



# **Cartography M.Sc.**

## **Master thesis**

### **Space as a Metaphor**

Design Guidelines and Evaluation of  
Map Imitation

Sacha Schlumpf



2023



## Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"Space as a Metaphor: Design Guidelines and Evaluation of Map Imitation"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Vienna, September 2023

Sacha Schlumpf





TECHNISCHE  
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# Space as a Metaphor

Design Guidelines and Evaluation of Map Imitation

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TECHNISCHE  
UNIVERSITÄT  
WIEN

MASTER THESIS

# Space as a Metaphor

Design Guidelines and Evaluation of Map Imitation

for obtaining the academic degree

**Master of Science**

in the degree programme

**International Master in Cartography**

submitted by

**Sacha Schlumpf**

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Je dédie ce mémoire à ma mère, à celle dont le soutien, la volonté et le courage à toute épreuve m'ont permis de réaliser mes rêves, qui malgré si peu m'a toujours donné tellement. Merci, maman, c'est grâce à toi que j'en suis là. Je t'aime.

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# Abstract

Map imitation is a type of data visualization in which individual data items are displayed on a visualization resembling a map. Examples of complete map imitations are rare, and none have been tested in a user study, although research on individual layers of map imitations does exist. Therefore, this research contributes to the topic by providing a comprehensive procedure on the production of a complete map imitation, testing user perception and understanding, as well as giving ideas and suggestions on how to design such a visualization. The study begins with a new definition of map imitation and the establishment of a framework. Then, an example of map imitation is produced and the design workflow is presented. The three main steps are detailed: preliminary considerations and preparation, data processing and creation of the main layers, and graphic design of the visualization to make it resemble a map. For some steps of the design workflow, potential additional political and design constraints due to industry requirements are presented. Next, the methodology for testing the map imitation is introduced. Two parallel surveys are conducted, one with the map imitation, the other with a graph showing the same information. Both surveys asking the same questions, comparing the results allows to determine how the map-likeness of the visualization influences user performance. The results show that the map imitation is more confusing than the graph, causes errors of understanding, and leads to different interpretations of the subject depicted. Finally, the limitations of the research are detailed and recommendations for future research are proposed.

**Keywords:** map imitation, map-like visualization, spatialization, data visualization, cartographic design, graphic design



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# 1. Introduction

Map imitation is an ongoing area of research. This form of data visualization is old, yet relatively uncommon. This chapter will explain the motivations of this research, present the research objectives and research questions, and argue how this study will contribute to the field of Cartography.

## 1.1. Motivation

The inspiration of this research is the following visualization from Hermann & Leuthold (2003), showing Switzerland in what was for me a unique, surprising and fascinating way of mapping my country (Figure 1). As someone familiar with Switzerland, this 'map' brought out a range of emotions. At first glance, I experienced mixed emotions, from curiosity to confusion. Once I understood that while being designed as a map, this visualization was in fact a graph, the emotions I felt became exclusively positive, from enthusiasm to strong resonance.

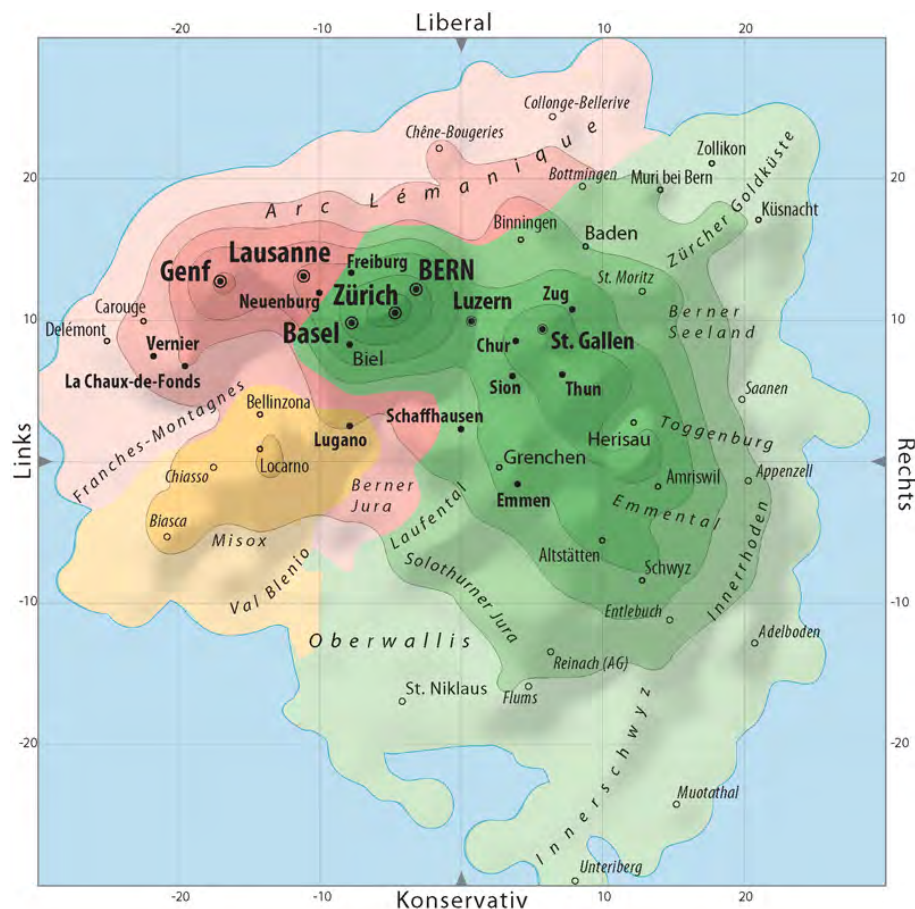


Figure 1 – Map of the Swiss political landscape (Hermann & Leuthold, 2003, p. 59)

Despite being published in 2003, only few similar visualizations have been published outside of scientific literature since then, which led me to have two questions.

1. How to make such a map? Initially, I was unsure on how to recreate such a visualization, since the point positions were not determined by geographic location. Furthermore, I was confused about the meaning and the production of the shaded relief. It was likely that the visualization was created using an addition of several techniques, and I wanted to try it out.
2. How do people perceive such a map? First, I was curious to know if people appreciate such visualizations and if they also experience positive emotions. Second, I was interested to know if the readers actually understand how to interpret such a visualization, as it took me some time to comprehend it.

Alongside these questions, two other motivations contributed to the decision to undertake this research. I had the opportunity to create such a visualization in a book publishing company, HarperCollins Publishers. A version of this visualization will be published in the 16<sup>th</sup> edition of the Comprehensive Times Atlas of the World, as well as other maps and visualization I had the chance to produce in the company. The experience I gained enables me to include knowledge of visualization design within an industry setting into this research.

The second motivation, which helped me and the company decide on climate change as the represented topic on the map, is the climate crisis that society is currently facing. As a solid source, the Intergovernmental Panel on Climate Change (IPCC), which is “the United Nations body for assessing the science related to climate change” (IPCC, 2023). The IPCC produces Assessment Reports approximately every 5 to 7 years. These reports are produced by hundreds of scientists worldwide who review and synthesize the latest scientific research on various aspects of climate change, including its causes, impacts, and possible adaptation strategies. The IPCC released the 6<sup>th</sup> Assessment Report in 2023. This report shows proof that the current climate change is caused by human activity, principally through the emission of greenhouse gases (Mukherji et al., 2023, p. 4). The rapid change in climate causes direct harm to the nature and, as the ecosystem and human vulnerability are interdependent, to the people: climate hazards such as heatwave, cyclones, heavy precipitation and wildfires are becoming stronger and more frequent, and an increasing number of people are facing food and water insecurity (Mukherji et al., 2023, p. 5). Moreover, the IPCC report states the following, which motivates and guides the relevance of the created visualization: “Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected” (Mukherji et al., 2023, p. 5). These vulnerable communities are especially affected by climate change and this crisis is only growing worse. One way to measure climate change is the global temperature change, which is directly linked to the intensity and frequency of climate hazards. The average temperature between 2011 and 2020 was 1.1°C higher compared to the average between 1850 and 1900, which serves as reference. By 2100, global warming is projected to be between 1.4°C and 4.4°C depending on the measures taken by governments and individuals to address greenhouse gas emissions. If current world policies remain unchanged, global warming is projected to reach 3.2°C (Mukherji et al.,

2023, pp. 7–12). Such a high level of global warming will increase human displacement, affect agriculture, spread infectious diseases, reduce water availability, and directly cause human deaths.

Taken this context, I had the will to give more visibility to this crisis, especially by highlighting the imbalance between those responsible for climate change and its victims.

## **1.2. Research**

In order to guide this research, objectives need to be established. This section therefore explains the objectives of this research and the corresponding questions that will be answered, as well as what this research brings to the science of Cartography. These research questions are answered in Section 6.2, as the main results of this thesis.

### **1.2.1. Research Objectives**

This research focuses on design and evaluation of map imitations. The following research objectives will structure this work.

- RO.1.** Determining the industry requirements that dictate the creation of a data visualization.
- RO.2.** Developing a comprehensive procedure for creating a map imitation, and creating an example.
- RO.3.** Evaluating the performance of a map imitation for knowledge transfer by comparing the user's perception and understanding of both a map imitation and a graph showing the same information.

### **1.2.2. Research Questions**

The three research objectives should be attained by answering the following corresponding research questions.

- RQ.1.** What criteria dictate the creation of a commercial data visualization?
- RQ.2.** How can a map imitation be designed?
- RQ.3.** How does the map-likeness of a visualization influence user performance?

### **1.2.3. Contribution to Cartography**

By responding these research questions, this research aims to make a valuable contribution to the field of Cartography. Although the topic of map imitation is widely researched since the late 1970s and is still an ongoing area of research. Many user studies were conducted to analyze the perception and understanding of the readers, and some studies compared parts of a map imitation with its graph equivalent. However, previous research only tested one layer at a time – points, relief, or lines. On the other hand, the design closest to the one proposed in this research, which is

the map imitation depicting the political landscape of Switzerland from Hermann & Leuthold (2003), was not tested with a user study. Therefore, what is new in this research is that the proposed design, which is a *complete* map imitation, is tested by a user study. By complete, it is meant that the map imitation designed in this research has multiple layers and visual elements of a conventional map.

In addition, this thesis provides a comprehensive step-by-step workflow on how to make a map imitation, for any topic and data. This aims to make the creation of a map imitation more accessible to people with experience in GIS, cartography and/or data visualization.

## 2. Literature

In order to create a map imitation and to shape an effective user study to test it, it is necessary to explore the existing research. This chapter will therefore start by listing the different terms and current definitions of what map imitations are, and propose a new definition which will then be used for the rest of this research. Based on this definition, the following section will introduce the three relevant historical periods of map imitation which led to the existence of this research. The next section will focus on the first usual step of the making of map imitation by introducing the concept of spatialization, and by explaining several spatialization techniques. The following section will explain the second step of the process by explaining how spatialized data can be designed in order to resemble a map. Afterwards, the following two sections will list the potential benefits and drawbacks of map imitation from the user perspective, in particular compared to a traditional graph. Finally, the key points will be summarized and this research will be placed in the framework.

### 2.1. Concept of Map Imitation: The Lack of a Common Term

For this research, the term *map imitation* was chosen, but it is not a universal term. In fact, through time and depending on the authors, many different terms are used, most of the time interchangeably. Wise used the term *landscape representation* (Wise, 1999, p. 1228). Skupin, in one paper, used the terms *spatial metaphor*, *landscape metaphor*, *map metaphor* and *map-like visualization of non-geographic information* (Skupin, 2000). Montello, Fabrikant, Ruocco and Middleton used *spatialization* (Montello et al., 2003, p. 316), a term which is then also used by Skupin (Skupin & Fabrikant, 2007). A few years later, Fabrikant, Montello and Mark used both *spatialization* and *landscape metaphor* (Fabrikant et al., 2009). In general, many authors utilize the term *map-like visualization* (P. C.-I. Pang et al., 2016). However, in their paper *The State of the Art in Map-Like Visualization*, Hogräfer et al. (2020) state that *map-like visualization* encompasses two distinct categories: *map schematization*, which consists of the modification of a map to make it schematic, and *map imitation*, which implies spatialization of abstract data and graphical imitation of a map. This term, which includes the two steps (spatialization and graphic design) is the one that will be used in this research. This term will also be used to describe previous occurrences, even when their authors did not call them map imitations. For this research, a *map imitation* is defined as a map-like visualization of non-geospatial data, or geospatial data, created by plotting individual data items onto non-geospatial coordinates, and designed to resemble a map using cartographic elements.

## 2.2. Periods of Map Imitation

Now that map imitation is defined, this section will introduce the three main periods and trends of map imitations that led to the existence of this research.

### 2.2.1. 17th and 18th Centuries: The Beginnings

Map imitations metaphorically representing matrimony are the oldest known examples and can be considered as the historical basis of map imitation. A major difference with recent examples is that this type of map imitation is not based on quantitative data and therefore does not use mathematically accurate transformation. The oldest known example is the Carte de Tendre of 1654 (Figure 2) representing matrimony and deceit, accompanying the novel *Clélie* from Madeleine de Scudéry (1655). Around two hundred years later was published the *Gazette de Tendre*, which tells a story taking place on the site depicted on the map, where characters travels on 'paths' between 'cities' and embark on 'rivers' (Colombey, 1856). More recently, Filteau (1979) analyzes 'geographically' the Carte de Tendre, based on the distance between features and their position on the map. The author points out that the map is still of great interest in French literature and at school.



Figure 2 – Carte de Tendre (Chauveau & Scudéry, 1654)

The idea of metaphorically representing matrimony as a map has been applied ever since by several artists (Figure 3).





Figure 3 – Various map imitations in chronological order. 1: La Carte du Royaume d'Amour (L'Hermite & Sadeler, 1659), 2: Allegorical Map of the Siege of the Castle of Love (Seutter, 1735), 3: A Map or Chart of the Road of Love, and Harbour of Marriage (Sayer, 1748), 4: A New Map of the Land of Matrimony (Barbauld, 1772)

### 2.2.2. The 1990s and the Web: New Challenges

The next relevant period for map imitation happens hundreds of years later, in the 1990s, with the growing democratization of databases and the Web (Skupin, 2000, p. 91). Documents of any type could then be digitalized, which gave rise to the need to be able to efficiently explore large quantities of information. “Clearly, another way was needed to both represent the documents and their contents, while permitting their rapid retrieval, categorization, abstraction, and comparison, without the requirement to read them all” (Wise, 1999, p. 1224). There was therefore a need for both a new type of data analysis and of data visualization.

The Department of Energy and the U.S. intelligence agencies funded the SPIRE project in 1994 to address this issue (Wise, 1999, p. 1224). Galaxies (1994), which then got enhanced with ThemeScope (1995), were two of their products (Figure 4). The software Galaxies places documents, visualized as points, on a plane, where more similar documents are closer to each other. ThemeScope takes this as a basis and then creates a surface from the points to better visualize clusters of similar documents. In the end of the process, a Gaussian function is applied which smooths the surface, making it topographically more plausible (Wise, 1999). It can therefore be considered as a map imitation. Wise’s paper introduces a key concept of any map

imitation: the Euclidian distance between elements is proportional to their similarity (Wise, 1999, p. 1226). In addition, Wise sets the two main steps involved in creating a map imitation by describing ThemeScape as “a spatialization of unstructured document information derived from GIS techniques that formed a landscape representation” (Wise, 1999, p. 1228).

Figure 4 – Galaxies (left) and ThemeScape (right) (Wise, 1999)

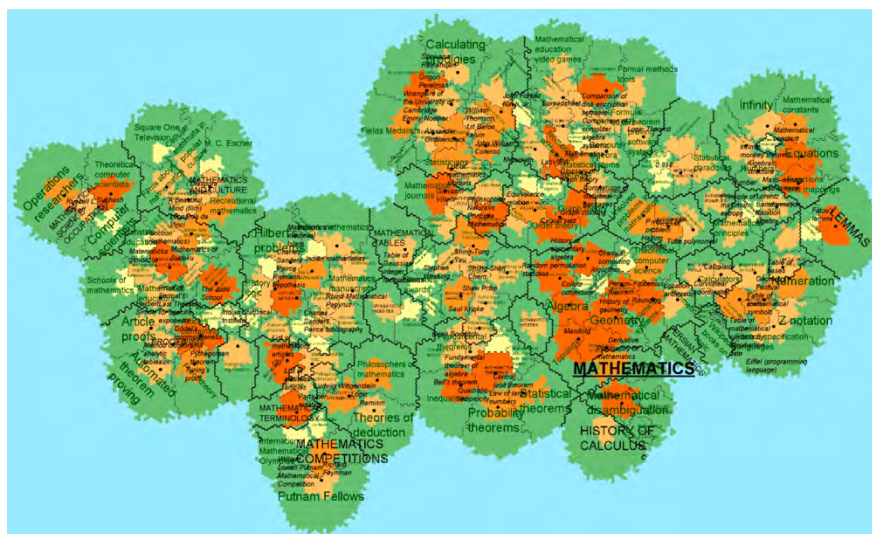


Figure 5 – Highlight of category “Mathematics” in the English Wikipedia, showing subcategories and their relative sizes (C.-I. Pang & Biuk-Aghai, 2011)



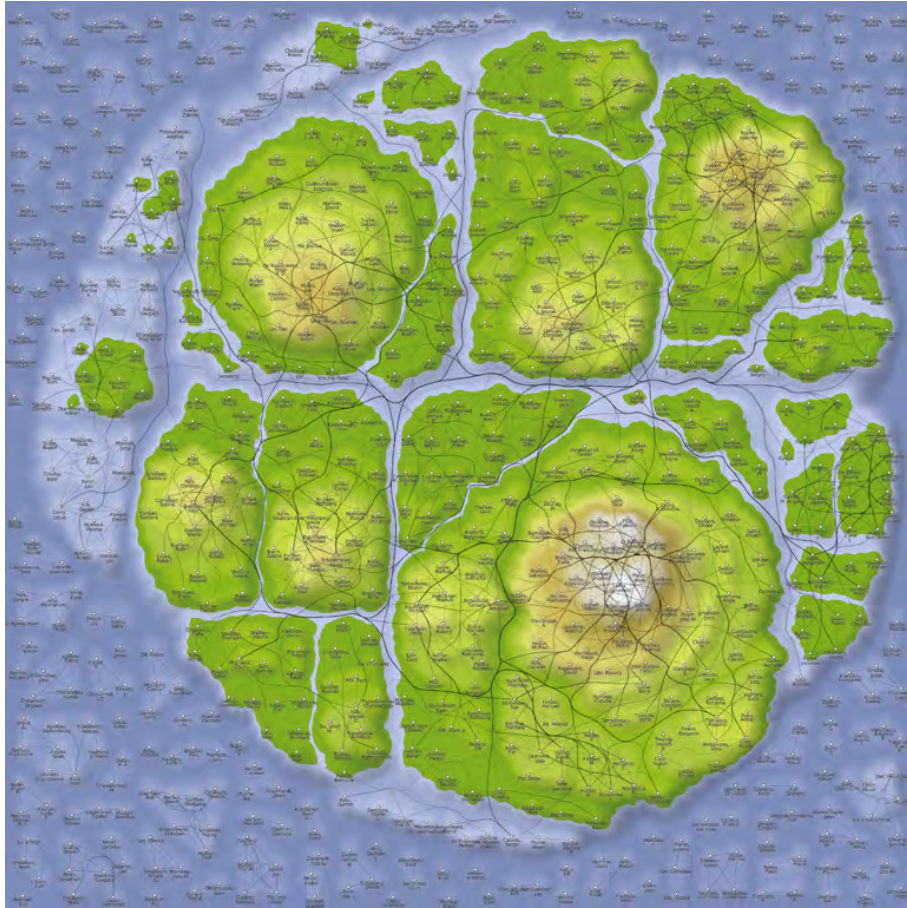


Figure 6 – Graph drawing collaboration graph (Gronemann & Jünger, 2013)

### 2.2.3. 21<sup>st</sup> Century: Broadening the Realm of Map Imitation

As observed, since the existence of internet, personal computers and GIS, map imitation focused on visualizing relationships between documents. However, since the 21<sup>st</sup> century, and continuing to this day, experts in data visualization have started including map imitation in their toolbox. As mentioned in the Chapter 1, Hermann & Leuthold (2003) developed an algorithm and made design suggestions to visualize political orientation as a topographic map. They published an atlas containing map imitations of Switzerland, including one for the country (Figure 1) and one for each canton and other administrative and cultural units. With their work, they opened a new era of map imitation, where map imitations can be used to visualize any topic. It is therefore in this new period that this research is being carried out.

