolve and change to characterize the EU energy consumption impacts on the environment.

3.1 Data

The first step in developing the installation was to acquire the data through open source platforms. We selected datasets according to: reliable source and required time span. The selected open source databases were: Eurostat, Organization for Economic Co-operation and Development, World Bank, International Telecommunication Union, European Environment Agency, and Institute National of Statistics.

The data used in the installation for the left and right panels refers to a time span from 2007 to 2020, and to the following indicators per EU country: population [3], total energy consumption [4], electricity consumption per inhabitant [5], bandwidth [6], users [7], internet usage frequency [8], renewable energy [9], fossil fuels [10], nuclear energy [11] and greenhouse gasses [12]. Lastly, we used the population indicator to calculate all other indicators per inhabitant. Countries with higher population would, as expected, have higher consumption values and by calculating the indicators per inhabitant, we aimed for a fairer comparison.

3.2 Left and Right Panels

The EU countries were divided into the left and right panels according to their indicators' average values, regarding energy consumption, energy sources, and ghg from energy consumption. We ranked all countries by the aforementioned averages and placed countries with higher ranking on the right panel, and with lower ranking on the left.

To understand the appropriate visual representation, it was necessary to analyze and filter the data and understand the type of variations and data variables. We chose to focus on radial representations, as they allow to group large amounts of information and distinguish pieces of information in a reduced space [3]. Also, this representation format allowed us to visually highlight countries through their size and position in space. The countries are then placed on the panels according to their geographic positions, without overlapping.

To map the data values to the visual variables (e.g., color, size, length), we used a simple normalization between the minimum and maximum values by indicator (regardless of the country or year). This way, we can compare the indicators among countries and over the different years. The visual mappings of each indicator in each country is presented in figure 2.

As we aimed to represent all 10 indicators per country and this could lead to a complex and clustered artifact, we decided to create two views on the same data. The first, the overview, aims to give a more general view of the data. The second, the country view, aims to give more detailed view with all the consumption indicators per country.

The overview only includes four indicators: (i) internet users; (ii) frequency of internet use; (iii) internet energy consumption; and (iv) internet ghg. In the overview (figure 3), users are represented by the radius of the yellow and blue

[3] `shorturl.at/tzF15`
[4] `shorturl.at/EINO5`
[5] `shorturl.at/jopr0`
[6] `shorturl.at/orAVX`
[7] `shorturl.at/aCOZ0`
[8] `shorturl.at/lptz0`
[9] `shorturl.at/DKOPV`
[10] `shorturl.at/dNR69`
[11] `shorturl.at/bILX4`
[12] `shorturl.at/kmO12`