## 2.3. First Step: Position in the Plane

All the previous examples of map imitations shared a common characteristic: they depict on a 2D space data that does not have a spatial component. To make it possible, each feature in the plane must be assigned a position in the plane. In the first period of map imitation, when representing matrimony, the artists did not use any mathematical transformation to decide on the position of elements, but rather made subjective decisions. In the recent periods, map imitations are made using spatialization techniques, which involve quantitative data and mathematical transformation. This section will first define what spatialization is, then give examples of spatialization techniques.

### 2.3.1. Concept of Spatialization

The concept of spatialization is inherently linked to the concept of map imitation. Except for the first-mentioned period of map imitations, all recent productions are created using spatialization. Several spatialization methodologies exist, and they all have the same objective: summarizing input data having multiple variables into two dimensions, which can then be used as coordinates on a plane (Skupin & Fabrikant, 2007, pp. 61–69).

Both non-geospatial data and geospatially referenced data can be spatialized (Skupin & Fabrikant, 2007, pp. 64–67). Non-geographic data can be classified into two categories, each of which gives spatialization a different purpose. For some data, there is already a pre-existing linkage between the items and spatialization is therefore used to visualize the existing structure in the space. On the other side, some datasets do not have pre-existing links between items, for which spatialization can help to reveal implicit relationships. Geospatially referenced data can be spatialized as well, despite already having a position in space. In this process, geographic location is ignored and the points are reassigned to a new location that does not correspond to the real-world location.

Now that the concept of spatialization is explained comes the matter of the intuitiveness and understanding for the readers. Montello et al. (2003) argue that people usually show a good understanding of the distance-similarity metaphor, meaning that they intuitively understand that data items that are more related to each other are plotted closer to each other (p. 328). This concept is what the authors call the first law of cognitive geography, which is the reverse of the first law of geography which states that “everything is related to everything else, but near things are more related than distant things” (Tobler, 1970, p. 236). While in the first law of geography, the similarity of objects depends on their distance, in the first law of cognitive geography, the distance between objects depends on their similarity. Although this distance-similarity metaphor seems to be intuitively understood, on the other hand, Skupin & Fabrikant (2007) argue that because spatialization methods are usually complex, it is difficult for the readers to understand the process behind it. Therefore, it is generally difficult to interpret the precise meaning of the position of spatialized data, with people often wondering what the axes mean, which is a complex question to answer (Skupin & Fabrikant, 2007, p. 65).

### **2.3.2. Spatialization Techniques**

There are several ways to spatialize data, and it is of interest for the creation of the map imitation of this research to examine what the possibilities are. All spatialization techniques are dimensionality reduction techniques, which means that the input data has multiple variables and is summarized into a few dimensions (Skupin & Fabrikant, 2003, p. 101). Skupin & Fabrikant (2003) list some of the most common spatialization techniques. The multidimensional scaling (MDS) method is one of the most popular methods, in which from a dataset is calculated a dissimilarity matrix, which is then the input of the MDS. This means that the resulted spatialization will directly depend on the similarity of the items. The self-organizing map (SOM) method is a similar technique with some differences, making it work best for very large datasets and more usable for classification purposes rather than for visualization.

Factor analysis is the method chosen by Hermann & Leuthold (2003) for the map imitation on Figure 1. Starting from a dataset with a large number of variables, and after calculation of their correlations, factor analysis reduces the input data into a low number of dimensions in a way that one can make sense of these dimensions. This means that names can be given to the axes, so that the reader can find a clear meaning of the location in space of the items, such as 'Unteriberg is very conservative' based on Figure 1. The principal component analysis (PCA) functions in a similar way, although the objective is to explain as much of the total variance in a few dimensions as possible, not the correlations.

Many other methods exist, these are only a few examples of popular ones. These techniques are the most common ways to give the data items a position in the plane.

## **2.4. Second Step: Graphic Design**

Once the data items have a position in the plane, the first step is done but the visualization is not a map imitation yet, since it still looks like a traditional graph. Therefore, the next required step is the graphic design of the visualization to make it resemble a map. Using several strategies, the designer can use cartographic techniques and elements to make the graph look like a map. In this section, the graphic design of map imitation is discussed by introducing and describing the design possibilities of the main layers that play an important role in making the imitation plausible, which will help in the creation of the map imitation of this research. Although there is a lack of research on the graphic elements that can make a map imitation convincing (P. C.-I. Pang et al., 2016, p. 75), here are a few suggestions based on research and on analyzes of map imitations.

### **2.4.1. Colors**

One of the first aspects to consider when visually imitating a map is the choice of colors. Hogräfer et al. (2020, pp. 654–655) explain that the color scheme of a map imitation is of an important role in making the imitation plausible. The authors present some important aspects to consider when choosing colors for the water and the land.

The ocean, and water bodies in general, play a role in making the visualization resemble a map. Traditionally, on all colored topographic maps the oceans appear in a shade of blue. While designing a map imitation, an easily applicable trick is therefore to set the background color of the visualization to blue. This can be seen for example on Figure 5 and Figure 6. While most of more traditional graphs have a white or neutral background, choosing a blue background can evoke the ocean and help the visualization resemble a map.

The main part of the map imitation, which is metaphorically represented as the land, also requires color. The choice of the color scheme mainly depends on the represented variable. When colors are representing categorical values, then the color scheme is generally inspired from political maps, where each area has a distinct color. This can be seen for example on Figure 1. When the colors serve as an emphasis to the relief, the color scheme is usually inspired from topographic maps, as on Figure 6.

#### **2.4.2. Relief**

The relief is a commonly added element on map imitations. It shows an additional layer of information, which is usually the density of items. Moreover, since relief is a cartographic element it is assumed that it helps the readers to perceive the visualization as a map. The relief can be visualized as contour lines, shaded relief or in 3D, coupled or not with color shades (Hogräfer et al., 2020, pp. 654–655).

The value of adding a relief on map imitation is uncertain. Fabrikant et al. (2009) proved with their experiment that the understanding of metaphorical relief is not self-evident for most people, especially for those who do not have much knowledge on topography. The authors argue that the relief creates confusion, coupled with the fact that people usually have difficulties to understand continuous phenomena. On the other hand, they also show that most of the time people intuitively understand the idea that a 'mountain' means 'more', and therefore a 'valley' means 'less'.

#### **2.4.3. Labels**

Another element that is of interest for this research is the labels. As all map imitations depict individual data items, for the visualization to be useful, the data items need somehow to be identifiable. This is the reason on all map imitations, the data items are accompanied by a label. Although there is no known recommendation for the design of labels on map imitation, it is of interest to analyze how they are designed for example on the map imitation on Figure 1. It is worth noting that on this map imitation, not all data items are shown: while the elements such as the areas and relief are made from the 2896 Swiss municipalities, only some of them are named. The named municipalities are shown with different types of labels and point symbols, depending on the number of inhabitants, which is directly inspired from topographic maps. Additionally, some names of regions such as mountain ranges are also depicted. This labeling approach will inspire the creation of the map imitation.

#### **2.4.4. Surrounding Elements**

Finally, it is interesting to observe what other cartographic elements can be included around the map imitation themselves. Map imitation of the 17<sup>th</sup> and 18<sup>th</sup> centuries often include several surrounding elements, such as a compass rose, a graticule, a title, a subtitle, textual information, a legend, and other elements. Recent map imitations, however, often do not include such elements. An idea is therefore to explore the use of surrounding elements for the creation of the map imitation of this research.

### **2.5. Potential Benefits**

Once the map imitation of this research will have been created, it will be evaluated through a user study, in particular to test whether map imitation has good reasons to be chosen as a data visualization type from the user's point of view. In the literature, almost no user study which clearly proved benefits of map imitation was found, but many authors assume some benefits. This section will therefore present some of the arguments about what supposedly are advantages of making a map imitation, but it needs to be taken with care since these are mostly assumptions from authors. Knowing the supposed benefits will help create the map imitation and shaping the survey. The section following this one will summarize the potential drawbacks of map imitation.

#### **2.5.1. Partially Intuitive**

As seen before, positioning data items in the plane is proven to be partially intuitive for people, who usually understand the distance-similarity metaphor (Montello et al., 2003, p. 328). Additionally, P. C.-I. Pang et al. (2016) argue that since maps are proven to be intuitively understood, even by children without prior training (Blades et al., 1998), then it means that readers also intuitively understand map imitations, but this has not been proven. Skupin & Fabrikant (2003) add that the intuitiveness of understanding of a map imitation does not depend on the people's background, and frame it as a benefit for map imitations. However, research also shows that map imitations are not so intuitive, which will be discussed in the next section.

#### **2.5.2. Curiosity to Explore**

There is at least one other benefit of map imitation, which is a more well-founded argument: map imitations supposedly encourage exploration of the data. In fact, one of the reasons map imitations exist is because they allow the exploration of complex datasets (Wise, 1999, p. 1224). In the same way that topographic maps help exploration and navigation of the real world, map imitations allow exploration of knowledge (Borner, 2010, inside back cover). Additionally, it is proven that when seeing something novel, the brain is stimulated in a way that it generates motivation to exploration (Bunzeck & Düzel, 2006, p. 376). According to this finding, since map imitation is not a common type of data visualization, it should generate more curiosity to explore its data than a traditional type of data visualization. It is therefore assumed that map imitation is a relevant type of data visualization when the aim is to encourage the readers to explore the data represented.

## 2.6. Supposed Drawbacks

Although map imitations have some potential benefits, they also come with several drawbacks, especially in comparison with a traditional graph. This section will explain some of them, found in the literature.

### 2.6.1. False Intuitiveness & Confusion

As observed, some authors claim that map imitations are intuitive. On the other hand, some authors argue that map imitations can be falsely intuitive, meaning that the readers may believe that they have understood, even though they have not: "The intuitive power of maps bears inherent dangers of misunderstanding, misinterpretation, and miscommunication" (Leuthold et al., 2007, p. 805). As explained before, Skupin & Fabrikant (2007) point out that spatialization is frequently misunderstood by the readers, and Fabrikant et al. (2009) that the relief is not universally intuitively understood. This means that all of the three dimensions of a map imitation which include a relief are subject to cause misinterpretation, which makes it a clear disadvantage for map imitations. Additionally, Hogräfer et al. (2020) argue that it is easier for the readers to interpret a familiar data visualization than a novel one (p. 668).

### 2.6.2. Cognitive Load

An aspect to consider when designing a data visualization is the cognitive load involved. Bunch & Lloyd (2006) define the cognitive load as "the amount of work needed to acquire and use information" (Bunch & Lloyd, 2006, p. 210). The authors explain this concept from a cartographic point of view. If the cognitive load of a cartographic task is too low, the map may not be stimulating enough and therefore generate boredom, whereas if it is too high, it may generate anxiety and hinder learning (Borner, 2010, p. 64; Bunch & Lloyd, 2006, p. 210). In that sense, the authors explain that if the reader of a map has to spend extraneous time searching for information due to vague instructions, the cognitive load is unnecessarily increased and therefore affects learning capacity (Bunch & Lloyd, 2006, p. 212). Additionally, since map imitations are not a common type of data visualization, it takes more time for the readers to understand it (Hogräfer et al., 2020, p. 668). Combined with the fact that the concept of spatialization often causes difficulties of understanding for the readers, map imitations therefore usually require a significant amount of effort and time on the part of the reader in order to be understood. In brief, due to the novelty of map imitation and its inherent complexity, the required cognitive load for map imitation is higher than for a traditional graph, making it a disadvantage for map imitation.

### 2.6.3. Memory

When the cognitive load is higher, short-term memory is directly affected (Bunch & Lloyd, 2006, p. 212). Research shows that map imitation leads to several problems when coming to memorization of information. For example, research has proven that people tend to have difficulties remembering accurate alignment of points on map imitation. Stevens & Coupe (1978) proved that the memory of points position is influenced by superordinate structures, such as polygons surrounding the points, causing memory distortion and recall errors. When comparing the relative position of two points, people tend to remember the relative position of the two polygons containing them rather than the points position. For example, on Figure 7, people tend to remember the point y being more to the left than the point x. This finding is confirmed later on by Tversky (1981), who also showed that people tend to make errors of alignment due to distortion in their memory, on both real-world maps and artificial maps. Additionally, Tory et al. (2009) proved with their experiment that people remember the position of points better when they are displayed on a dot display than on a 2D map imitation.

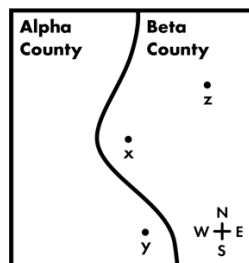


Figure 7 – Testing the memory of relative position of points in an incongruent condition, based on Stevens & Coupe (1978)

Taking into consideration these three major problems will be crucial in the process of creating the map imitation for this research. Several new ideas to get around these problems will be presented, for both the steps of spatialization and graphic design. Afterwards, these ideas will be tested in the user study.

## 2.7. Framework

Now that the important context has been set, this last section will summarize the key points and place this research in the framework.

First of all comes the question of the relevance of doing this research. As explained, there is a lack of research on the benefits and drawbacks of map imitation. Although there are many assumptions about potential benefits of representing data in that form, there is almost no user study proving it. On the other side, many problems have been proven, especially for the understanding and memorization of points position. However, it is still not clear yet how people perceive and understand a *complete* map imitation, composed of several layers. Moreover, as explained, spatialization is a technique allowing the analyze of complex data and the discoveries of implicit links which, however, comes with some issues, the main one being that it seems very complicated

for the readers to understand what the axes mean, and to go beyond the understanding of the distance-similarity metaphor.

Given all of this, this research's relevance can be justified in three main ways. Firstly, map imitations were mostly made for a limited range of topics and uses, and it is of interest to broaden the possibilities of use of this visualization type. Secondly, there is a need to explore ideas for creating map imitations which reduce confusion often experienced by people, in particular due to the spatialization. In this regard, the technique which will be used in this research is simpler: the data items will be positioned based on two variables, as on a scatter plot, as proposed by Hogräfer et al. who argue that “meaningful proximity can trivially be achieved by directly encoding two dimensions from the data in two axes of the visualisation” (Hogräfer et al., 2020, p. 650). It is assumed that this technique will diminish confusion regarding the meaning of the axes. Since the concept of *map imitation* is defined for this research as “map-like visualization of non-geospatial data, or geospatial data, created by plotting individual data items onto non-geospatial coordinates, and designed to resemble a map using cartographic elements”, the map imitation created for this research will remain fitting with this definition. Thirdly, there is a need to research the potential benefits and drawbacks of map imitation from the graphic design perspective. It will therefore be tested whether the design of the visualization influences how people perceive the topic and understand what is depicted, and what are the potential benefits and drawbacks of making a graph resemble a map.

According to the historical classification of map imitation, this study takes place in the most recent period, focusing on broadening the possibilities for using map imitation. This research aims on making map imitation a more democratized type of data visualization.



## 3. Design Workflow

Now that the framework is established, the map imitation can be created, guided by the RO.1 and RO.2 and in order to answer the corresponding RQ.1 and RQ.2. This chapter will give a comprehensive procedure on how the map imitation of this research is made, as well as how to think and design a similar map imitation for any subject. The chapter is divided in three sections: the first one will detail the preliminary steps and explain how to prepare the data; the second one will explain how to process the data in order to place the points in the plane and to generate the relief and will provide a Python script which makes both steps; the third one will explain how to design the visualization to resemble a map.

### 3.1. Preparation

First of all, the outline of the map imitation needs to be defined. Once the topic is chosen, datasets of good quality and of interest should be found and prepared. This section details the preliminary requirements, including data preparation.

#### 3.1.1. Preliminary Considerations

Before beginning the process of making a map imitation, it is necessary to determine if it is the suitable type of visualization for the selected subject and dataset. One aspect which makes map imitation an interesting visualization choice is the high number of variables that can be represented. Using the method proposed in this research, four variables can be depicted on the same visualization. It is therefore important to ensure that four interesting, high-quality variables are available and, furthermore, that representing them on the same visualization is relevant in two regards: the variables should have a semantic link between them, and plotting them together should reveal meaningful trends that motivate reflection and discussion.

#### 3.1.2. Company Constraints on Territories

In case the designer makes the visualization for a commercial company, which is the context of the map imitation of this research, he or she must consider supplementary factors in the process. Notably, the designer must follow the company's internal rules regarding countries and territories, as observed in the context of HarperCollins Publishers after discussions with J. Lennox and S. Shanks (personal communication, 2023). Any atlas publishing company has to make political decisions, such as which countries are recognized as independent, what borders are official and which are disputed, which names are used, and so on. The list of countries used by HarperCollins Publishers was used to create the map imitation of this research. As a general recommendation, when creating a visualization involving countries and territories in a commercial context, the designer should pay particular attention to the company's internal policy to avoid causing any legal problems to the company.

### 3.1.3. Data

With the company's requirements in mind, it is now time to search for data. Not all data can be used for a map imitation, only some types of data are usable for each variable. Moreover, the quality of the map imitation will highly depend on the relevance of the chosen data for the selected topic. Therefore, designers of map imitations are encouraged to spend time on researching and selecting interesting and high-quality data.

That being said, here are some guidelines for data selection. Five variables need to be selected, for the following elements: the horizontal  $x$ -axis, the vertical  $y$ -axis, the relief  $z$ , the colored areas, and the data points labels. As justified in Section 2.7, the axes  $x$  and  $y$  will not be based on a spatialization technique, but rather rely on two continuous variables that will be normalized. In case they follow an exponential distribution, they may need a logarithmic correction. For the map imitation of this research, the  $x$  variable is the country's greenhouse gas emissions per capita (Climate Watch, 2019; United Nations, 2019), which will receive a logarithmic correction, and the  $y$  variable is a score from 0 to 1 corresponding to the country's vulnerability to climate change (University of Notre Dame, 2019), based on its exposure, sensibility and ability to adapt to the negative impacts of climate change.

The relief will then be calculated following the method of Leuthold et al. (2007). With their method, the height of the relief is influenced by both the density of data items and a variable  $z$ . This  $z$  value can be any continuous variable. However, it is important to note that the resulting relief emphasizes high  $z$  values, depicted as mountains, while the lowest  $z$  values determine the shape of the island by fading into the ocean. It is therefore necessary to choose a variable in which higher values are of more interest than lower values. For example, population is an appropriate variable, as basing the relief on it highlights where a high number of people share similar characteristics, directing attention to where more people are affected. Population per country (United Nations, 2019) is the chosen  $z$  variable for the map imitation of this research.

Finally, areas of different colors will be created and it is necessary to consider what the colors will represent. As observed, the colors can either emphasize the relief, as on a topographical map, or show a categorical variable by mimicking a political map, which is the option chosen for this research. For better results, the categorical variable should have a low number of unique values. The variable chosen for the map imitation of this research is the classified income per capita provided by The World Bank, which classifies all countries in 4 categories (The World Bank, 2019).

Table 1 summarizes the usable types of data for each variable, with examples for geospatially referenced as well as for not geospatially referenced data. The aim of this table is to give concrete examples to generate ideas and motivation to create other map imitations.

Variable	Data type	Example (Geospatially referenced data)	Example (Not geospatially referenced data)
Labels	Nominal	Country names	Names of school children
$x, y$	Continuous	GHG emissions per capita, Vulnerability score	Average grade in mathematics, Average grade in English
$z$ (Relief)	Continuous	Population	Annual income of the parents
Areas	Nominal	Continent (Africa, Asia, Europe, Oceania, N. America, S. America)	Marital status of the parents (married, separated, divorced, widowed)
	Ordinal	Economic status (low, medium, high)	Highest education level of the parents (high school diploma, bachelor's degree, master's degree, doctorate)
	Discrete	Desertification risk (1-5)	Number of siblings
	Classified continuous (discrete)	Press freedom index (< 40, 40-70, 70-85, > 85)	Age (< 8, 8-10, 10-12, > 12)

Table 1 – Type of data for map imitation

## 3.2. Processing

Once the data is prepared, it can be processed in order to give the data items a position in the plane and to create a density surface which can then be designed as a relief. This section details both these steps. A Python script that performs these operations is available in the appendices.

### 3.2.1. Position in the Plane

As explained in Section 2.7, the position in the plane will be determined by two variables. It is easier to understand for the readers, because they can directly read the meaning of both axes, unlike axes showing scores of dimensionality reduction methods which can be difficult to interpret (Skupin & Fabrikant, 2007, p. 65). It is also easier to implement as it requires less data, less time and less statistical expertise, allowing more people to create their own map imitation.

To ensure that data points are centralized on the visualization, in order to create a convincing landmass,  $x$  and  $y$  variables need to be normalized. Normalizing data ensures it is on a similar scale, without modifying the relationships between data elements. The variables are normalized so that the minimum value is always 0.3, and the maximum 0.7. Having all values in this range ensures that the relief, generated in the next step, does not have  $x$  and  $y$  values lower than 0 or greater than 1, which corresponds to the chosen bounding box in which the layers will be exported. If the variables have an exponential distribution, a logarithmic correction can be applied to obtain a more homogenous point cloud. Both  $x$  and  $y$  variables are normalized using one of the following two formulas.

Without logarithmic correction:

$$f(x) = \frac{(b - a) * (x - x_{min})}{x_{max} - x_{min}} + a$$

With logarithmic correction:

$$f(x) = \frac{(b - a) * (\log_{10}(x) - \log_{10}(x_{min}))}{\log_{10}(x_{max}) - \log_{10}(x_{min})} + a$$

Where  $x$  is the value to be normalized,  $x_{min}$  and  $x_{max}$  are the minimum and maximum values of the variable,  $a$  is the new minimum value (0.3) and  $b$  is the new maximum value (0.7).

These new normalized  $x$  and  $y$  variables can now be considered as the ‘coordinates’ of the data items. These coordinates are used to place the points in the plane and will be used to generate the relief. The data points can then be exported as a georeferenced vector, such as Shapefile, ready for use in a GIS software.

### 3.2.2. Relief

Once the data items have new coordinates, the second layer that can be created is the raster which will then be visualized as a relief in a GIS. For map imitations, this raster is typically a smoothed density surface and several methods exist to generate one (Hogräfer et al., 2020). The method used in this research, proposed by Leuthold et al. (2007), is a logarithm that adds a weight to a kernel density. This means that the algorithm considers both the density of points and a variable  $z$  to determine the value of the generated surface. The visualized relief then shows where there is high density of data points with similar  $x$  and  $y$  values as well as great  $z$  values. The algorithm, textually described in their paper, has been translated into a usable Python script for this research.

The way the algorithm works is the following. As an input data, it needs three variables, one for each dimension of the relief. The variables  $x$  and  $y$  correspond to 2D coordinates of where each data point  $i$  is located, i.e. the normalized variables. The third variable  $z$  corresponds to the weight, which for the map imitation of this research is the country’s population, and will influence the height of the relief. The  $z$  variable can have a logarithmic correction to give different results.

Based on a resolution chosen by the user, which will define the number of pixels for each side of the raster output data,  $n$  meshgrids are created, where  $n$  corresponds to the number of data items. For each data point  $i$ , the  $z$  value is saved in the corresponding  $(x, y)$  pixel of the meshgrid  $i$ . Therefore, only one pixel per meshgrid has a value, the other pixels equal zero. Then, for each meshgrid, a two-dimensional Gaussian function is calculated with the following formula.

$$f(x, y) = \exp\left(-\left(\frac{(x - x_i) + (y - y_i)}{2\sigma^2}\right)\right)$$

Where  $x$  and  $y$  are each pixel’s coordinates,  $x_i$  and  $y_i$  are the coordinates of the original data point, and  $\sigma$  is a parameter chosen by the user to modify the shape of the bell.

Each meshgrid is saved in a list. They are then all summed, meaning that in the resulting meshgrid each  $(x, y)$  pixel is the sum of  $n(x, y)$  pixels. This resulting meshgrid is the final density surface. Figure 8 illustrates the algorithm.

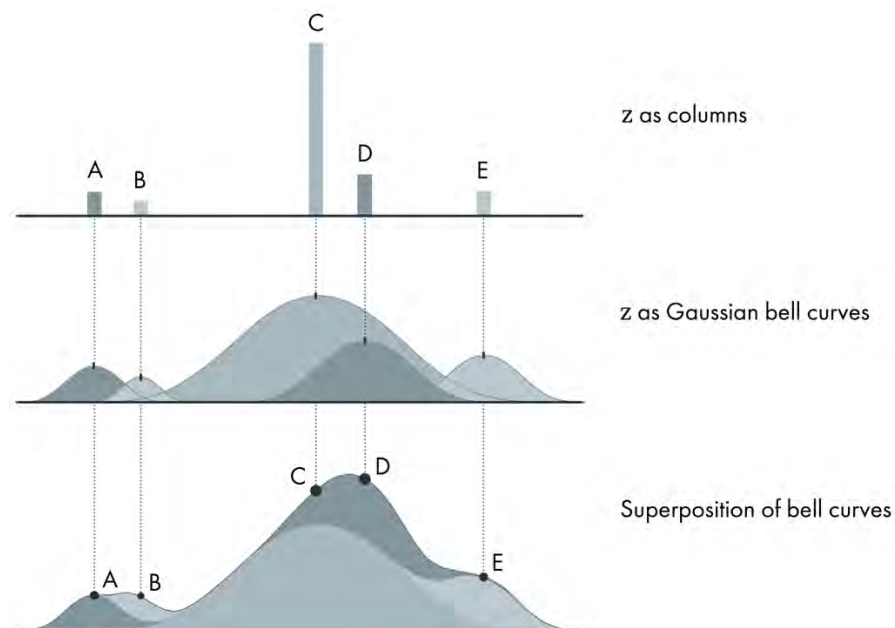


Figure 8 – Modelling of the density surface. Based on Leuthold et al. (2007)

The density surface can then be exported as a georeferenced raster, such as GeoTIFF, ready for use in a GIS software. The geographical position and projection of the raster do not correspond to any accurate geography, but having the same coordinate system for both the data point layer and the relief layer is a requirement to correctly overlap them.

Once imported in a GIS software, the shaded relief can be generated. The software used for this research is ArcGIS Pro from Esri, but other software can be used to achieve the same results such as the open-source QGIS. The shaded relief can be created using raster functions. It is recommended to set the sunlight on the top (*Why Does The Sunlight Come From The North In Shaded Relief Maps?*, n.d.), which is usually the default parameter. Additionally, contour lines can be created, which can help imitate the style of a map. Contour lines can easily be created from the density surface, using geoprocessing tools.

The commented and usable Python code for parts 3.2.1 and 3.2.2 is available in the appendices.

### 3.2.3. Ocean

The next layer that can be created is the ocean. As observed in literature, the ocean plays an important role in making the visualization resemble a map. It can be added by creating in a GIS a layer of 'water', which is then used to mask parts of the relief. To achieve this, firstly a square with at least the dimensions of the relief needs to be created. Then, a contour polygon needs to be generated from the density surface. Every value below the contour value will be covered by the ocean, meaning that the chosen contour value will determine the shape and the vastness of the metaphoric island. Once the contour polygon is generated, it can be erased from the square using an erase geoprocessing tool. The new polygon corresponds to the metaphoric ocean.

### 3.2.4. Areas

Finally, the last layer that can be created is the colored areas based on a categorical variable. Area generation based on a categorical attribute can be done by a large number of methods. The one proposed for this research is based on a geometric tessellation technique, using Voronoi polygons: "A Voronoi mesh partitions the view into cells by assigning all empty positions of the space to the data point closest to it." (Hogräfer et al., 2020, p. 653). A Voronoi (or Thiessen) tessellation can be generated from the data points, using geoprocessing tools. All attributes from the data points should be kept in the new polygons, where each Voronoi polygon corresponds to one point. The previously chosen categorical attribute can be used to symbolize the Voronoi polygons, assigning one color per attribute.

While this method allows the reader to accurately assign each data point to their categorical value, shown on the left of Figure 9, it poses problems for map imitation. Firstly, it does not yet help the reader to read any trend. Secondly, it is not realistic enough, as political boundaries are generally not as clear-cut. In order to address these two concerns, the idea proposed is to add two steps as shown on Figure 9, carried out in a graphic design software. Firstly, when a Voronoi polygon is surrounded by polygons of the same class, the polygon is colored the same as the surrounding class, and a small circle is added under the point corresponding to the Voronoi polygon. The purpose of this operation is to reveal trends. Secondly, the boundaries are manually modified by adding artificial details to make them more plausible, inspired by the user study of P. C.-I. Pang et al. (2016) which showed that details on the borders play an important role in making a visualization resemble a map. After both steps, each point is still on the color corresponding to its class, but the trends are more visible and the imitation is assumed to be more convincing.

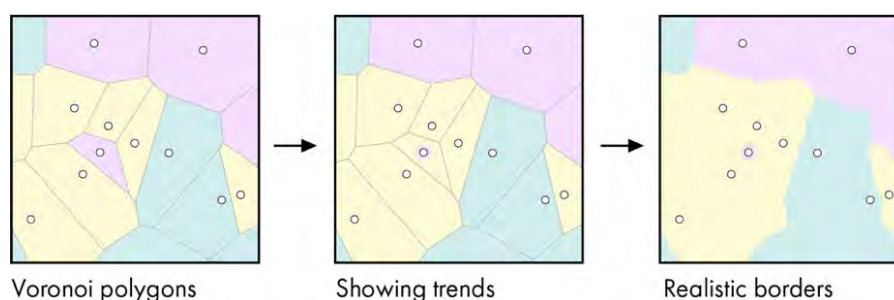


Figure 9 – Modification of the areas

### 3.3. Design

Once all the layers have been generated, they can be assembled and designed so that the visualization resembles a map. This section will start by introducing the design constraints that come when making a visualization for a company. Afterwards, it will explain how the different layers can be overlapped and how they can be designed in a graphic software. Then, suggestions will be made for supplementary surrounding elements to guide and help the readers of the map imitation. Finally, some recommendations will be given on how to achieve an efficient hierarchy of the different elements.

#### 3.3.1. Company Constraints on Graphic Design

As the design of the map imitation has started in a company, it is of interest to detail the constraints involved. Companies of a certain size that publish designs have their own corporate design guidelines, which then usually guide the production of any new design. These guidelines apply to every aspect of a design: colors, typefaces, sizes, layouts, etc. According to S. Shanks (personal communication, 2023), in the case of HarperCollins Publishers, the design depends on the book series. Times Atlas books share a common design: for example, the typeface used is Futura PT; the texts must be 100% black; colors are chosen from defined color schemes; and so on. It is therefore strongly recommended that designers working for a company are familiar with the company's design guidelines.

For the purposes of this research, the map imitation created does not follow the company's design guidelines, but is designed according to the needs of the research objectives. The version of the map imitation which is used by HarperCollins Publishers in the 16<sup>th</sup> edition of the Comprehensive Times Atlas of the World is in the appendices.

#### 3.3.2. Layering

Once all layers have been created, they can be overlapped in the GIS software. The layers should be overlapped as shown on Table 2, from top to bottom.

Layer	Generated from	Type
Labels	Data points	Text
Points	Data points	Points
Contour lines*	Density surface	Lines
Ocean	Density surface	Polygon
Shaded relief*	Density surface	Raster
Voronoi polygons*	Data points	Polygons
*optional layers		

Table 2 – Layering

Since the data points and the density surface have the same coordinate system, all the layers can be easily overlapped in the GIS software. The layers can either be exported individually in appropriate file types (all layers as vector type, e.g. SVG or PDF, except the shaded relief as a raster type, e.g. TIFF), or exported all at once as a PDF file, which will preserve the division of the layers.

### 3.3.3. Central Elements

Once the layers are correctly overlapped, they need to be stylized in order to make the visualization resemble a map. The software used in this research is Illustrator from Adobe, but other software can be used to obtain the same results, such as Affinity Designer from Serif, or the free and open-source software Inkscape.

#### A. Ocean

Usually in map imitation, the ocean is depicted as a shade of blue (Hogräfer et al., 2020). This practice is highly recommended, since the ocean plays an important role in making the map imitation look like a map, combined with the fact that it usually occupies a large portion of the layout. Changing the blue to a white color, for example, would make it look more like a traditional graph. The ocean also plays the role of the negative space, which makes the whole design 'breathe'. This space can be used to place the supplementary elements, such as the legend, title, etc. However, it is a good practice to keep enough distance between elements, to keep clarity, balance and readability, as explains the book *White space is not your enemy* (Hagen & Golombisky, 2017).

#### B. Labels

The labels can be automated directly in GIS. For this research, however, it was chosen to place them manually in the graphic software, allowing more freedom and case-by-case treatment. Some cartographic design rules were followed (Cron, 2021; Imhof, 1975).



- Start with the center of the map
- No labels may overlap
- Where possible, labels should remain inland, as there are no points on the coast.
- For each point, the corresponding label should be placed in position 1 if possible, otherwise 2, etc. according to Figure 10.

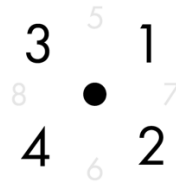


Figure 10 – Labels placement

Although these rules were most often respected, the manual placement of the labels left a certain amount of freedom, which was sometimes taken in order to place them in a way that was subjectively more visually appealing.

### C. Relief

The exported shaded relief is a grey scale raster file. Since it is using only one hue, it can easily be blended with the rest of the map using a blending mode, available in any design software. The blending mode chosen is 'Multiply' with an opacity of 70%. The relief layer is placed on top of the areas layer and masked by the ocean layer.

### D. Areas

For the inland areas, the colors should be chosen to resemble a map and be easily distinguishable. After several tries for the colors, the ones kept are beige and green, which are colors that look 'natural', evoking sand and forests. The two lowest categories are represented in two shades of beige, the two highest in two shades of green. This choice was made because it is assumed that people may associate dry sand with poverty and verdant forest with wealth.

### E. Symbols

As on the map imitation of Hermann & Leuthold (2003), different symbols can be used to represent the z-value of data elements, also represented by relief. This allows the reader to know more precisely the z-value of each element, in this case the population of each country. The countries were therefore classified in five categories, with familiar thresholds. Each category is represented by a symbol and a specific font and size. With such a large number of labels (almost 200), variation in size is crucial to improve legibility. A minimum size of 5 pt has been defined.

### **3.3.4. Surrounding Elements**

The core of the map imitation is now complete. However, some surrounding elements can be added to guide readers. These elements are inspired by map imitations from the 17<sup>th</sup> and 18<sup>th</sup> centuries.

#### **F. Texts**

The map itself cannot be understood without explanatory elements. Firstly, a title should be added and should remain short and simple, while conveying a message. 'Emissions per capita' is summarized by 'Responsibility', with deliberate bias to quickly interest the reader and to imply that the map denounces the countries mainly responsible for climate change. The year of the data is indicated as a subtitle. A small explanatory was added to help the reader understand it what is depicted. Data and authorship are indicated as well.

#### **G. Compass rose**

An element which has not been observed in recent map imitation is the compass rose. This element is proposed in this research as a way to make the visualization easier to understand by using this common cartographic element to summarize the meaning of the horizontal and vertical axes. This idea was motivated by the fact that it was difficult for many people to find the names of the variables on the map imitation of Hermann & Leuthold (2003), which are placed on the borders. During the production of the map imitation in this research, the fake compass rose was found to be very useful by many people.

#### **H. Legend**

Finally, a legend can be added to explain the other variables: population (relief), population (symbols), and income (colors). For the last two ones, the legend was designed in a traditional way. Designing a legend for the relief was more challenging, as the relief usually created a lot of confusion for the people reading previous versions of the map imitation. Several legends were tested, including an explanatory text, a visual explanation and a combination of the two. The last option was chosen because it enabled a greater number of people to understand the relief. A section of the relief is shown, with examples of 'low' and 'high' density, and a text summarizes the concept. A balance had to be found between the need to explain such a unique and difficult use of a shaded relief and the simplicity that a legend needs to preserve, partly because of the limited space available.

### **3.3.5. Visual hierarchy**

Hierarchy of information is maybe the most important aspect when designing a data visualization. With a well thought visual hierarchy, the designer can indirectly guide the readers' eyes to what he or she wants (Hagen & Golombisky, 2017, p. 77). In order to achieve a good visual hierarchy, the first step is to rank all elements based on their importance for understanding the visualization.

- Very high importance: Title, Ocean/Land, Compass rose
- High importance: Date, Explanatory text, Legend, Labels, Symbols, Areas
- Intermediate importance: Relief, Grid, Axes values & names
- Low importance: Data source, Authorship

Once the ranking is made, the design must be based on it. Visual hierarchy can be achieved using different parameters, such as position in the layout – people tend to read the top first – as well as size, color, contrast, negative space around it, etc. (Hagen & Golombisky, 2017, p. 77). For example, the compass rose is designed with a lot of space around it, which is a way to highlight it, and is large relative to the overall layout. Another example is the relief, the purpose of which is mainly to make the visualization resemble a map and not to give precise information, since more accurate information about the population can be found using the symbols. The relief is therefore subtle, so as not to draw the reader's attention too much.

### 3.4. Summary

Table 3 summarizes the steps previously explained and serves as a comprehensive procedure for creating a map imitation.

Section	Objective	Steps	Software
Preparation			
3.1.1	Considering the visualization choice	Are variables linked semantically? Will representing them together motivate discussion?	
3.1.2	Considering company constraints	What are the internal policies of the company for countries and territories?	
3.1.3	Selecting data	Labels (nominal) $x, y$ (continuous) $z$ (continuous) Areas (nominal, ordinal, discrete, classified continuous)	
Processing			
3.2.1	Normalizing $x$ and $y$	Normalization of both variables to a common range Optionally, application a logarithmic correction	Python
3.2.2	Generating relief based on $z$	Calculation of a density surface with a weight ( $z$ ) Density surface used as a DEM Generation of a shaded relief and contour lines	Python, GIS
3.2.3	Generating the ocean	Generation of a polygon masking low DEM values	GIS
3.2.4	Generating the areas	Generation of a Voronoi tessellation Aggregation of certain Voronoi polygons Addition of details on borders	GIS, Graphic software
Design			
3.3.1	Considering company corporate design	Identification of colors, typefaces, layout, etc.	
3.3.2	Layering	Overlapping all the layers	GIS
3.3.3	Designing central elements	Edition of the layers to make them resemble a map	Graphic software
3.3.4	Designing surrounding elements	Addition of fake cartographic elements to guide the readers	Graphic software
3.3.5	Adjusting the visual hierarchy	Edition of elements to give them appropriate visual weight	Graphic software

Table 3 – Comprehensive procedure for creating a map imitation

### 3.5. Proposed Map Imitation

Figure 11 is the final version of the map imitation of this research.