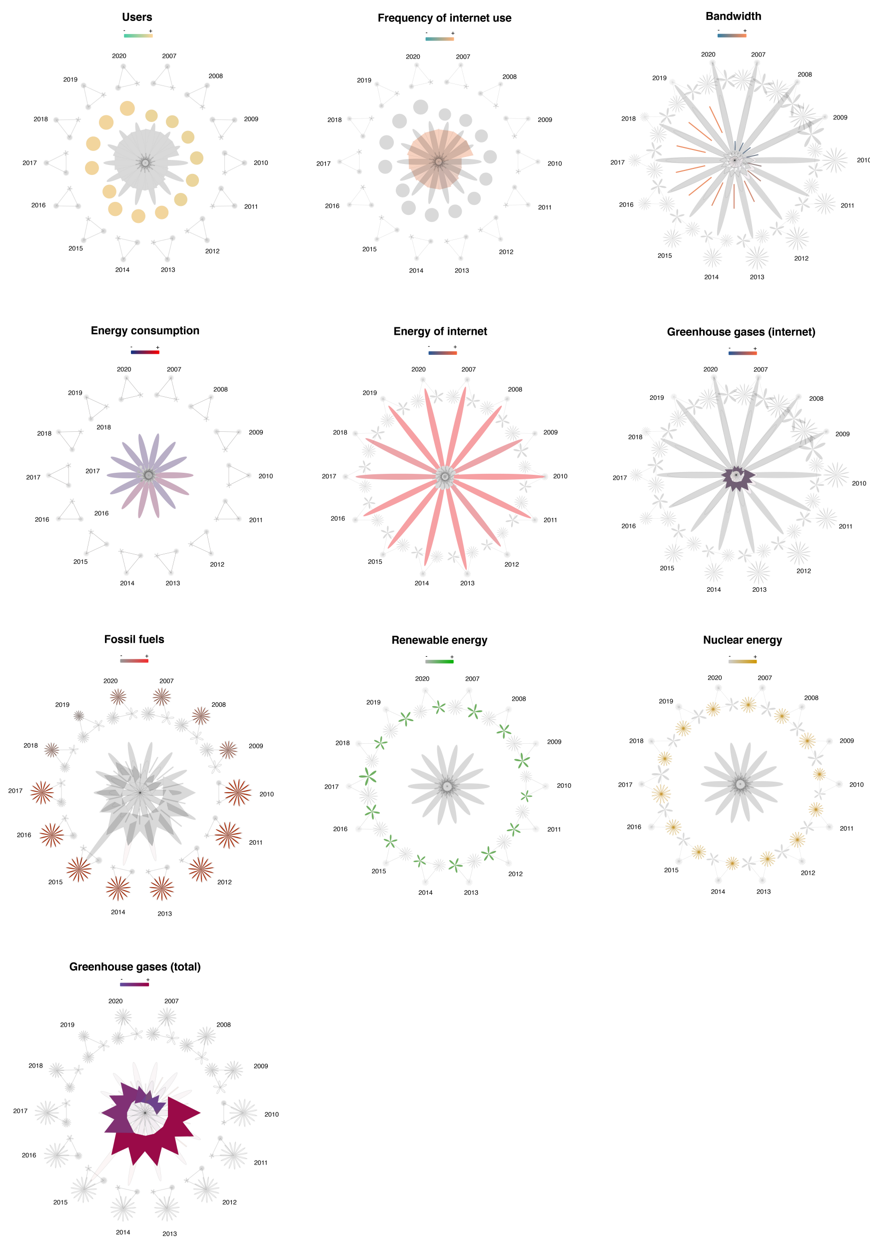

Fig. 2. Visual mapping of left and right panel. Here we highlight the the shapes resulting in the visual mapping of each indicator.

circles—the larger the average value, the larger and yellow the circle, the smaller the average, the smaller and blue the circle—and by its distance to the center of the shape—the greater the distance, the greater the value. The frequency of internet usage is mapped through the pie slices length: the higher the average value per inhabitant, the longer the pie slice. The internet power consumption and internet ghg are also mapped through length. Internet energy consumption is mapped through a vertically flattened ellipse, which is bigger or smaller in length according to the consumption value. Finally, the internet ghg is mapped into the triangle's distance to the center.

Figure 3 shows the 27 countries of the EU. About 14 countries belong to the left panel and the remaining EU countries with the greatest impact on the environment (e.g., Germany and Italy) are on the right. We can perceive that the countries with higher impacts have higher numbers of internet users (blue and yellow circles) and, therefore, higher values of internet usage (orange pie slices). Note that both values are increasing throughout the years (i.e., increasing clockwise in size). On the other hand, countries with higher energy consumption (pink petals) that produce energy through fossil fuels end up also having an impact on the environment as reflected in the ghg (pink triangles), as we can see in Malta and Finland. Malta has the highest values of ghg at the beginning of 2007, but this value is decreasing over time, which may represent the impact of positive measures.

The country view contemplates the following data: internet users, internet usage, frequency, bandwidth, internet energy consumption, total country energy consumption, total ghg, internet ghg, and energy sources (fossil fuels, nuclear energy and renewable energy).