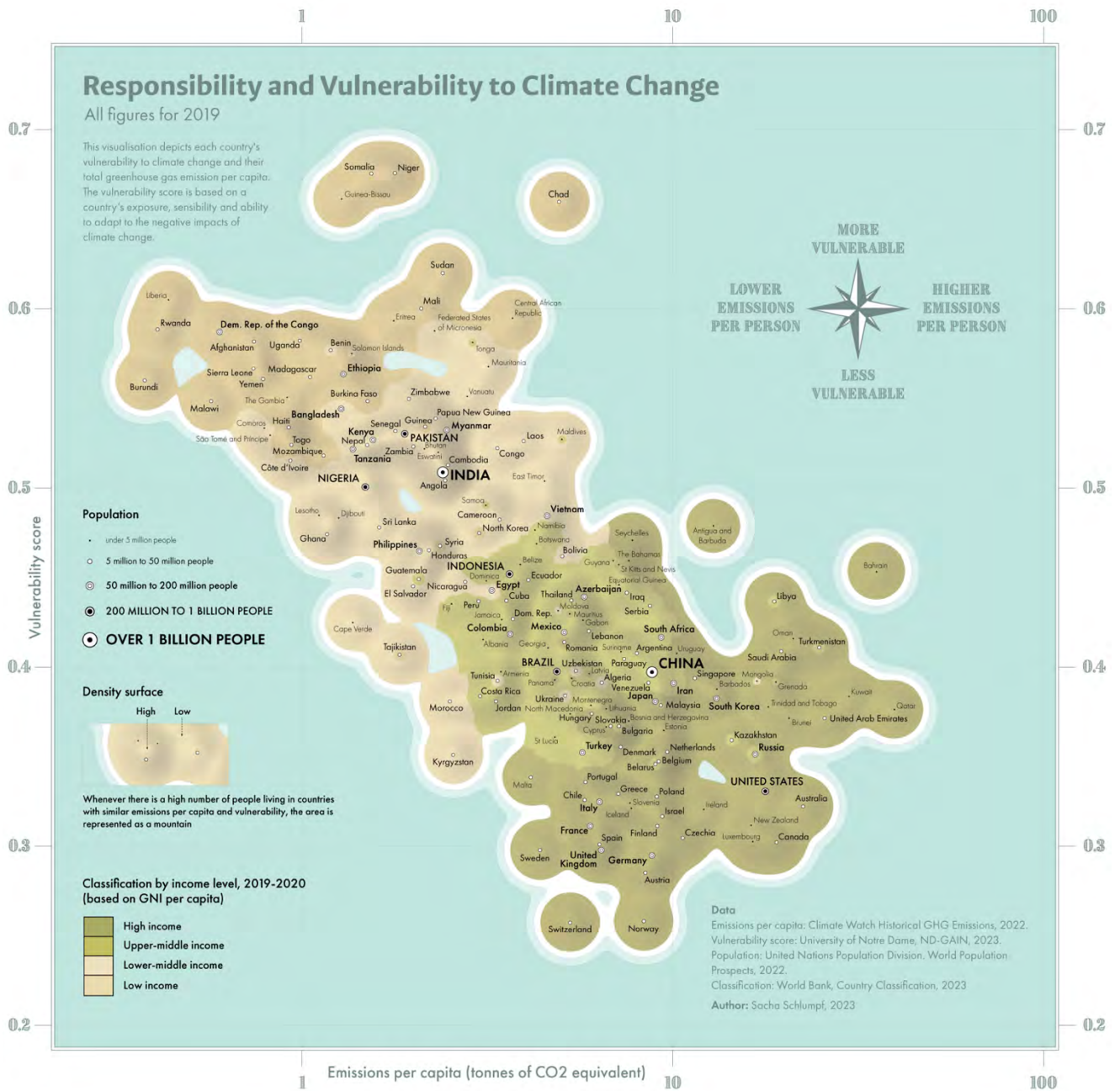


Figure 11 – Proposed map imitation



## 4. Methodology

Now that the map imitation is created, with its step-by-step procedure being detailed, it can be tested with a user study. As stated in the RO.3, and in order to answer the corresponding RQ.3, the objective is to test how the resemblance of the visualization to a map influences the people's perception and understanding of the data depicted. To achieve this, two online surveys will be created, having the same questions but different visualizations. One will include the proposed map imitation, while the other one will include a version without any cartographic element. Comparing the results of both surveys will allow to measure the potential benefits and drawbacks of the map imitation.

This chapter will first describe how the graph version of the map imitation was conceived. The next section will explain how the surveys were created and structured, detailing the contents and purpose of each part. Finally, the last section will explain how both surveys were shared in order to reach participants.

### 4.1. Graph Version of the Map Imitation

In order to discover how the design of a map imitation influences readers' perception and understanding, it is necessary to compare it with a more traditionally designed graph (Figure 12). To do this, every cartographic element was removed: the ocean, the relief, the lakes, the polygons, the compass rose, and the frame. Every other element was kept, in the exact same location, so that the results can be compared effectively.

The only major change that was made concerns the visualization of the 'income per capita' variable. As the colored areas appearing on the map imitation in the background of the labels were considered to be a cartographic element, they were removed and another visualization had to be chosen to represent this variable. On the graph, the points and labels themselves are then colored. The colors were chosen to be easier to distinguish because the area where the colors appear is much smaller than on the imitation map. The legend was modified accordingly.

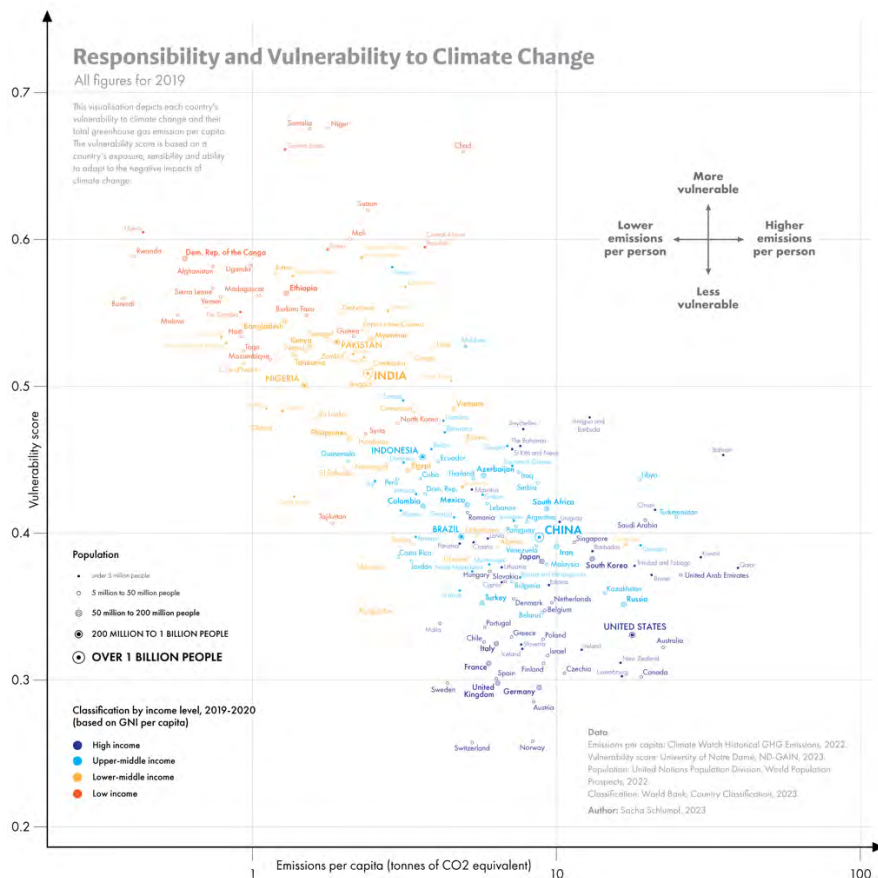


Figure 12 – Graph version of the map imitation

## 4.2. Conception of the Surveys

The website chosen to create the survey is Survey123 from Esri. It provides everything needed for the purposes of this user study: all the necessary types of questions are there, as well as the support of multiple languages and screen sizes.

Two surveys needed to be created, with the same questions but accompanied by a different visualization – the map imitation or the graph. For the sake of simplicity, the survey that includes the map imitation will be called the *Map Survey*, while the other is called the *Graph Survey*. The surveys mix both quantitative and qualitative questions. After a brief introduction that presents the context of the study to the participant, the visualization is presented and the participant is encouraged to take the time to understand it.

The next part, part A, asks 5 Likert scale questions (6 in the Map Survey) which focus on what the participants think about the visualization in general, with four possible answers from 'Strongly disagree' to 'Strongly agree'. This allows to understand how people perceive the map imitation and to gather general opinions. Since the questions are of a broad nature, it is assumed that this part is not discouraging for the participants, which is an important aspect to consider when designing a survey. In the same part, a final open question allows participants to indicate if there is anything specific that they do not understand in the visualization. Finally, in the Map Survey,



participants are asked to indicate whether they have already seen the visualization, in case they know the author personally.

In the next part, part B, the participants are asked 4 open questions (5 in the Map Survey). In this part, the visualization is no longer shown and participants are asked not to go back in the survey. The questions focus on general understanding of the visualization. The aim is to test the influence of the design of the visualization on participants' short-term memory and understanding. The additional question in the Map Survey is designed to check whether the participants understand the meaning of the relief.

Then, part C aims to check whether participants really understand how to read the visualization by asking them specific questions. This part requires a way in which the questions can only be answered by understanding the visualization. For this reason, it was necessary to replace the real country names with fake names (Figure 13). Otherwise, people might assume answers based on their knowledge of the world. For example, to the question "Between Qatar and Norway, which country pollutes more (per capita)?" some participants might try to answer without looking at the visualization. To generate these fake names, the natural language processing model ChatGPT was used with the following prompt: "Generate 7 fake country names, each starting with a corresponding letter of the alphabet". The fake names are the following: Albora, Belmar, Caeloria, Duskar, Elysium, Floriana and Galdoria. The map imitation and graph with the fake names can be found in the appendices.

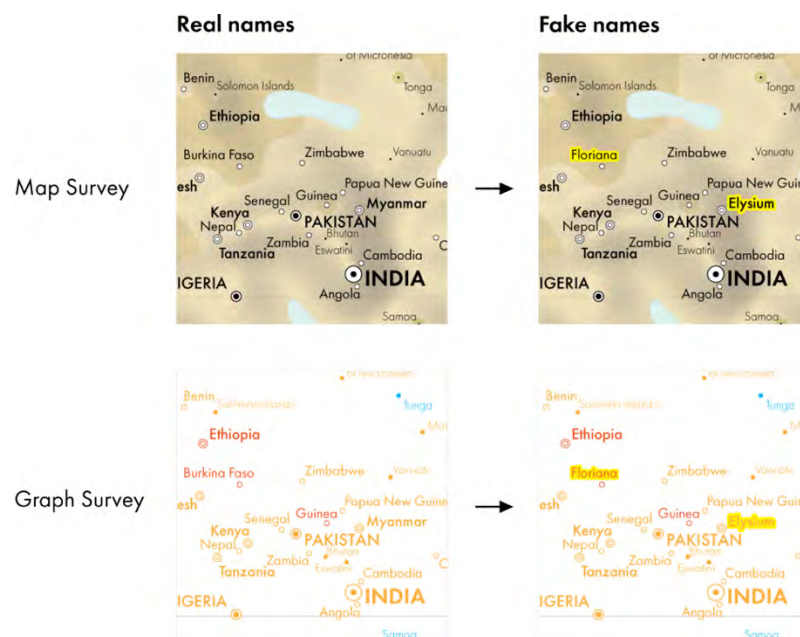


Figure 13 – Fake names

The final part asks personal questions about the age, gender, background and color blindness, which helps knowing what biases the participants might have and seeing whether the distribution of participants between the two surveys is satisfactory.

Table 4 summarizes the different parts of the surveys.

Part	Objective	Question types	With the visualization
Introduction	Giving context to the participant	None	No
First look	Encouraging the participant to spend some time discovering and understanding the map imitation/graph	None	Yes
Part A	Testing the perception, gathering general opinions	5 Likert scale questions (+1 in Map Survey) 1 open question (1 yes/no question in Map Survey)	Yes
Part B	Testing the influence on short-term memory & understanding	4 open questions (+1 in Map Survey)	No
Part C	Testing the precise understanding	10 questions with correct/wrong answers	Yes (fake names)
Personal information	Gathering demographic data	4 questions + 1 voluntary comment	No

Table 4 – Content of the surveys

### 4.3. Publishing the Surveys

To broaden the reach of the surveys, they have been translated into French, including the map imitation and the graph. The French versions of the map imitation and the graph can be found in the appendices. The language of the surveys could be changed between English and French at any time.

A single link was created which randomly redirected people to one of the two surveys. This link could easily be shared on social media and was accompanied by a text pretending that there was only one survey. It was important that people did not know that there were two surveys to avoid the same person taking both surveys. The link was shared on LinkedIn, Instagram, Facebook and WhatsApp, with accompanying texts in English, French or both languages, depending on the main audience.

## 5. Results

After being online for two weeks, the surveys provided interesting results. This chapter presents the results of both surveys, each section presenting a specific part. The results of both the Map Survey and the Graph Survey will be displayed side by side to allow comparison.

For parts A, B and C of the surveys, the differences between the map and the graph will be tested statistically using the Two-Proportion Z-test. The  $\alpha$  level chosen is 0.05. The hypotheses are the following.

$H_0$ : The proportions in the two surveys are equal ( $\mu_1 = \mu_2$ ).

$H_1$ : The proportion in the Map Survey is higher/lower than in the Graph Survey ( $\mu_1 > \mu_2$  or  $\mu_1 < \mu_2$ ).

The alternative hypothesis  $H_1$  is adjusted to 'higher' or 'lower' depending on which proportion is higher. Each test yields a p-value, which will then be compared to the chosen  $\alpha$  level. If the p-value is less than  $\alpha$ , the null hypothesis  $H_0$  is rejected. In this scenario, the alternative hypothesis  $H_1$  is considered to be valid. In concrete terms, when the p-value is lower than 0.05, this will mean that there is a significant difference – considering the sample size – between the results of participants with the map imitation and participants with the graph. In these cases, the corresponding results will be flagged and analyzed in more detail in Section 6.1.

To simplify, the term 'visualization' will denote both the map and the graph when necessary. All results are rounded off to 1 decimal point, except for p-values, which are rounded off to 3 decimal places.

### 5.1. Demographics

First of all, it is relevant to know what characteristics the participants have. This section provides demographic information on the participants based on what they responded in the surveys' last section.

The surveys were published on July 6, 2023, and closed on July 21, 2023, meaning they were online for 15 days. In total, 111 people completed a survey, 55 completed the Map Survey and 56 completed the Graph Survey. Twelve participants of the Map Survey had seen the map or a previous version of it before the survey, representing 21.8% of participants of the Map Survey.

### 5.1.1. Age

Participants are between 20 and 75 years old. For both surveys, the median is 27 years old. The fact that mostly younger people took part in the survey was expected, since the surveys were shared on social media. The third quartile is higher for the map than for the graph (Figure 14).

## Age

Range and quartiles

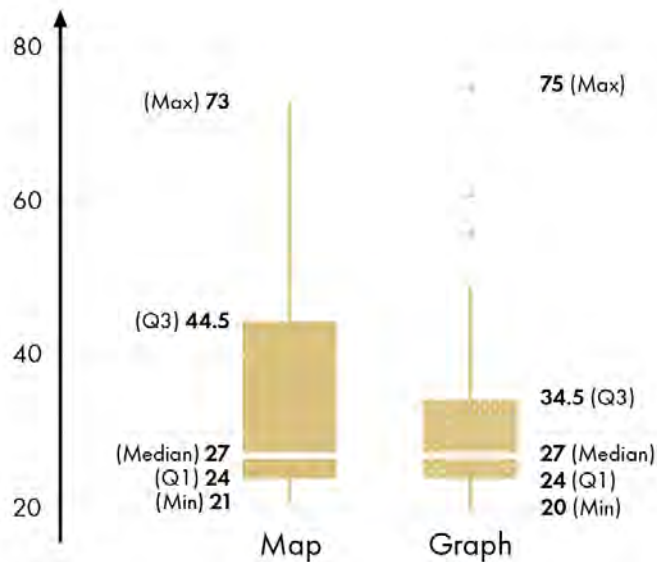


Figure 14 – Results, Age

### 5.1.2. Genders

The distribution of genders is similar in both surveys. About half women and half men took parts in the surveys, as well as 3 non-binary persons (Figure 15).

## Genders

Distribution

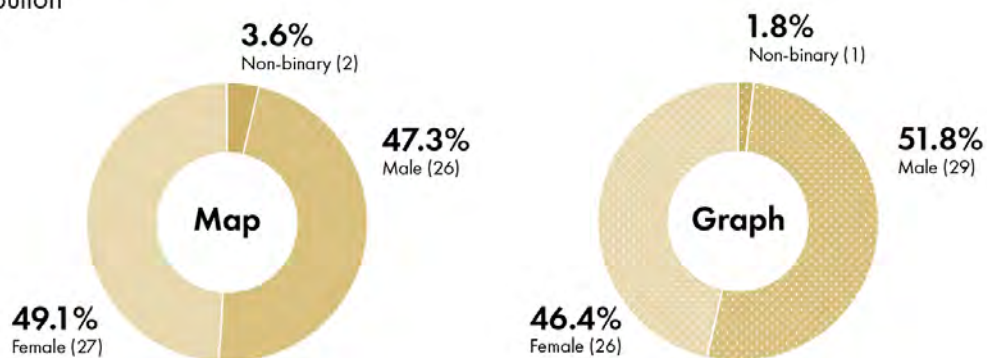


Figure 15 – Results, Genders

### 5.1.3. Background

The participants were asked if they had a background in one or many of these fields: 'Cartography, GIS, Geography, or related', 'Data analysis, Statistics, or related', 'Data visualization, Information design, or related' and 'Graphic design'. A fifth option was: 'None of the above'.

The majority of participants have a background in cartography (or a related field), which can be attributed to the way the surveys were shared. It is noteworthy that 20% of participants in the Map Survey and 32.1% of participants in the Graph Survey do not have a background in a field related to this research. Only few participants have a background in Graphic Design (Figure 16).

## Background

Selected fields

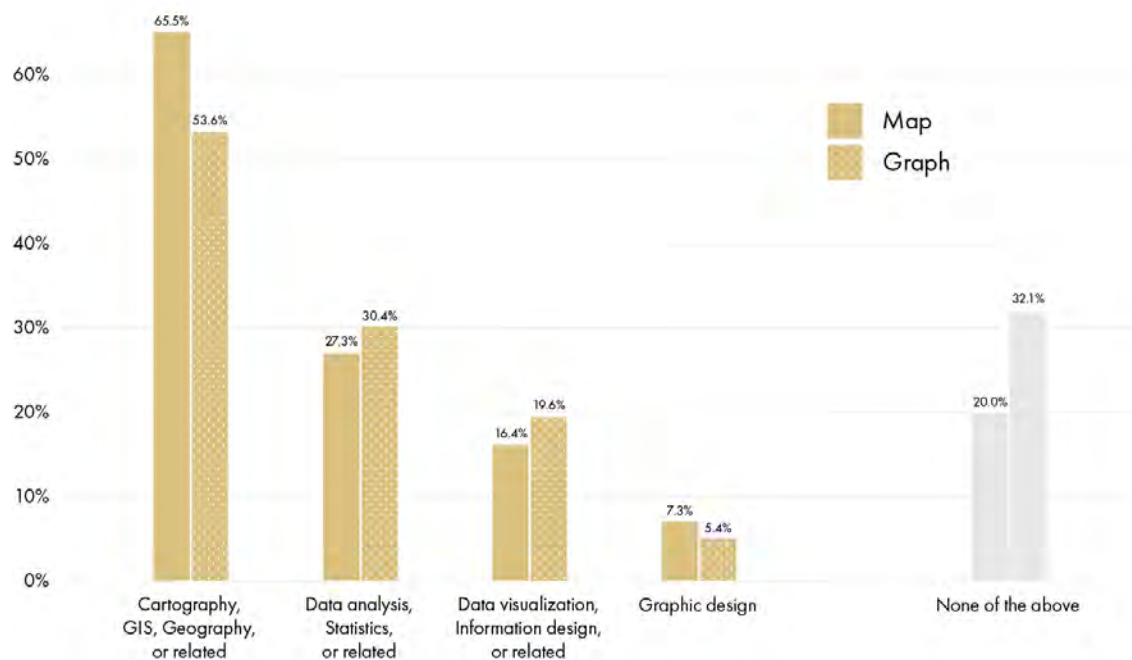


Figure 16 – Results, Background, Selected fields

While most participants reported having a background in one of the related fields, some selected multiple categories, with three participants having a background in all related fields (Figure 17).

## Background

Distribution

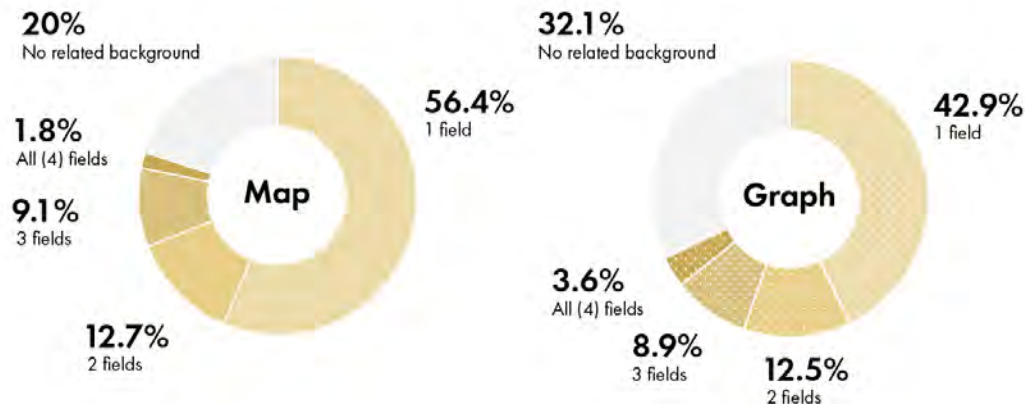


Figure 17 – Results, Background, Distribution

In general, the participants were mostly young and educated in fields related to the study, which could have influenced the results.

### 5.2. Part A

The Part A, which was presented to the participants after they had spent some time reading and understanding the visualization, contained general questions about the visualization.

#### 5.2.1. Questions A.1 to A.6

The first 5 questions were Likert scale questions and participants could check one of four answers: 'Strongly disagree', 'Disagree', 'Agree', 'Strongly agree'. An additional question (A.6) of the same type was asked only in the Map Survey. All questions were general questions, aiming to know the participants' perception of the visualization.

Possible biases for this set of questions must be acknowledged. The participants were aware that the visualization and the survey were made by the same person, which may have influenced them to respond with a more positive outlook. Moreover, since the surveys were shared in a way that many participants knew the author personally, responses could have been biased towards more positive answers.

The results are summarized on Figure 18.

## Part A

### Distribution of answers

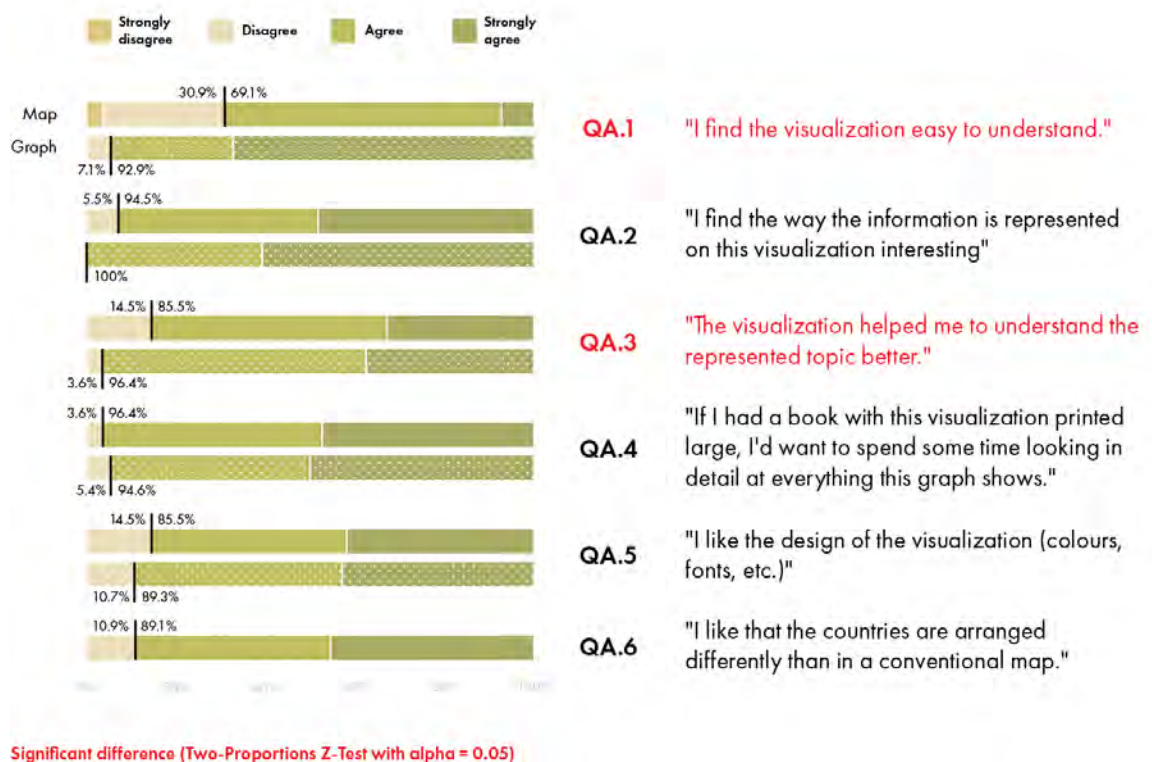


Figure 18 – Results, Part A

Questions A.1 and A.3 point out a statistically significant difference between the map and the graph. The results of question A.1 demonstrate that the participants found the graph easier to understand than the map. This particular question, for the map, also has the highest rate of participants disagreeing, and is the only one where participants expressed a 'Strongly disagree' response. In contrast, for the same question, the graph got two thirds of 'Strongly agree'. According to the results of the question A.3, the graph was more effective than the map in aiding participants' understanding of the topic. These significant differences will be analyzed in more detail in Section 6.1.

Questions A.2, A.4 and A.5 did not show any significant differences between the map and the graph. Question A.6 reveals that around 9 out of 10 participants found the concept of the map imitation interesting, in comparison to a conventional map.

Except for question A.1 in the Map Survey, all questions received at least 85% of positive responses. This can be interpreted as indicating that participants generally had a good experience with both visualizations, but this interpretation should be treated with caution given the possible biases.

### 5.2.2. Question A.7

In the end of Part A, the participants had a chance to mention if there was something they did not understand on the visualization. Figure 19 presents how many times each aspect was mentioned.

#### Question A.7

"Is there anything you don't understand on this visualization? If yes, what?"

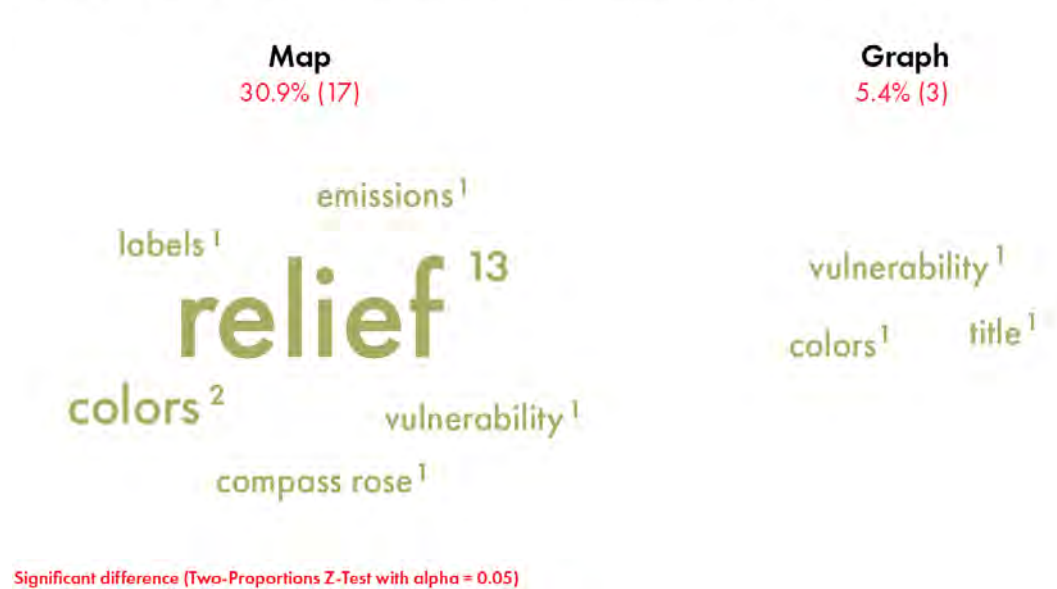


Figure 19 – Results, Question A.7

There is a statistically significant difference between the two visualizations, a higher number of participants mentioning an aspect which they did not understand on the map imitation than on the graph. It appears that the graph did not pose major understanding difficulties, with only 3 participants mentioning an aspect they did not understand. The map imitation seems less intuitive, with one layer that appears to be especially confusing for the participants: the relief, mentioned by 13 people. This will be analyzed more in detail in Section 6.1.



### 5.3. Part B

In the Part B of the surveys, participants could not see the visualization anymore and instructed not to go back in the survey. They had to respond to 4 questions (5 in the Map Survey) about the visualization they saw. The questions were open-ended, allowing participants to write as much as they wished.

#### 5.3.1. Question B.1

The first question was: *"In one sentence, what message do you take away from this visualization?"* The objective was to examine the impact of the visualization type on what the participants can recall and how they choose to summarize it. Here are a few examples of some recurrent responses.

*"The map shows the vulnerability of countries concerning climate change (e.g. how affected countries are by consequences of climate change) and also their contribution to climate change".* Some answers, like this one, provide a detailed and explicit description of the two major concepts, the 'vulnerability' and 'emissions per capita' variables, that determine the position of the countries on the visualization.

*"How vulnerable some countries are to climate change effects, and how the emissions are distributed on a per capita basis."* Some participants cited both main variables, but did not establish a casual connection between them.

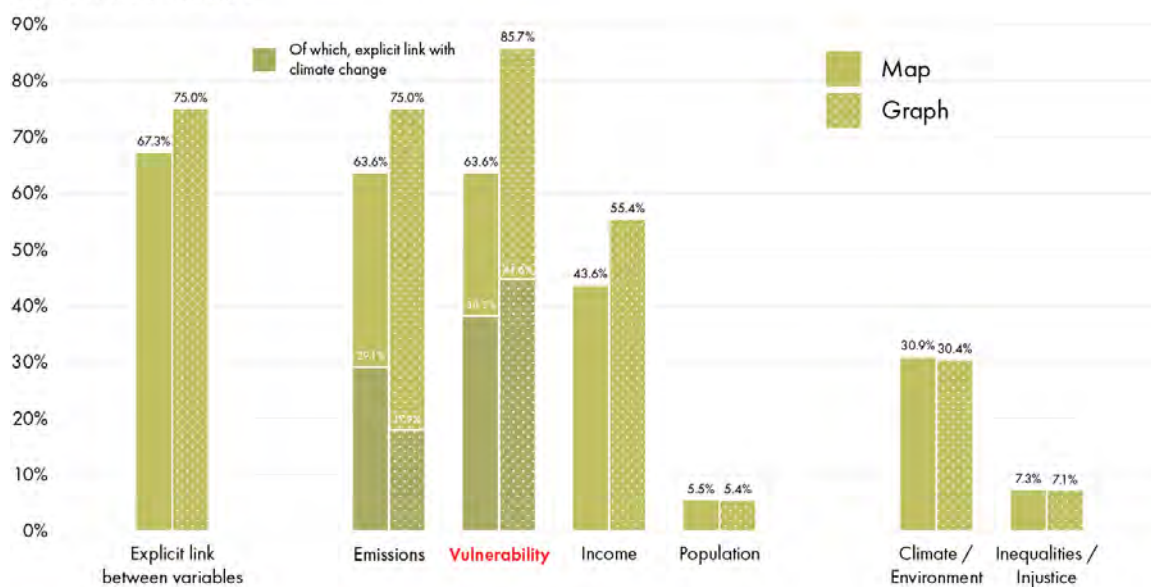
*"The world's not fair."* Some answers emphasized the inequalities as a main message of the visualization.

Figure 20 summarizes all responses. Each answer has been linked to one or several mentioned concepts. For the variables 'emissions' and 'vulnerability', dark green color indicated that the participant specified that emissions are a cause of climate change and/or that vulnerability is a consequence of climate change.

## Question B.1

"In one sentence, what message do you take away from this visualization?"

Occurrence of main concepts



Significant difference (Two-Proportions Z-Test with alpha = 0.05)

Figure 20 – Results, Question B.1

Only the occurrence of the 'vulnerability' variable shows a significant difference between the map and the graph. This variable is one of the two main ones of the visualization, and is not visualized as commonly as emissions per capita. For these two reasons, it was expected that participants would mention it in their response. Although 85.7% of the participants mentioned it for the Graph Survey, only 63.6% mentioned it in the Map Survey. This will be analyzed in the Section 6.1.

The other two variables, 'income' and 'population', were mentioned less frequently than the two main ones. Around 30% of participants mentioned climate change or the environment in their responses, with no significant difference between the two visualizations. Notably, around 7% of the participants in both surveys mentioned inequalities between the countries, with some responses expressing political opinions.

### 5.3.2. Question B.2

The second question of part B was: “If a country is on the top-left of the map, what does that mean?” The actual meaning of a country located on the top-left is that its emissions per capita are low, and that its vulnerability is high. Additionally, these countries generally have lower income per capita. Although this is not directly determining the countries’ location on the visualization, it is a relevant observation. The results are summarized on Figure 21.

### Question B.2

“If a country is on the top-left of the visualization, what does that mean?”

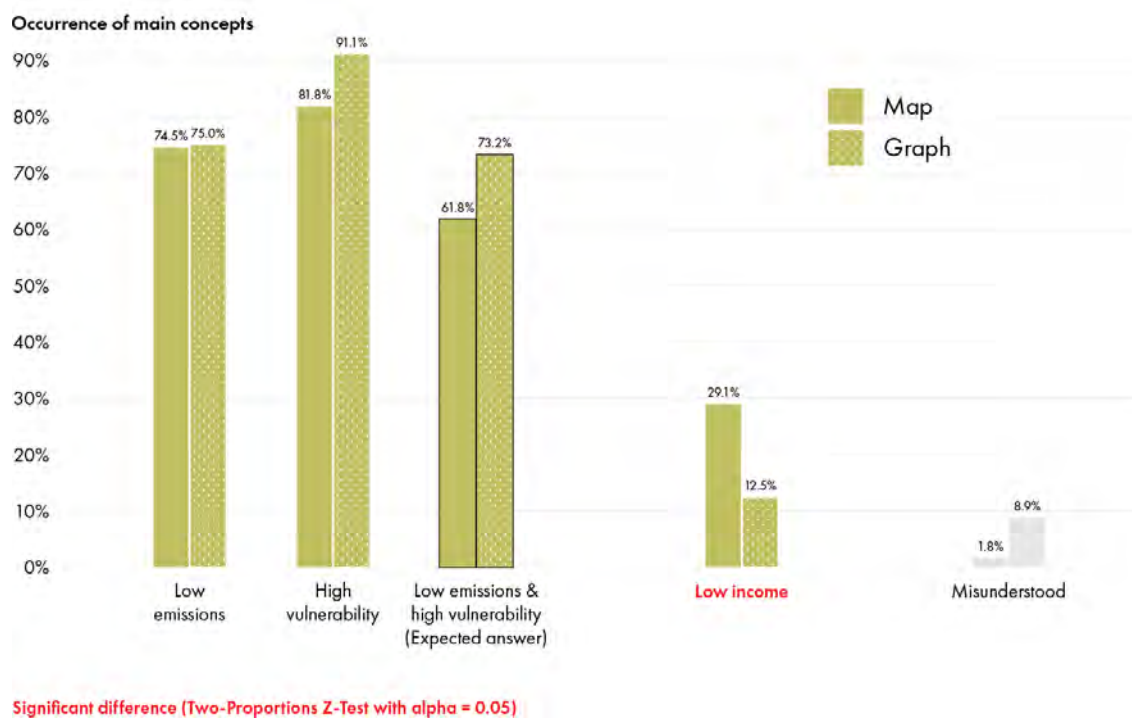


Figure 21 – Results, Question B.2

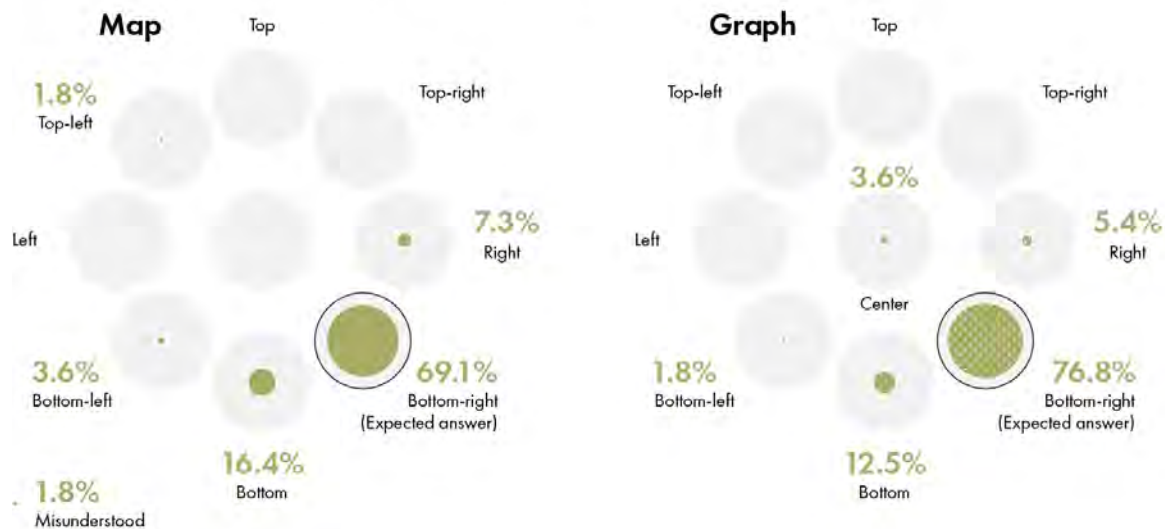
Approximately two thirds of the participants provided the expected answer, with no significant difference between the map and the graph. However, significantly more participants responded that if a country is located on the top-left it means it has a low income per capita. Although this is not what determines the location of countries on the visualization, it is a fact that most countries with low emissions per capita and high vulnerability have a lower income per capita. It is worth noting that this observation appears more frequently after reading the map than the graph. This will be analyzed in Section 6.1.

### 5.3.3. Question B.3

The third question of the Part B was: “Where on the visualization are the rich countries generally located?” As both visualizations show, rich countries are usually those who emit more greenhouse gas per capita and who are less vulnerable to climate change, which positions them on the bottom right of the visualizations. Therefore, an answer saying ‘bottom right’ or ‘south-east’ was expected. The results are summarized on Figure 22.

## Question B.3

“Where on the visualization are the rich countries generally located?”



Significant difference (Two-Proportions Z-Test with alpha = 0.05) – None

Figure 22 – Results, Question B.3

There is no significant difference between the map and the graph. It is, however, worth noting that with both visualizations, most participants were able to identify and remember the general location of rich countries.

#### 5.3.4. Question B.4

Question B.4 was: “How can you recognize a densely populated country on the visualization?” After reading the responses, it was realized that this question was poorly worded. The aim of this question was to see if the participants understood how to read the ‘population’ variable and, for participants who had the map imitation, to see which visual variable they were relying on between the symbols and the relief. However, for better results, the word ‘densely’ in the question should have been ‘highly’. Some findings can still be drawn from the answers (Figure 23).

### Question B.4

“How can you recognize a densely populated country on the visualization?”

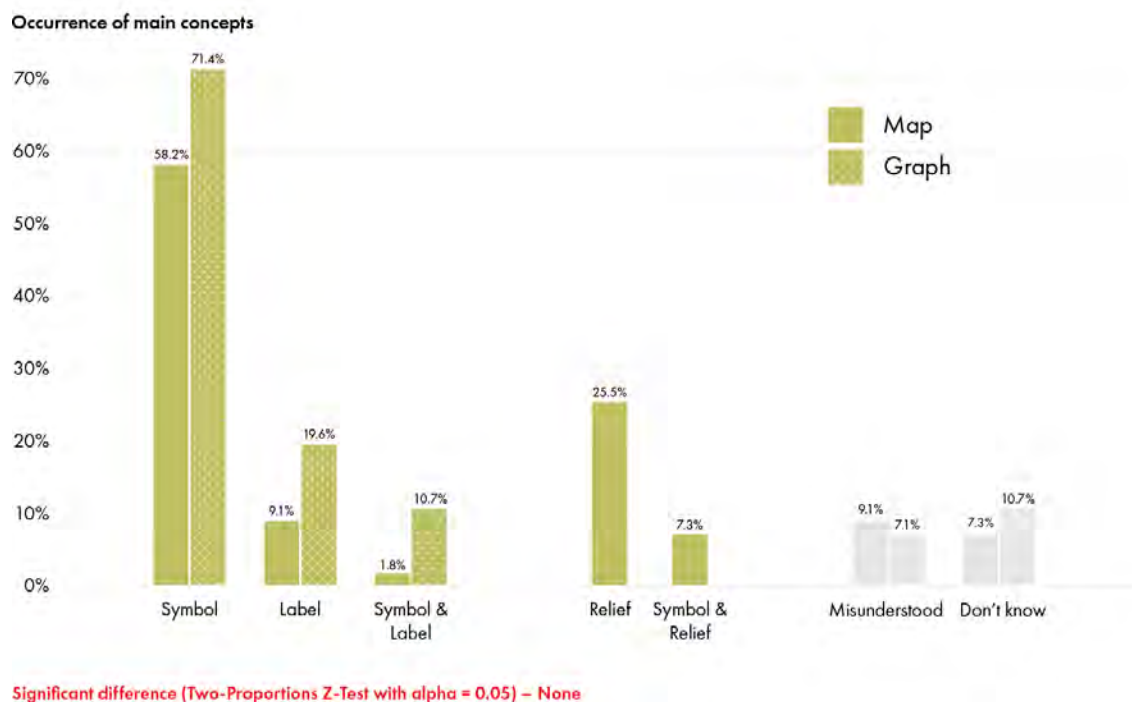


Figure 23 – Results, Question B.4

There is no significant difference between the results of the two surveys. A similar proportion of participants mentioned the size and type of symbols and labels. Interestingly, 25.5% of participants in the Map Survey mentioned the relief, even though the relief does not show how densely populated the countries are. This contributes to the finding that the relief was a difficult variable for participants to understand and interpret. This will be analyzed in more detail in Section 6.1.