The users, frequency of internet use, internet energy consumption, and internet ghg are mapped as in the overview. Then, the total energy consumption is mapped in the same way as internet energy consumption as they are semantically related—it is mapped across the length of the vertically flattened ellipse. The country's total ghgs are also mapped in the same way as internet ghgs—triangle's distance to the center. Bandwidth is only mapped across length. The energy sources such as nuclear energy, renewable energy and fossil fuels are mapped with the size of three different shapes. Figure 4 shows the country view of the Czech Republic, Estonia, Spain, Finland, Germany, Bulgaria, Malta, Portugal, and Slovenia, according to the indicators in figure 2.

In figure 4 we can observe the data of nine EU countries between 2007 and 2020. The data corresponding to each year is mapped clockwise, starting at the left. For example, we can analyze that the country with the greatest impact is Finland (in energy consumption—pink petals) and Malta (in ghg and fossil fuels—red star). We can also observe that Germany is the country with the highest number of internet users (yellow circles), and Slovenia and Finland the countries with the highest values in terms of nuclear energy (yellow stars). In terms of highest values of renewable energy (green flower), Malta, Slovenia, Finland, and Estonia are at the top.

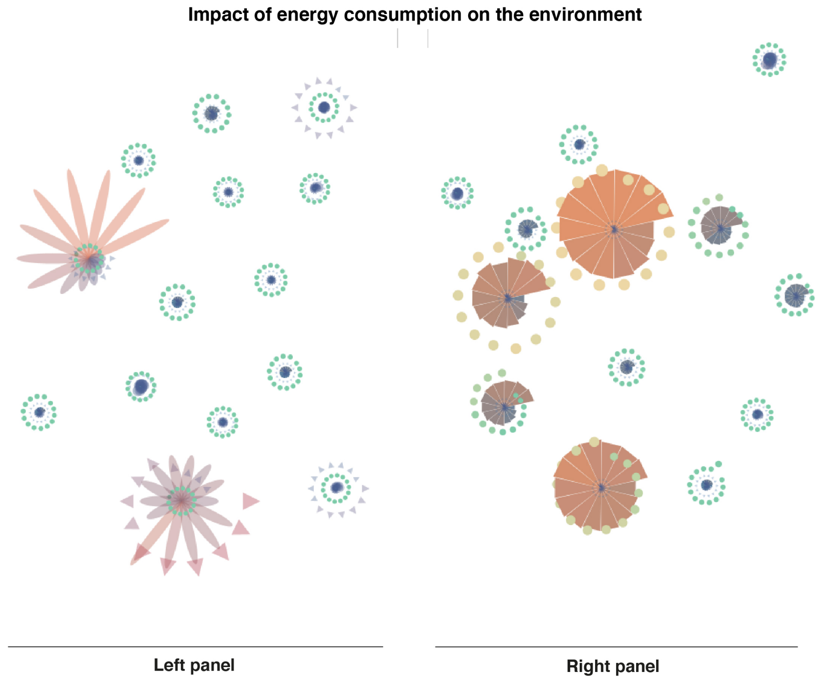

Fig. 3. Overview of the left and right panel. On the left, countries with lowest impacts on the environment. On the right, countries with highest impacts on the environment.

3.3 Central Panel

The main goal of the visual metaphor for the central panel is to translate the impact of energy consumption represented on the left and right panels, into an aesthetic experience.

In the central panel, we use an ecosystem of swarming boids—also seen in other projects [8,13,10]—that behave as an interpretation of the data represented in the left and right panels. In our representation, the higher the values of energy consumption in the EU countries, the higher the noise and the more cumulative the ecosystem becomes. Our intent is to create awareness on our consumption behaviors by creating a more complex and visually cluttered artifact.

The very unpredictability of the visual results of the ecosystem allows space for imagination. The perception of the artifact is subjective and differs according to several factors: (i) experience/knowledge of ecosystems functioning; and (ii) association of color and shape to data. Next, we discuss how the swarming rules are applied, how we define the number of organisms (i.e., boids) in the ecosystem, and how we visually represent them.