### 5.3.5. Question B.5

Question B.5 was only asked in the Map Survey. Since the relief is an uncommon visual variable, and something specific to the concept of map imitation, it was necessary to examine if the participants understood how to read it. The question was: “What does the relief represent?” (Figure 24).

### Question B.5

“What does the relief represent?”

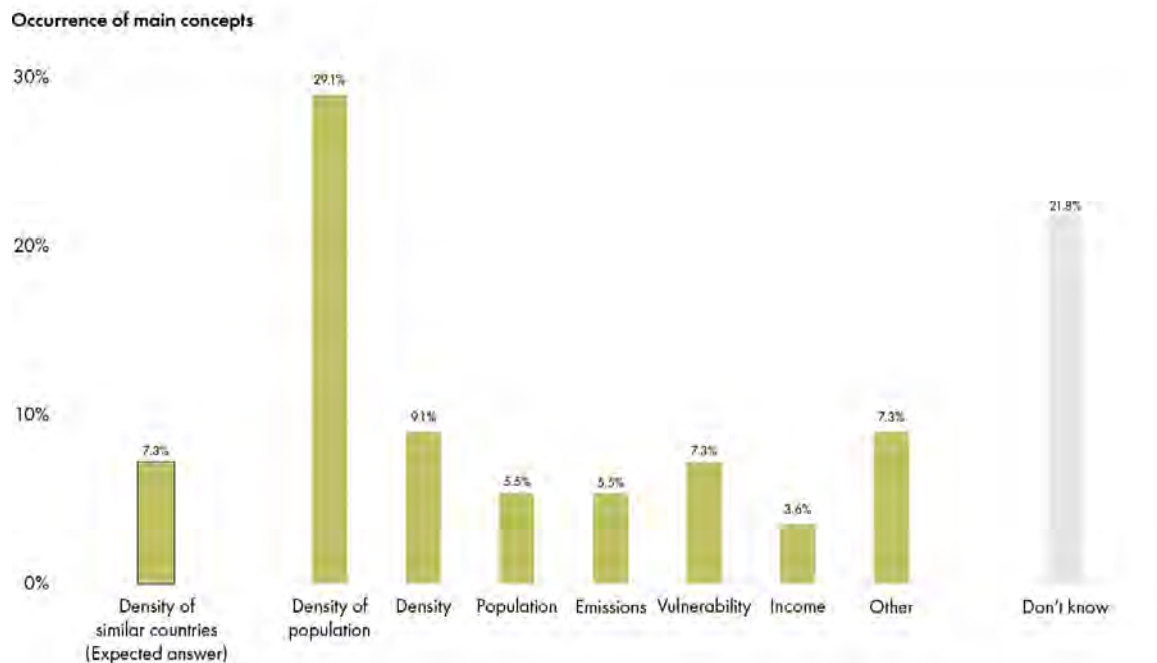


Figure 24 – Results, Question B.5

Only 7.3% of the participants answered correctly by explaining that the relief shows where there is a high density of countries with similar conditions. 9.1% of participants answered that it shows density, without specifying. The most common answer, with 29.1%, was that the relief represents population density. 21.8% of participants answered that they did not know, making this the question with the highest percentage of people who did not know. It can therefore be argued that the relief of this map was not understood by the participants, which will be argued in more detailed in Section 6.1.

## 5.4. Part C

In the Part C, participants were asked to answer 10 questions that could only be answered by understanding the visualization. The objective is to test whether the participants truly understand how to read it. The results are summarized on Figure 25. The results with the questions are shown on Table 5.

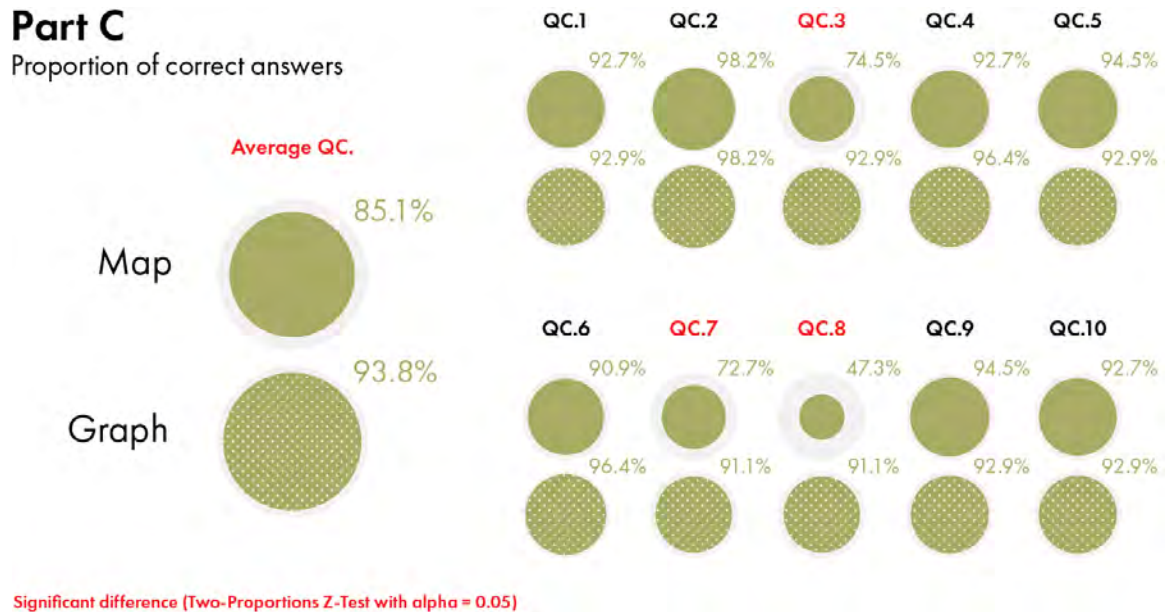


Figure 25 – Results, Part C

Three questions have significantly different results between the map and the graph, as well as for the overall average of all 10 questions. Questions C.7 and C.8 were about the income per capita, which was visualized with colors. The colors were different on both visualizations. On the map, they were chosen to make the visualization resemble an island using beiges and greens. The two beiges and two green colors appear more similar to each other on the map than on the graph, which was possible due to the large surface where colors appeared. On the graph, colors were chosen to be easily discernible, considering the small size of the symbols. This disparity between the map and the graph seems to have led to significant errors of understanding. The answer to the question C.3, however, could be found in the same way on both the map and the graph, as it referred to the position of the countries on the visualization. The map imitation resulted in more incorrect responses to this question, at 74.5%, as opposed to the graph with an accuracy of 92.9%.

The average of 93.8% of correct answers to the graph can be considered a good score. On the other side, the map leads to more problems of understanding, with a score of 85.1%. This will be analyzed in the Section 6.1.

Question	Answers (correct answers)	Correct answers		P-value (significant*)
		Map	Graph	
QC.1:	"Between Albora and Belmar, which country pollutes more (per capita)?" Albora Belmar	92.7%	92.9%	1
QC.2:	"Between Albora and Belmar, which country is more vulnerable to climate change?" Albora Belmar	98.2%	98.2%	1
QC.3:	"Duskar..." Pollutes more (per capita) than Caeloria Pollutes less (per capita) than Caeloria Is more vulnerable to climate change than Caeloria Is less vulnerable to climate change than Caeloria	74.5%	92.9%	0.018*
QC.4:	"Floriana..." Pollutes more (per capita) than Elysium Pollutes less (per capita) than Elysium Is more vulnerable to climate change than Elysium Is less vulnerable to climate change than Elysium	92.7%	96.4%	0.658
QC.5:	"What is the vulnerability score of Albora?" Open answer (around 0.45)	94.5%	92.9%	1
QC.6:	"What are the emissions per capita of Belmar? (in tonnes of CO2 equivalent)" Open answer (around 10)	90.9%	96.4%	0.420
QC.7:	"What is the income level of Caeloria?" High income Upper-middle income Lower-middle income Low income	72.7%	91.1%	0.024*
QC.8:	"What is the income level of Caeloria?" High income Upper-middle income Lower-middle income Low income	47.3%	91.1%	0.000*
QC.9:	"How many people are living in Floriana?" Open question (5 million to 50 million)	94.5%	92.9%	1
QC.10:	"How many people are living in Galdoria?" Open question (50 million to 200 million)	92.7%	92.9%	1
QC.	Average	85.1%	93.8%	0.000*

Table 5 – Results, Part C



## 5.5. Voluntary Comments

Finally, at the very end of the surveys, participants had the opportunity to write a voluntary comment. This short section will highlight some answers that are useful for the discussion.

In the Map Survey, many participants expressed great interest in the visualization and the topic. However, many participants also mentioned the difficulty they had in understanding how to read it. Several participants wrote that they found the colors representing the income classes difficult to distinguish.

In the Graph Survey, the comments were mostly positive. Many participants expressed interest in the visualization and the topic. Interestingly, one person suggested that 'clouds' of color in the background would help to show the different income classes more clearly, which describes what appears on the map imitation.



## 6. Discussion

Now that the results have been presented in detail, the final step is to draw some key conclusions. This chapter will first analyze the results and highlight the main findings that were found. Then, the three research questions of this thesis will be answered. Finally, ideas and recommendations for future research will be presented.

### 6.1. Discussion of the Results

This section will discuss the main findings of the surveys. First, the limitations of the method and what it implies for the results will be explained. Then, the main findings will be presented, and the benefits and drawbacks of map imitations based on the study will be summarized.

#### 6.1.1. Limitations

The method used to analyze the map imitation has some limitations. Publishing the surveys online instead of being in person allowed to gather more responses but had the drawback that participants could not see the visualization in their real format. The perception of colors changes depending on if a visualization is seen on paper or on the screen. More importantly, the size was smaller than on paper, especially for participants answering from a smartphone, which forced participants to zoom in some parts of the visualization in order to be able to read the texts, which may have influenced the perception of both visualizations. Additionally, because of the way surveys were shared, many participants knew the author personally, which may have influenced the results, especially for Part A. It is also essential to note that the participants were mostly young and educated in the fields related to this study. Different sample groups may produce different results.

Moreover, due to the chosen method, certain aspects were not tested. In particular, the main supposed benefit of map imitations, which is that this type of visualization makes the reader curious to explore its data, was not fully tested. Question A.4 responses provide some subjective opinion on this matter, but no clear conclusions can be drawn. This aspect of map imitations could be tested using several of the following methods. Firstly, it would be relevant to show new participants both visualizations side by side and ask them to select the one they would like to explore. This would be a way to see if more people feel curious about the map imitation. Secondly, performing an eye-tracking analysis while showing the map imitation and comparing the results to the graph may be an interesting approach. It could show whether or not the reading behavior of the participants differs based on the type of visualization. Thirdly, measuring the time needed to answer the questions would give supplementary insight. As a longer time could signify either confusion or interest, it would be important to ask an additional question, such as asking participants if they found the visualization easy to understand or not.

But above all, it is crucial to consider that this study tested a single map imitation. Although it led to interesting findings, they should be considered with caution as other map imitation designs could lead to different findings.

### **6.1.2. Main Findings**

Despite the mentioned limitations, the results of the surveys led to several findings.

#### **A. The map imitation is more difficult to understand and leads to more errors than the graph**

Both the map and the graph were presented to the participants without context nor additional explanation. The only way participants could understand the visualization was by reading the legend and the different surrounding elements, which were the same in both the map and the graph, with an exception for the legend of the shaded relief.

However, the visualization type has influenced the understanding of the depicted data. The main variable that caused problems is the income per capita, represented differently on both visualizations. While the graph depicted the four classes in a traditional way (the color of the symbol itself corresponds to one of the four classes) the map imitation depicted this data in a less conventional way, which was supposed to help the readers to understand the trend that richer countries have greater emissions per capita while being less vulnerable to climate, and vice versa. To achieve this, some countries symbols appear on a large homogeneous color surface, while some appear on top of a smaller rounded surface. Not only this visualization choice led to more errors and confusion, as indicated by questions C.7 and C.8 and mentioned in several voluntary comments, but participants of both surveys understood the trend, with no particular advantage for the map imitation, as shown with question B.3.

Interestingly, question C.3, which could be answered by reading both the vertical and horizontal axes, shows a significant difference between the two visualizations, with a higher success rate for the graph. This result is unexpected as the answer can be found exactly the same way on both visualizations. Therefore, it seems that something about the map imitation made it more confusing to understand. This finding is supported by the responses to question A.1, which asked if the participants find the visualization easy to understand and showed a significant difference. The map imitation is clearly more difficult to understand than the graph. Generally, many participants found the map imitation confusing, as shows question A.7.

#### **B. The message retained depends on the visualization type**

Although both visualizations presented the same information, the key message retained by the readers differed. Question B.2 shows that the participants who had the map imitation noted a lower income per capita for countries in the top left significantly more than those who had the graph. It appears that the visualization method of the 'income per capita' variable influences user perception, with more emphasis on the map imitation than on the graph. Question B.1 explicitly asked for the main message of the visualization. The 'vulnerability' and 'emissions per capita' variables were the two main variables of the visualizations, and it was expected that both would

be mentioned in the responses. However, while the 'emissions per capita' variable was equally mentioned in both surveys, participants seem to have noticed the 'vulnerability' variable more by reading the graph than the map imitation.

A potential explanation is that the participants experienced more cognitive load with the map compared to the graph due to its visually complex nature. It may have been less difficult to identify the main variables on a graphically simpler visualization. Additionally, it is possible that the understanding that the points' position is determined by two variables is more intuitive on the graph than on the map imitation. With these two considerations in mind, it is plausible that the focus of the participants' attention was more on the vertical and horizontal axes, i.e. the two main variables, on the graph than on the map imitation.

For the topic of climate change, with the goal that people discover the link between the greenhouse gas emissions per capita and its vulnerability to climate change, the map imitation appears to be a less appropriate visualization compared to the graph. This finding is confirmed by question A.3, which asked if the visualization helped the participants to understand the represented topic better and showed a significant advantage for the graph. In general, it seems that map imitation can lead to readers overlooking crucial information, but retaining secondary information better.

### **C. The relief is superfluous and confusing**

The last main finding of the study is that the relief is not understood by the readers. When participants with the map imitation were asked if there was anything on the visualization they did not understand (question A.7), several mentioned the relief. Moreover, question B.5 showed that only 7.3% of participants understood what it represents. It was expected that participants would need more time to understand the meaning of this uncommon visualization layer, but it was unexpected that the understanding rate would be this low. Most people have incorrectly interpreted the relief as showing population density. It is difficult to identify the cause of this problem, as it may occur at any of three levels.

1. Map imitation design: One possible explanation could be the specific design of the relief map and its legend. It is possible that the design could be improved for better understanding.
2. Method selection: Another possible reason could be that the method chosen, which makes the relief based on both points density and a variable, leads to confusion. It is possible that other methods would be easier for the reader to interpret.
3. Relief on map imitation in general: Finally, it is possible that the relief is a confusing visualization layer and could inherently cause problems of understanding.

In that sense, it is not possible to draw a definitive conclusion based on these results. It is incorrect to assume that the results indicate that relief on map imitation is intrinsically bad. Nevertheless, it is clear that the relief as it is on the map imitation of this research is not easily understandable and leads to incorrect interpretations. Since the understanding of this layer is not intuitive, it also means

that it can contribute to unnecessary cognitive load, which may increase difficulties in understanding the whole visualization.

### **6.1.3. Benefits and Drawbacks of Map Imitation**

The purpose how the user study was to find the benefits and drawbacks of a complete map imitation, taking inspiration on what research has shown for individual layers of map imitations. As explained in the limitations, the main benefit of map imitations, which is that they spark curiosity to explore, was not really tested. In general, the user study did not show any clear benefit for the map imitation. All the results either showed equivalent success between the visualizations or a significant advantage for the graph.

The user study did confirm all supposed drawbacks of map imitations.

1. False intuitiveness and confusion: This drawback is the most evident based on the surveys' results. The map imitation led to many mistakes and misunderstandings. Some aspects of the map imitation were falsely intuitive, as in the case of the relief where most participants answered that the relief shows population density although it is not the case.
2. Cognitive load: Although this aspect could be tested more in depth, there are still some indicators which show that the participants experienced a higher cognitive load on the map imitation than on the graph, which led to more confusion. Many visual elements did not serve a clear purpose or required a high amount of time for the reader to be understood, which is a clear drawback in comparison to the graph, which was easier to understand.
3. Memory: The last supposed drawback found in literature, which is that map imitations lead to more memory errors on point position than dot displays, was not directly tested in the user study. Other aspects of memory, however, were tested, in particular how readers remember the main aspects of the map imitation they just saw. In that regard, the study showed satisfying results with both visualizations, except when participants were asked what key message they retained from the visualization. Surprisingly, with the map imitation significantly fewer participants mentioned one of the two main variables, which is a drawback in comparison to the graph.

In overall, the surveys' results clearly demonstrated that this map imitation has more drawbacks than benefits. Although in most cases, both visualizations performed equally well, when there was a difference, the graph performed better than the map imitation. All in all, there are many advantages to representing data on a graph rather than as a map imitation, and in the particular context of this study a graph seems to be a better way to represent data than a map imitation.

## 6.2. Research

All the elements are now in place to provide precise answers to the three research questions. This section will answer each question, building on what has been done in this research. Finally, ideas and recommendations for future research will be provided.

### 6.2.1. RQ.1

***What criteria dictate the publishing of a data visualization in an industry context?***

The design of a data visualization for commercial publishing is dictated on two aspects. Firstly, when the visualization had a geographical component, the designer should be aware of the company's internal policy on countries and territories. It is crucial for the design to comply with the rules on borders and names. Secondly, for any data visualization, the design should follow the corporate design, which frames the choice of typefaces, colors, layout, and so on.

The corresponding RO.1, *Determining the industry requirements that dictate the creation of a data visualization*, is considered partially achieved. Section 3.1.2 and Section 3.3.1 detail some industry requirements and contribute to this research objective. However, these criteria are based on the knowledge of a single company, and although it is assumed that they apply to the sector in general, it has not been proven in this research. In addition, due to the limited scope of this research, this research objective was of a lower priority than the other two, and led to less extensive research.

### 6.2.2. RQ.2

***How can a map imitation be designed?***

This research provides a comprehensive procedure on the creation of a map imitation. It is important to note that this procedure allows the creation of map imitations using the selected methods. Other procedures, with different techniques, could be developed.

The procedure is detailed in Section 3.4. As explained, a map imitation can be designed in three steps:

1. Preparation: The designer should take preliminary considerations, especially by reflecting on if map imitation is the appropriate visualization type for the aim, and by considering potential external constraints such as company requirements. Then, the designer should select five appropriate variables.
2. Processing: The designer should then process the data. Two variables should be normalized and potentially applied a logarithmic correction and then used as coordinates for the data items. A relief can be generated from these points based on their density and a third variable. The ocean can be generated in a GIS based on the relief, and the areas can be created by generating Voronoi polygons in a GIS which are then modified in a graphic software.

3. Design: The designer should carefully design the visualization to make it resemble a map. The potential external constraints should be considered, such as typefaces, colors and layout defined by a corporate design. The previously created layers can then be overlapped in a GIS, then designed in a graphic software to resemble map layers. Surrounding elements, such as textual information, legend and compass rose can be created and added to the map imitation in a graphic software. Finally, all elements should be adapted to get an appropriate visual hierarchy, which will guide the readers.

Therefore, the corresponding RO.2, *Developing a comprehensive procedure for creating a map imitation, and creating an example*, is considered achieved. The comprehensive procedure is detailed in Section 3.4, and the example is presented in Section 3.5.

### 6.2.3. RQ.3

#### ***How does the map-likeness of a visualization influence user performance?***

In this research, an example of map imitation was tested by comparing its influence on user performance with a graph displaying the same information. The map imitation resulted in poorer user performance on several aspects. This visualization type was more difficult for people to understand, and some aspects and layers were frequently misunderstood. Moreover, the relief created confusion and led most people to believe they understood it although they did not. Finally, when people were asked to summarize the main message of the visualization without seeing it, significantly more people did not mention one of the two main variables depicted after reading the map imitation than the graph. All in all, it appears that the map-likeness of the visualization has a negative influence on user performance.

The corresponding RO.3, *Evaluating the performance of a map imitation for knowledge transfer by comparing the user's perception and understanding of both a map imitation and a graph showing the same information*, is considered achieved. Two parallel surveys were conducted to test the users' perception and understanding, as explained in Chapter 4. The results of these surveys were presented in Chapter 5, and key findings were detailed in Chapter 6.

### 6.2.4. Future Research

This research led to several relevant findings. Future research is then encouraged, as there are several ways this research could be extended. This subsection will present suggestions on two aspects in which this research can be further pursued.

The first aspect on which this research can be extended concerns the type of map imitation. In this research, one example has been created and tested, for one topic and one set of variables. However, this is not only one way to produce a map imitation, and several other examples could be produced and tested. Different map imitations can be created by altering one or more of the three main steps. In the preparation, different topics and different data types can be selected. In the processing, different methods can be used, for both the position in the plane – for which traditional spatialization techniques can be used – and the relief. Finally, in the design, where different choices could lead to different user perception and understanding.



The second aspect concerns the user study. For this research, it was decided to conduct an online survey including both quantitative and qualitative questions. This method allowed to test several aspects of the map imitation, but not all of them. For example, the supposed benefits of map imitation were not tested enough. Several other methods could be used, including conducting surveys in a controlled environment or using eye-tracking methods, and would reveal other aspects of map imitation.

All in all, further research is needed on the topic of map imitation as there are several aspects which remain unexplored. Map imitation has the potential to become a more popular form of data visualization, but it has not reached its full potential yet.



## 7. Conclusion

In this research, the concept of map imitation was introduced by giving a new definition, which helped define historical periods of this visualization type. It was then argued that this research takes place in the most recent period, in which map imitation is being broadened to new possibilities of use. The potential benefits and drawbacks of this visualization type were then listed: map imitations are supposed to be partially intuitive and to make readers curious about its content, but are also supposed to be confusing, in particular because of the high cognitive load they demand, and are supposed to lead to memory errors. Most of these aspects were proven but only for individual visualization layers. This research therefore aimed at moving research forward by testing these potential benefits and drawbacks on a complete map imitation, with several layers. Moreover, this research aimed at contributing to the topic of map imitation by introducing new design ideas, and by making an example using a subject which has not been visualized on a map imitation before: climate change.

Once the framework was set, the design workflow was introduced. Designing a map imitation was divided into three main steps. Firstly, the designer should take preliminary considerations about the topic represented and the datasets available. Secondly, the data should be processed in order to create the main layers: the points should be places in the plane by normalizing the two main variables and potentially applying a logarithmic correction; the relief should be generated based on the points density and a third variable; the ocean should be created based on the relief; the areas should be generated based on a fourth variable. Thirdly, using a graphic software, the generated layers should be designed to resemble a map and additional surrounding elements should be designed to provide necessary information to the readers. In some parts of the design process, potential constraints related to industry requirements were presented in case the visualization is created in the context of a company. As a summary, a comprehensive procedure on the whole design workflow was provided, and the example produced was presented.

This example was then tested on users in two parallel user studies. Participants were redirected to one of the two surveys, unaware that two surveys coexisted, and answered essentially the same questions. In one survey, the questions were about the map imitation, while in the other, the questions were about a graph showing the same information, which was created by taking the cartographic elements of the map imitation and slightly modifying some details. By comparing the results of both surveys, it was possible to find the benefits and drawbacks of the fact the visualization resembles a map.

The results of the surveys were then presented and discussed. Although the results were mostly similar with both visualizations, when there was a statistically significant difference, it was in favor of the graph. The map imitation was perceived as confusing for a significant number of participants,

led to more errors of understanding than the graph, and made some participants forget one important variable when asked to summarize the main message of the visualization. The layer that posed the most problems was the relief, which unnecessarily increased the cognitive load of the map imitation and probably contributed in making the visualization confusing and difficult to understand.

However, some limitations of this research were highlighted. The participants of the surveys were mostly young and educated in fields related to this study, which may have influenced the results. The visualization tested is a single map imitation, and other map imitation designs could lead to different results. Moreover, different user study methods may lead to different results and findings.

In that regard, future research is encouraged. Different map imitations could be produced using different techniques, especially for positioning the points in the plane and generating the relief, which are two steps for which various techniques exist. Additionally, different user studies could be conducted, in particular using eye tracking to test whether map imitations do enhance curiosity to explore. There is still a lot to discover in the field of map imitation, and scholars are invited to join in this exploration and contribute to its growth.

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## 9. Appendices

### 9.1. Python Script

The Python script which creates new coordinates and generates the density surface is available online.

[https://kartoweb.itc.nl/msc-carto-thesis/materials/sacha\\_schlumpf/](https://kartoweb.itc.nl/msc-carto-thesis/materials/sacha_schlumpf/)

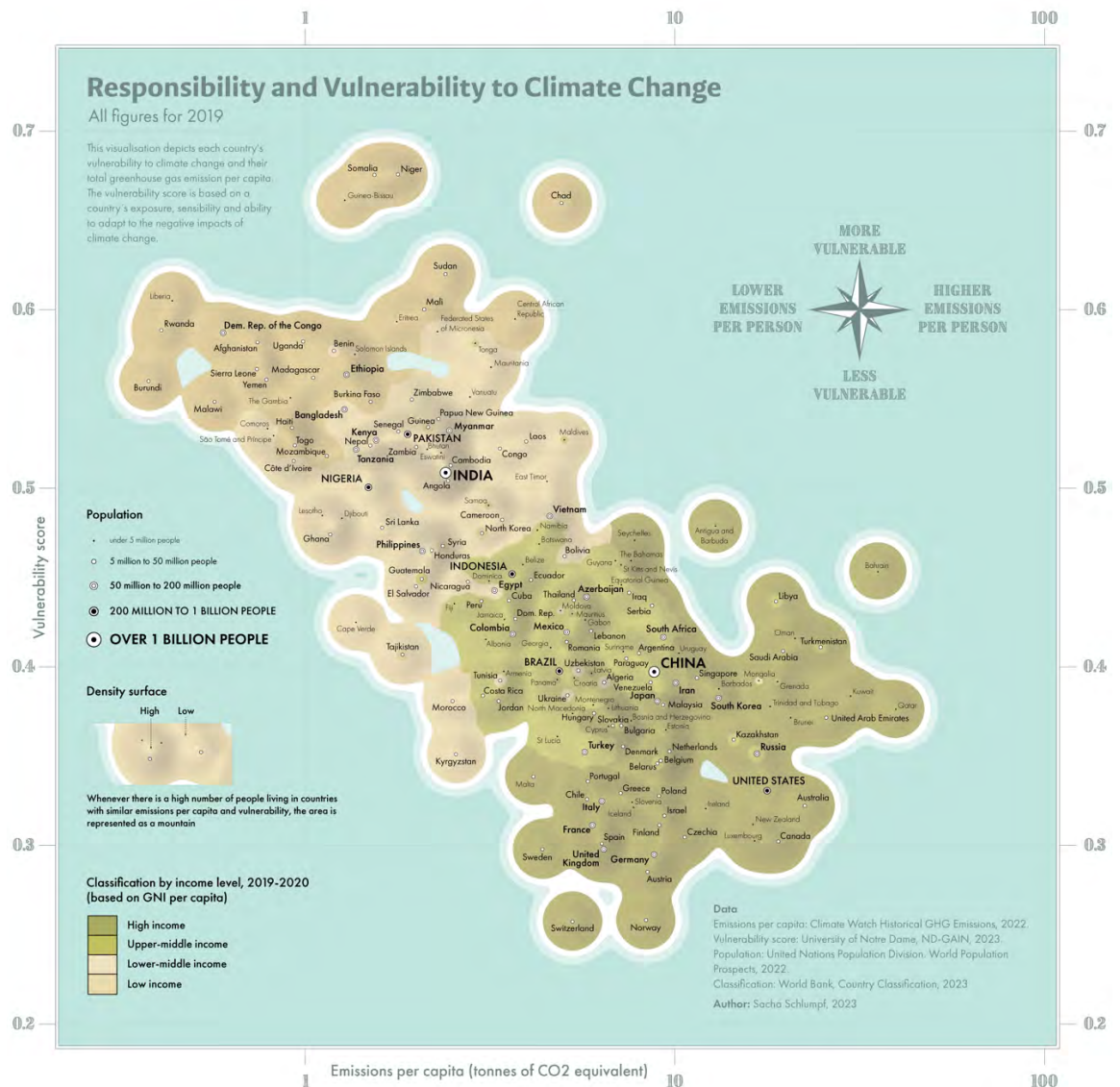


## 9.2. Map Imitation and Graph

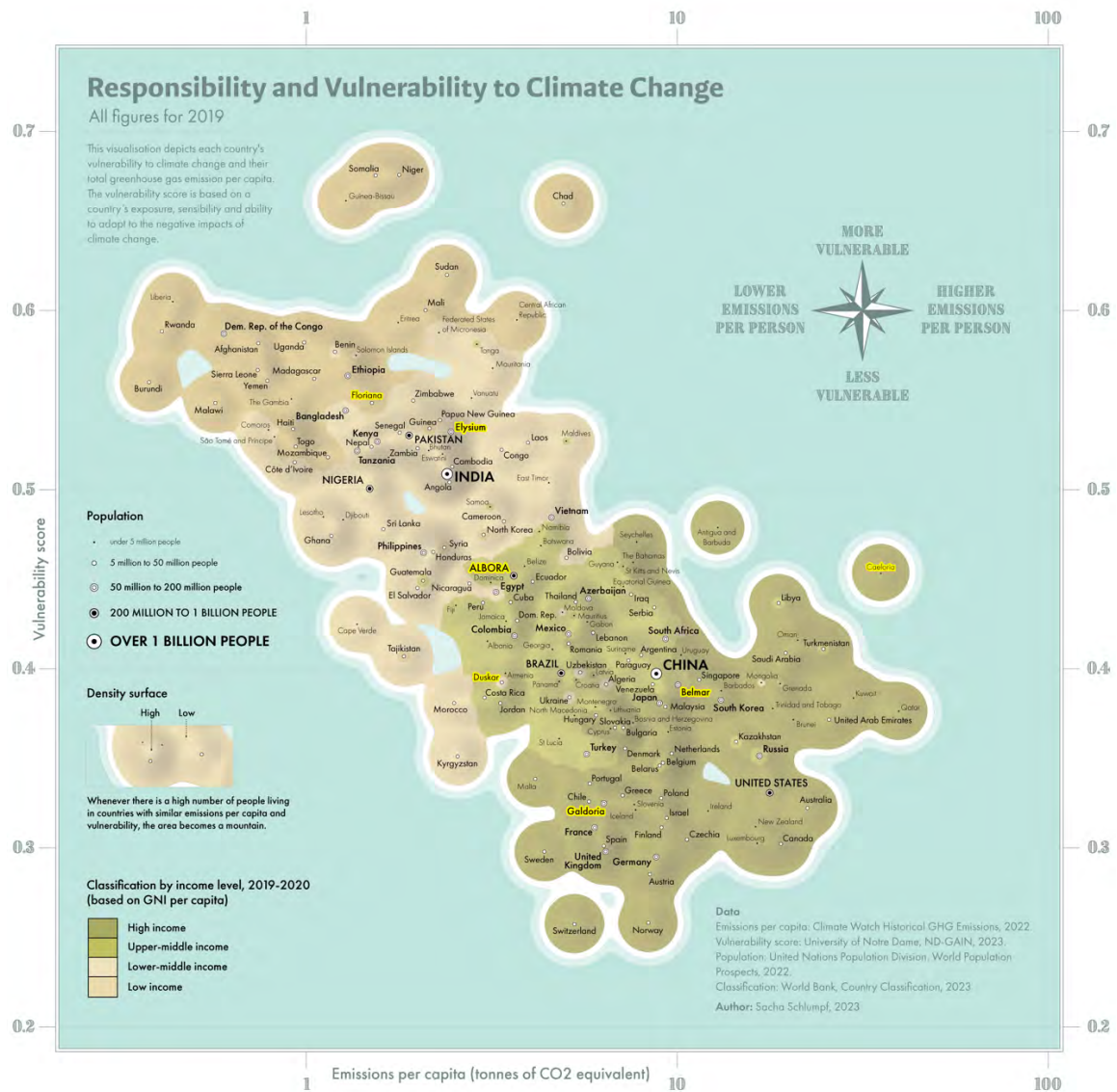
The French versions of the map imitation and the graph are available online.

[https://kartoweb.itc.nl/msc-carto-thesis/materials/sacha\\_schlumpf/](https://kartoweb.itc.nl/msc-carto-thesis/materials/sacha_schlumpf/)