The ecosystem is based on the swarm system proposed by Craig Reynold [11] and it represents the number of users of 5 internet networks available at the

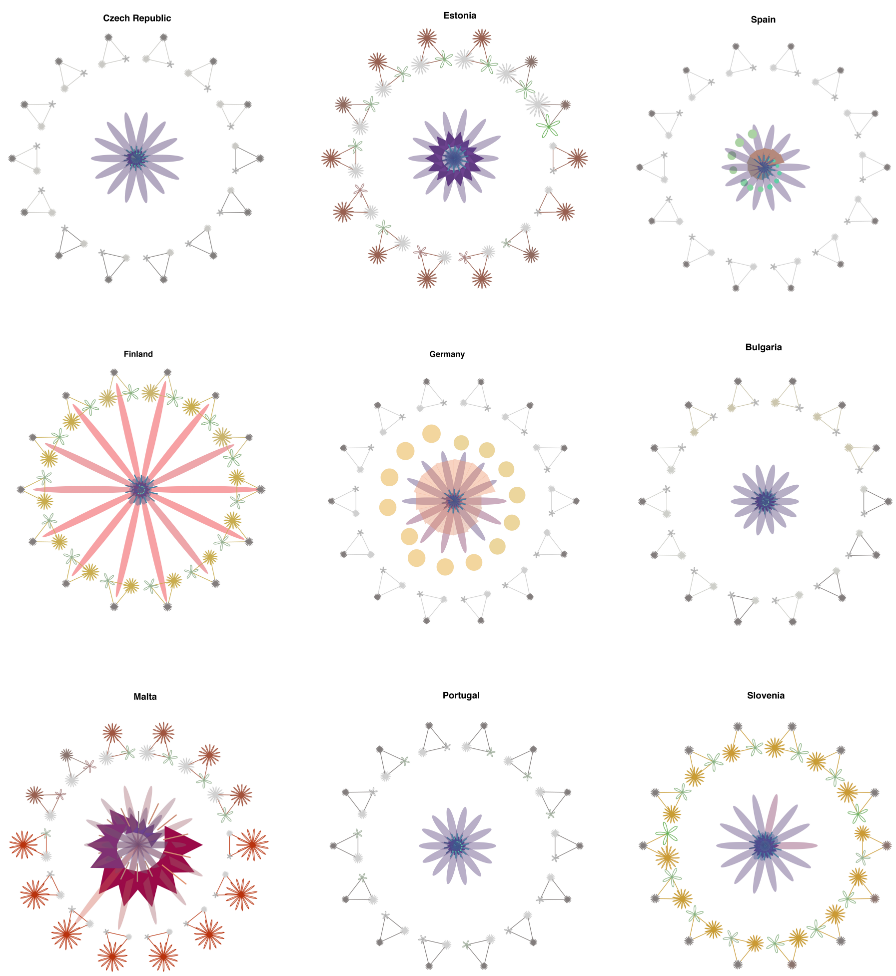

Fig. 4. Country view of different EU countries.

installation site. The behavior of the boids is based on three fundamental rules: separation, alignment, and cohesion. Each boid represents a user from a certain internet network and swarms together with other boids of the same type.

To enable the viewers to create a visual connection between panels, we change the boids' behaviors—and therefore representations—, according to the left and right panels. When no country is selected, the behaviors are adjusted to the average consumption values of the EU countries, and when a country is selected in the left/right panel, the behaviors are adjusted to the consumption values of the selected country. We chose to use only three indicators: internet usage

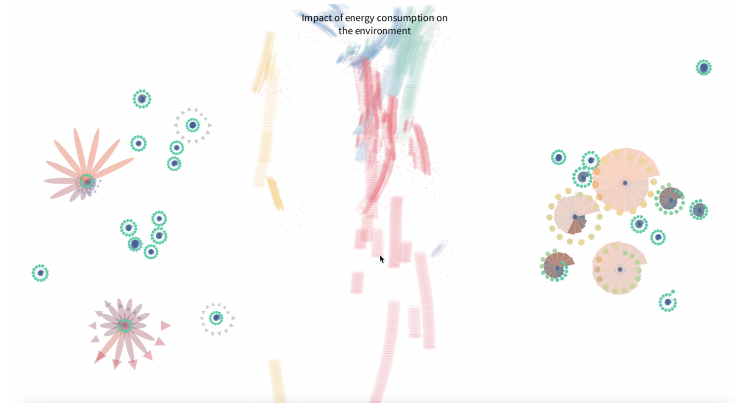

Fig. 5. Central panel with the final visual representation.

frequency, internet energy consumption, and internet ghg. This choice is due to the fact that they are represented in both overview and country view of the left and right panel.

To define the changes in the boids' behaviors, we compute the average indicator value of all years and divide it by the average by the maximum value (of the countries and indicator between 2007 and 2020). This final value defines the behavior/representation of each boid. Thus, the behavior/representation of the boid is defined and redefined as the user interacts with the panel and selects different countries or the overview.

Regarding the boids' visual representation, they are colored according to the internet network they represent and their shape and size represent the indicator and the indicator value, respectively. Regarding the shape, internet usage frequency is represented by an arch, internet energy is represented with petals and internet ghg is represented by triangles. The bigger these shapes, the higher the indicator value.

We tested the change of background, the trail to give continuity to the positions of the boids, and addition of particles. However, we opted for a cleaner and more organized ecosystem to facilitate the perception of the different representations for the different countries' values (figure 5). The final result of the ecosystem can be seen at the following url: `https://drive.google.com/file/d/1hPyZK_z2J-sTNKN6PhiYKZtL8Bt_dmEG/view`.

3.4 Interaction

The interaction with the installation was developed with the aid of the Arduino IDE tool and other devices considered necessary to test the approach we intended to follow. We used the Serial library, to allow communication between Processing and Arduino, and used other two Arduino libraries: the EspRotary library and the Button 2 library. The main objective of the interaction is data filtering and

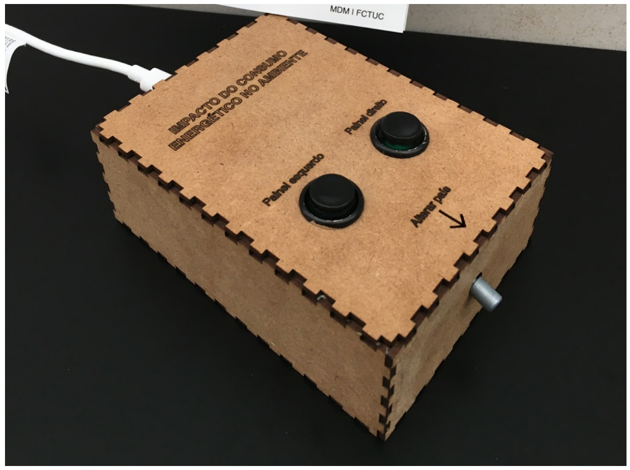

Fig. 6. Box created for the interaction with the left and right panel.

therefore we opted for the following solutions: (i) use a rotary encoder to change the country selected by the user; and (ii) use on/off buttons to trigger specific events in the system. To interact with the installation the users can use the rotary encoder to change countries and the buttons to change views—press once to show the Country View and press twice to show the Overview.

We created a box that allows interaction in any location of the installation. For the development of the box (figure 6), we opted for laser cutting and used laser printing for additional information (i.e., title and identification of the buttons). Finally, all elements were arranged on the box to facilitate the handle and interaction with the box.

4 User Testing

We defined a set of user tests to analyze and understand the participants' interaction with the artifact, detecting main errors, improvements, and suggestions. To carry out the tests, we defined a set of objectives: (i) understand the interpretation of the visual representations; (ii) perceive if the interaction is efficient; (iii) analyze if the colors and shapes aided the visual interpretation of the artifact; (iv) analyze if the exploratory ecosystem of the central panel conveyed the connection between panels, improving the communication with the user; and (v) evaluate whether the artifact raised awareness on energy consumption from internet use.

We performed two tests: an interaction test, to analyze the interaction with the artifact, and a perception test, to analyze the representations' visual impact.