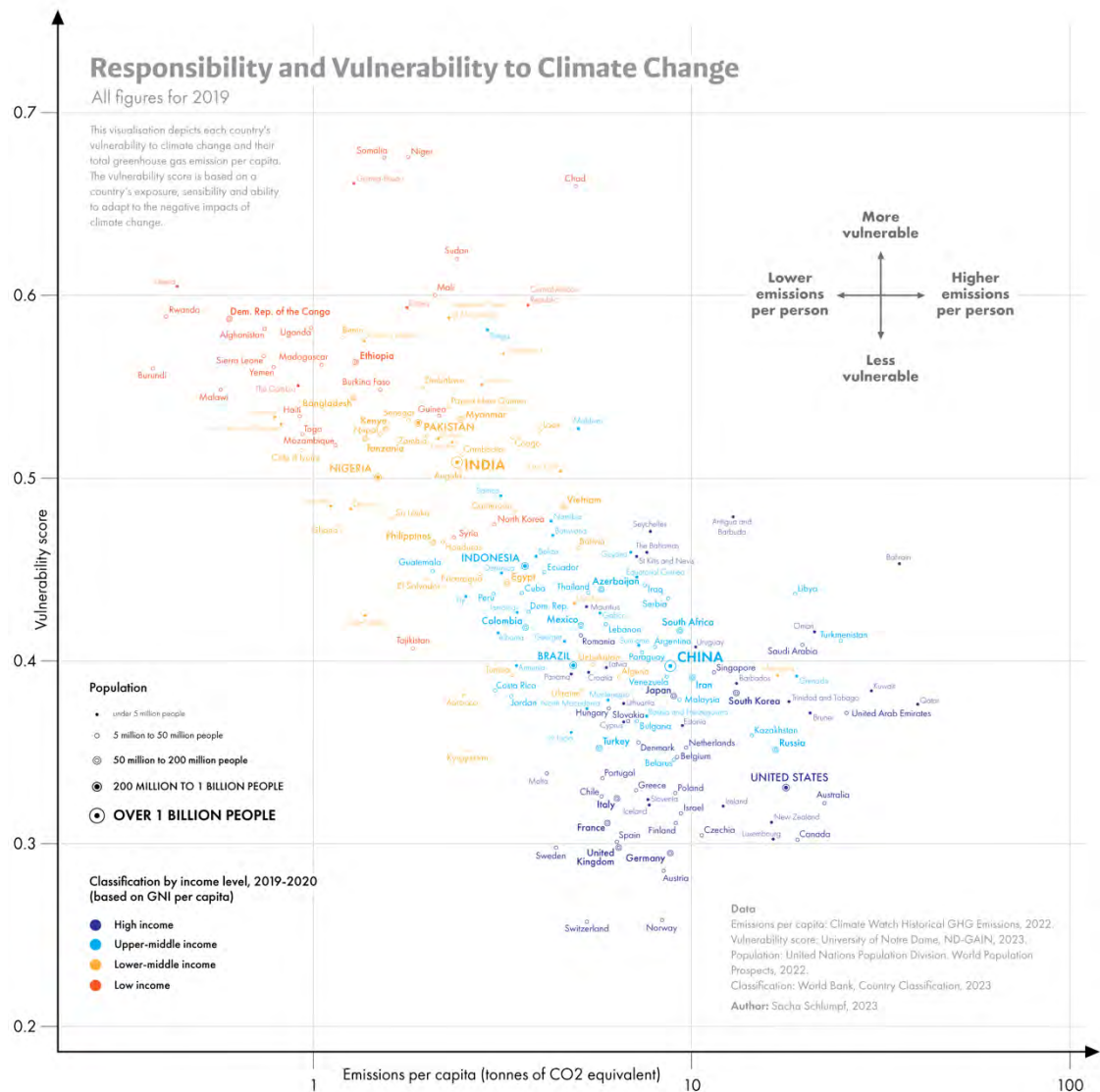
### A. Map Imitation



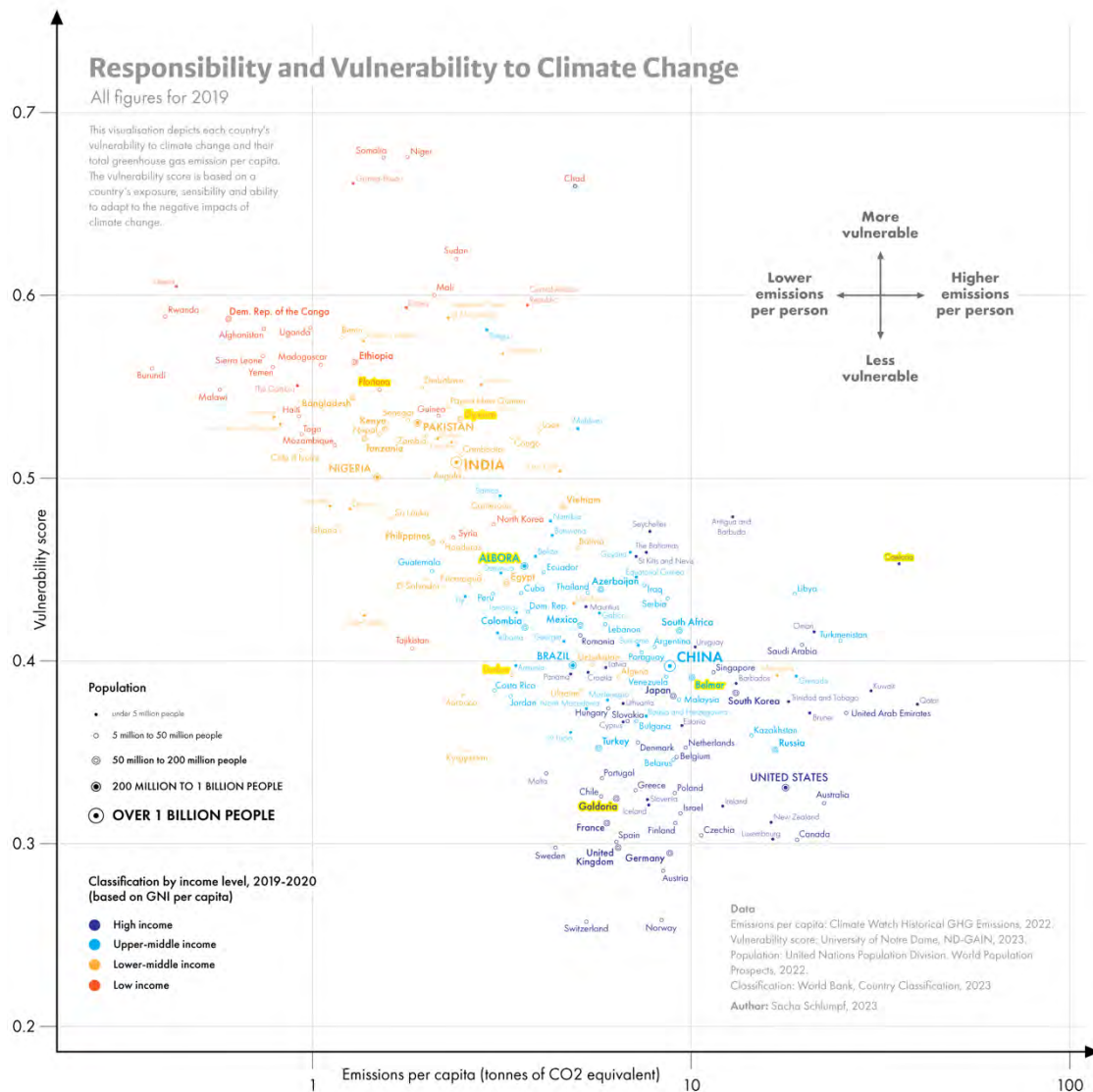
## B. Map Imitation with Fake Names



## C. Graph

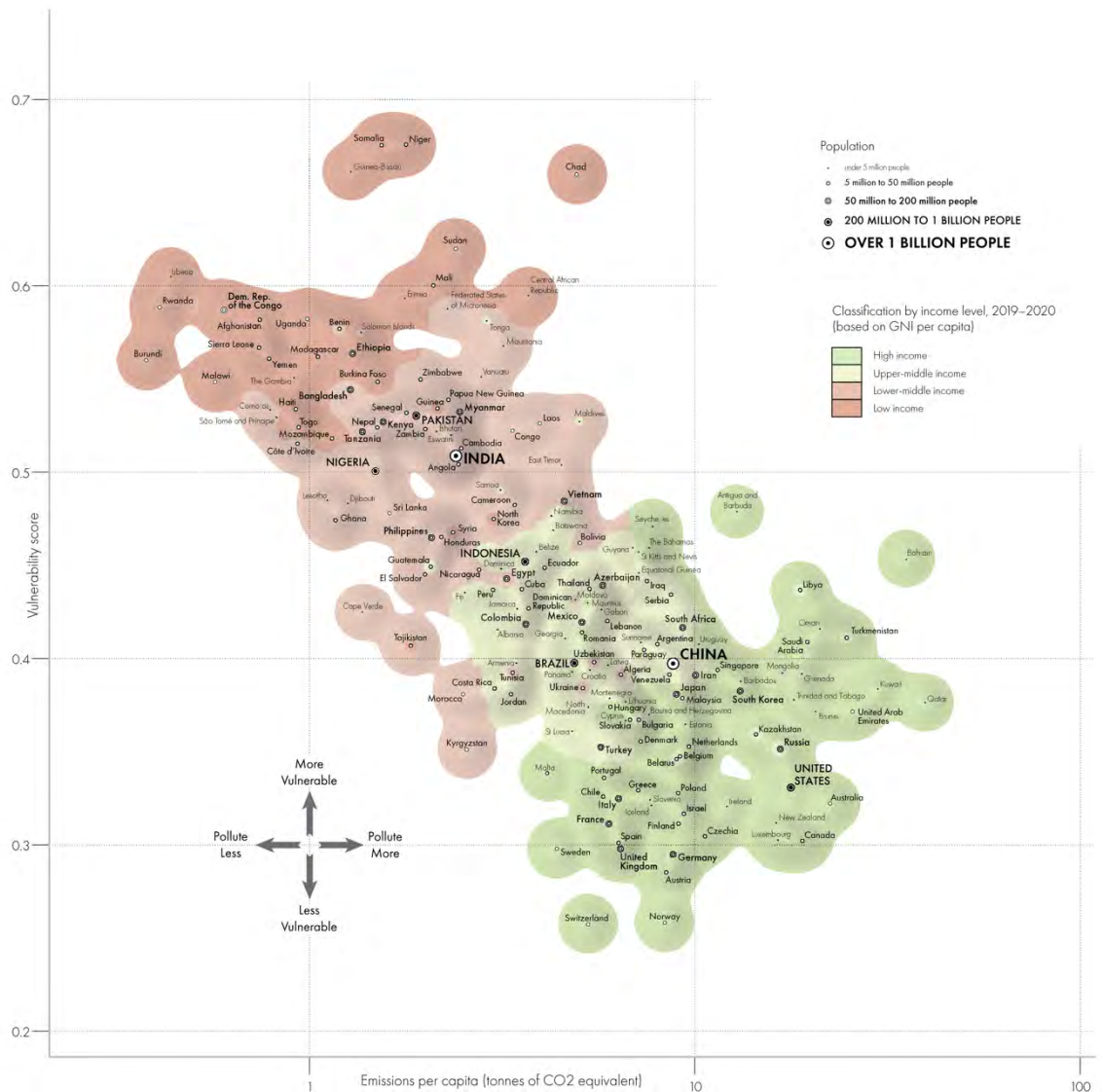


## D. Graph with Fake Names





### 9.3. Map Imitation Published by HarperCollins Publishers



#### Responsibility for and vulnerability to climate change 2019

This visualisation depicts each country's vulnerability to climate change and their total greenhouse gas emission per capita. The vulnerability score is based on a country's exposure, sensibility and ability to adapt to the negative impacts of climate change and the higher the score the more vulnerable. The relief is based on population density, with higher areas indicating greater population and this generally depicts population trends.





## 9.4. Surveys

This is the English version of the Map Survey. In the Graph Survey, each instance of the map imitation was replaced by the graph and each instance of the word *map* was replaced by the word *graph*. Yellow highlighting (not visible to participants, shown only on screenshots) indicates a question not present in the Graph Survey.

The questions marked with a red asterisk were mandatory and the participants were unable to go to the next part without answering them.

### Introduction

**Français:** Vous pouvez changer la langue de ce questionnaire en cliquant sur le menu en haut de cette page.

Thank you for showing interest in this study!

My name is Sacha, I'm currently finishing my Master's degree in Cartography at the Technical University of Vienna. This survey is part of my research for my Master's thesis. **Your answers are extremely valuable to my research.**

Participation in this survey is completely voluntary, and you have the right to withdraw at any time. Only completed surveys will be considered in my research. This survey is **anonymous**. All data collected will be used solely for the intended research objectives. The results will be published in my research and made available to the public.

You will need around **10 minutes** to complete this survey.

Please answer this survey **only once**.

Contact: Sacha Schlumpf

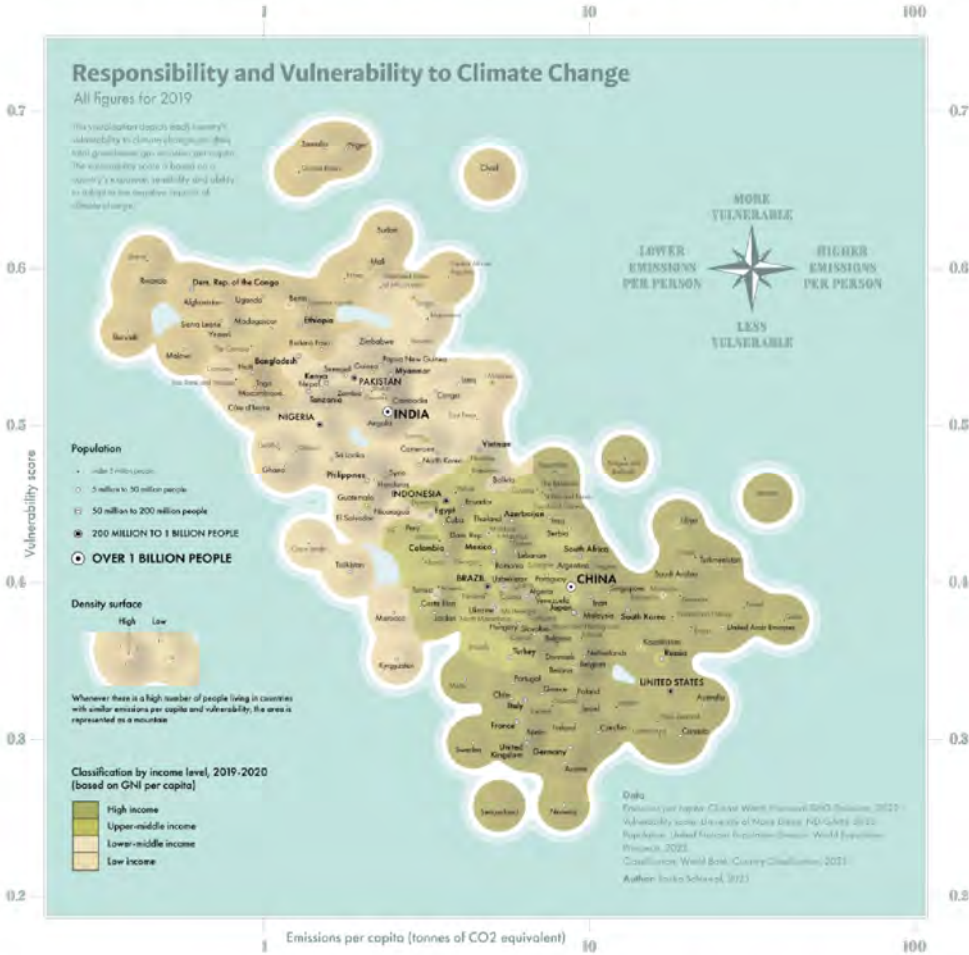
By clicking 'Next,' you indicate your agreement with the aforementioned data collection practices and terms.

Next

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First look

Take some time reading and understanding what this map is showing



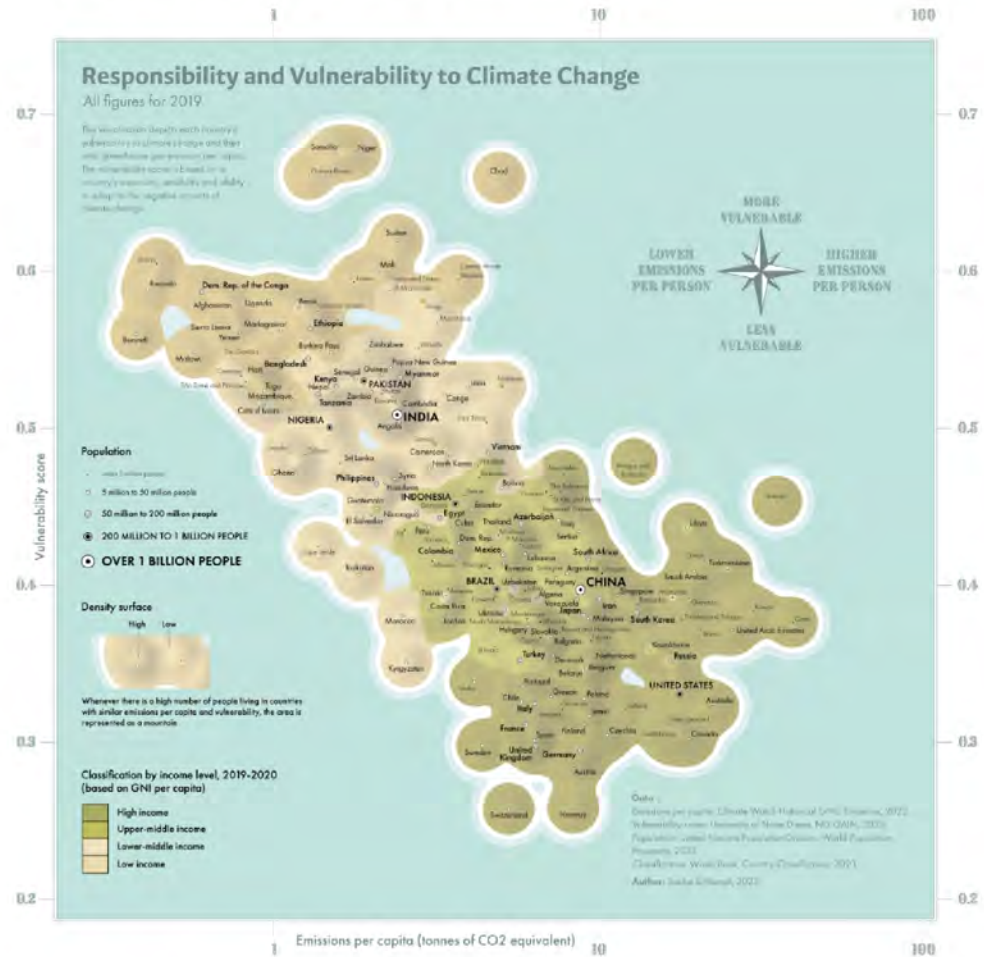
If you're on a mobile phone, you can zoom in on the map with your fingers, just as you would on a picture.

For the purposes of this research, please do not share this map online.

When you think you understood most of what the map shows, click "Next".

## Impression

Do you agree with the following statements?



For the sake of this scientific research, please answer **honestly**.

"I find the map easy to understand."\*

Strongly disagree Disagree Agree Strongly agree

"I find the way the information is represented on this map interesting"\*

Strongly disagree Disagree Agree Strongly agree

**"The map helped me to understand the represented topic better."\***

☐ Strongly disagree ☐ Disagree ☐ Agree ☐ Strongly agree

**"If I had a book with this map printed large, I'd want to spend some time looking in detail at everything this map shows."\***

☐ Strongly disagree ☐ Disagree ☐ Agree ☐ Strongly agree

**"I like the design of the map (colours, fonts, etc.)."\***

☐ Strongly disagree ☐ Disagree ☐ Agree ☐ Strongly agree

**"I like that the countries are arranged differently than in a conventional map."\***

☐ Strongly disagree ☐ Disagree ☐ Agree ☐ Strongly agree

**Is there anything you don't understand on this map? If yes, what?**

**Have I shown you the map in person?\***

If you have already seen that map or a previous version of that map before (in case you know me personally), please click 'Yes'.

☐ Yes ☐ No

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## Perception and Understanding

### Instructions

Please don't go back in the survey.

Here are 5 questions about the map you just saw. In case you don't know an answer, write "I don't know".

**In one sentence, what message do you take away from this map?\***

**If a country is on the top-left of the map, what does that mean?\***

**Where on the map are the rich countries generally located?\***

**How can you recognize a densely populated country on the map?\***

**What does the relief represent?\***

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## Map Comprehension

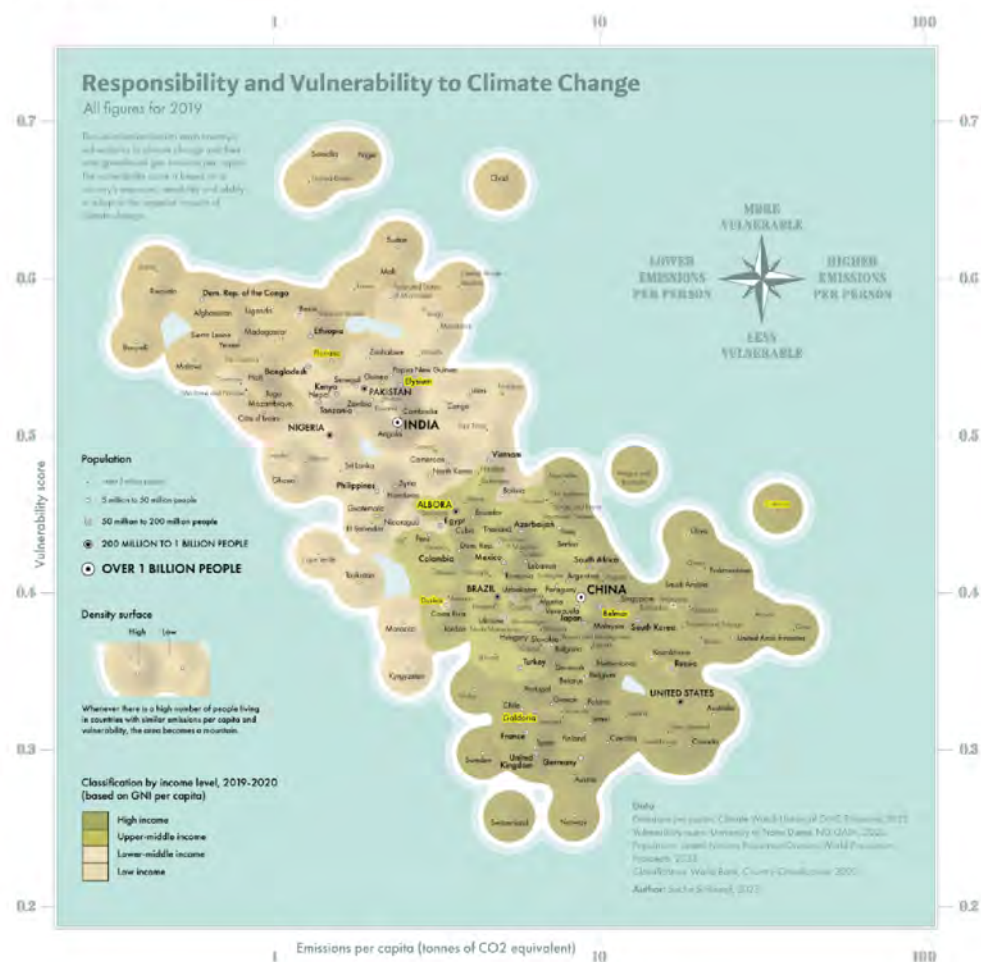
### Instructions

In this section, you'll be asked 10 questions about the map you just saw.

The map is always the same. There is no time pressure, take your time.

On the map, there are certain countries whose names have been replaced with fake names, and they are highlighted in yellow. It is important to consider these fake country names as if they were real countries. The aim is for you to be able to answer the questions solely by reading the map, without relying on your personal knowledge of the world.

### Question 1



**Between Albora and Belmar, which country pollutes more (per capita)?\***

☐ Albora

☐ Belmar

☐ I don't know

**Between Albora and Belmar, which country is more vulnerable to climate change?\***

☐ Albora

☐ Belmar

☐ I don't know

**Duskar...\***

Multiple answers possible.

☐ Pollutes more (per capita) than Caeloria

☐ Pollutes less (per capita) than Caeloria

☐ Is more vulnerable to climate change than Caeloria

☐ Is less vulnerable to climate change than Caeloria

☐ I don't know

**Floriana...\***

Multiple answers possible.

☐ Pollutes more (per capita) than Elysium

☐ Pollutes less (per capita) than Elysium

☐ Is more vulnerable to climate change than Elysium

☐ Is less vulnerable to climate change than Elysium

☐ I don't know

**What is the vulnerability score of Albora?\***

**What are the emissions per capita of Belmar? (in tonnes of CO2 equivalent)\***

**What is the income level of Caeloria?\***

☐ High income

☐ Upper-middle income

☐ Lower-middle income

☐ Low income

☐ I don't know



What is the income level of Duskar?\*

☐ High income

☐ Upper-middle income

☐ Lower-middle income

☐ Low income

☐ I don't know

How many people are living in Floriana?\*

How many people are living in Galdoria?\*

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## Personal information

### Note

In this **last section**, a few personal questions will be asked.

None of these questions are mandatory. I'm grateful if you accept to answer them, as the answers will lead to a better analysis of the results. **However, if there is any question you don't feel comfortable to answer, feel free to leave it blank.**

All responses are processed anonymously.

### How old are you?

### To which gender do you identify?

☐ Female

☐ Male

☐ Non-binary

☐ Other

**Do you have an academic and/or professional background in one or many of the following fields?**

Multiple answers possible.

<input type="checkbox"/>	Cartography, GIS, Geography, or related
<input type="checkbox"/>	Data analysis, Statistics, or related
<input type="checkbox"/>	Data visualisation, Information design, or related
<input type="checkbox"/>	Graphic design
<input type="checkbox"/>	None of the above

**To your knowledge, are you colour-blind?**

Meaning that you're unable to distinguish certain colours.

<input type="radio"/>	Yes
<input type="radio"/>	No

**Any comment?**

<div></div> <div>255</div>
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## 9.5. Surveys Raw Results

The raw results of the surveys are available online.

[https://kartoweb.itc.nl/msc-carto-thesis/materials/sacha\\_schlumpf/](https://kartoweb.itc.nl/msc-carto-thesis/materials/sacha_schlumpf/)