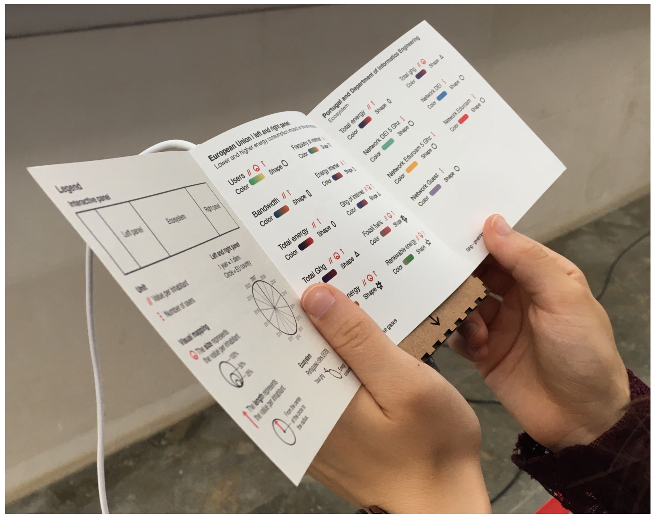

Fig. 7. Leaflet with the visual mappings.

4.1 Interaction Test

The interactive tests were carried out at the Department of Informatics Engineering of the University of Coimbra with six participants. The participants where from distinct areas: two from the area of management and administration, one Master's student in Design and Multimedia, two Master's students in Data Science and a researcher in the field of computer engineering.

All interactive tests followed the same procedure: introduction to the artifact, completion of a set of interactive tasks, and final questionnaire. The tasks covered the left and right panel and aimed to understand the effectiveness of the interaction. Participants interacted spontaneously with the materials provided: box and information leaflet. The leaflet (figure 7) contains the description of the visualizations and the project's synopsis. The box provides interaction with the interactive panel.

The participants were asked to perform the following tasks: (i) explore the left and right panel overview; (ii) select a desired country; and (iii) explore the resulting artifact of the selected country.

Some participants felt an initial difficulty in interacting with the artifact due to, for example, not knowing that the leaflet contained information regarding the interaction possibilities.

According to the time needed to accomplish the tasks, we could see that participants with greater knowledge about Information Visualization had a more active participation and made more comments about what could be changed in the panels to be better perceived by the participants (e.g., adding a caption with percentages to highlight relevant data in each country).

The observations given by the participants at the end of the test centered around two topics: the visual representations and the caption. The visual representations were difficult to memorize and, in the caption, the biggest problems were the lack of information, such as the consumption by country in text and percentage.

With the results we can conclude that the chosen interaction can be improved so those who have less contact with interactive visual artifacts can easily interact. However, through the analysis of the participants' reaction throughout the test, we can say that, in general, the artifact generated curiosity and lead them to explore its features and make suggestions for improvement.

4.2 Perception Test

The perception test consists of a questionnaire that aims to understand the effectiveness of the visual representations. The tests were carried out with 31 participants with different experiences and areas of professional activity.

The vast majority of participants (77%) were between 18-25 years old, with the others being between 26 and 41 years of age. Of the 31 participants, 16 (52%) are male and the remaining 15 (48%) are female. The professional area of the participants differs, but three main areas of activity stand out: graphic design (29%), management and administration (16%) and marketing and advertising (16%).

We used google forms[13] to make a quantitative and qualitative analysis of the answers. The tests were not supervised, they were sent to the participants who performed the tests in the environment that was most convenient for them.

The perception test was divided into four sections. In the first section, the project and the questionnaire were contextualized. Subsequently, we present a set of questions related to the participants' profile, to understand their activity, experience, and knowledge in the area under study. In the second section, we first defined single choice questions to understand how the reader perceived the data presented in the visual representations. Then, the questions are related to the artifact problems, ecosystem functioning, and data insight. In the third section, the questions were aimed at analyzing the participant's perception of the experience with the artifact through first person premises and selection responses. Finally, a visual and global appreciation of the artifact was requested.

According to the answers from the perception test, the best way to raise community awareness of environmental problems is through dissemination in the media (38%), exposure of data on consumption and ecological footprint (25%), or through environmental manifestations (16%).

We could perceive that the academic training of the participants had some impact on the reading of the artifact, and the participants with greater technological knowledge showed less difficulties. This was also verified during the interaction test in which a Data Science participant (with previous knowledge in the area of Data Visualization) was able to easily understand how the data were

[13] `https://forms.gle/EGfCQ3ooQjJaMGcGA`

mapped and mentioned intervals of data values. However, the artifact managed to catch the attention of all participants and arouse curiosity, even without prior knowledge in the area of Data Visualization.

In the central panel, we analyzed how the swarm system was perceived by the user, in which we obtain the following results: 61% of the participants were able to distinguish the networks by colors; 58% of the participants were able to associate the shape of the boids with the data and 67% of the participants were able to understand the developed system.

Most participants gave suggestions for improvement, regarding the way the caption was presented and the way the data was mapped into visual representations. The suggested changes in the perception test focus on the following: remove overlaying shapes, addition of detail and information, and improve the relationship between panels.

5 Discussion

In the left and right panels, we used color, shape, and size which, together, created higher visual emphasis on the countries' indicators. In this way, we intended to make the users aware of the issue of environmental impact and the influence of energy and the internet on the environment. Through color, we aimed to distinguish different values. For example, high values of energy or internet consumption, greenhouse gases, and fossil fuels are colored with reddish colors and low values are colored with bluish colors. In the other hand, high values of renewable energy and nuclear energy are colored in green and yellow, respectively. These colors were chosen due to their semantic connotations: green is can be associated to nature, red can be associated to an alert state, yellow can be associated to energy, and blue to calmness. Also, by using size the aim was to better distinguish indicators with higher values from the ones with lower values.

With the results obtained from the user tests, we noticed that the participants had some difficulties in understanding the visual representations of the indicators. This may be due to the high number of indicators represented and to the caption not being fully explicit and objective. Additionally, the high number of indicators also produced other constraints such as the memorization of each representation and overlapping figures. However, much of the representations were perceived by the participants, as well as its main message. The majority of indicators accurately perceived by the participants were internet related.

In the central panel, the visual metaphor involves the symbolic use of spatially arranged boids that metaphorically express the concept (impact of internet usage on the environment) through visual transformations that occur according to the selections of the left or right panels. When boids represent a greater value of consumption, more boids are added, creating a cumulative impact of consequences on the environment. The ecosystem metaphor suggests the relationship between the use of internet networks (central panel) and the energy consumption impacts of the EU (left and right panel), through the demonstration of the consequences in the way boids are represented in the ecosystem.

We believe that to speed up the reading of the artifact for different people with different knowledge and experiences, we need, for example, to create an artifact that incorporates contextual indications to the visual representations. These indications can be textual or visual (e.g., the display of rankings to help people contextualize a country in relation to the EU).

6 Conclusion

The main focus of this project was the analysis and visual representation of the impact of energy consumption on the environment. The first phase of the work process was directed towards the identification of the problem and the definition of target audience and visual metaphor. The second phase focused on the development and implementation in Processing and Arduino. Finally, in the last phase of the development process, user tests were carried out to understand how the participants interact with the installation (interaction test) and how they interpret the visual representations (perception test).

The conclusions drawn from the results of the tests clarify that there is room to improve the artifact, especially regarding the information leaflet and the visual representations. Nonetheless, participants considered the project important for the community and mostly appreciated the visual representations. The main improvements in our project are: (i) use of the most current data, preferably up to the current year; (ii) improve the relationship between the interactive panel and the information leaflet; (iii) add rankings and informative captions on the panel; and (iv) improve the box handling (i.e., wireless).

As a future work, we intend to create a personalized experience for each user, through the calculation and analysis of their carbon footprint data in real time. By introducing and analyzing these variables in detail, we aim to help understand the human footprint derived from energy consumption in the environment.

Finally, the development of this project made it possible to recognize the impacts of European Union countries on the environment, energy consumption, and the relationship with internet use. The impact of energy consumption and internet usage on the environment is an open field for new explorations in the area of data visualization due to the relevance of the topic and available data related to energy consumption and the environment.

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