Teaching climate change

Creating and testing an interactive visualization of carbon emissions in order to increase awareness

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Abstract

A gap of knowledge exists between the latest climate change research and the general public. The goal of this thesis is to bridge that gap by making the information more accessible and easier to understand. A proof-of-concept model is created with the goal to visualize carbon emission data, namely size relations between countries, source of emissions per country and the current state of carbon emissions compared to a stated goal (the Paris Agreement), and give the user options to reach said goal by manipulating percentages of renewable energy, electric vehicles, and industry, on a global or local scale. User studies are then performed with members of the target group (students age 13-15) to test whether these visualizations are intuitive and accurately communicates the visualized data. The studies are effective and the goal of the visualization is reached.
Sammanfattning

Preface

Thanks to mom and dad for making me and Björn and Tino for indulging me.
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Chapter 1

Introduction

This chapter serves as the introduction to the degree project, discussing the subject background, relevant work, the aim for the thesis and the delimitations.

1.1 Background

Climate change is an effect caused mainly by the increased burning of fossil fuels, which results in the average temperature of the world increasing, as well as the global atmospheric concentration increasing. As humanity becomes increasingly more aware of the issue, there has been international efforts to contain and reduce the amount of emissions, in order to combat climate change, such as the Kyoto protocol and the Paris Agreement. [1] [2] However, there still exists a gap in knowledge between the most recent scientific studies and the general public, as evidenced by the existence of climate change deniers.

The most highlighted goal set currently is the Paris Agreement, which has 197 parties and has been ratified by 172. It is an agreement within the United Nations Framework Convention on Climate Change (UN-FCCC) to deal with emission mitigation, adaptation and financing. The aim of the Paris Agreement is: [3]

1. Holding the increase in the global average temperature to well below 2 degrees Celsius above pre-industrial levels and to pur-
sue efforts to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

2. Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;

3. Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development

The Paris Agreement also contains set emission levels on a country-by-country basis, to be reached by a set year, usually 2020/2025/2030.

The goal of this thesis is to attempt to reduce the gap of information by creating methods of visualizing the current state of carbon emissions globally, therefore making the information more easily accessible and intuitive to members of the target group (students age 13-15). If successful, members of the target group will have an increased knowledge of climate change after having used the visualization. This includes communicating information about the Paris Agreement, how close various countries are to reaching it, and what changes need to be made in order to reach it.

1.2 Related work

One existing visualization of carbon emissions is the Global Carbon Atlas. [4] It visualises both carbon emissions and CH4 emissions globally, displaying the amount of emissions for each country over a timeline from 1960 to 2015. It does not cover any future goals such as the Paris Agreement, or any projections such as the IPCC projections. It also does not discuss the different sources of emissions (such as transport, energy generation, industrial processes, et cetera).
The European Commission has also created a series of emission charts, both carbon dioxide emissions and GHG emissions (GreenHouse Gases, where carbon dioxide is the most prevalent), through EDGAR (Emissions Database for Global Atmospheric Research). The data is visualised with a color-coded heat map, with no additional information, and also displayed in chart form. The EDGAR time series spans from 1990 to 2015, and like Global Carbon Atlas, it does not contain projections or details on emission sources. They also include gridmaps of their emission data.

The World Resources Institute, WRI, has also created a semi-interactive visualization of carbon emissions. Theirs includes a pre-recorded
spoken monologue about the emissions, and shows amount of emissions from the top emitting countries on a timeline from 1860 to 2011. There is no visualization of emission sources of future scenarios such as set goals or projections, rather focusing on comparing emission amounts between countries over time.

Figure 1.3: The World Resources Institute visualization of the biggest emitters in 2011.

The World Bank has created simple visualizations of carbon emission amounts from 1960 to 2014, which are shown as graphs (line/bar) or a color-coded world map. [7] It also shows a country by country analysis of carbon emissions in 1960 and 2014, with a small line graph representing character of the growth. Similarly to the previously mentioned visualization, it does not visualize emission sources or future projections or goals.
1.3 Objective

The primary goal of this thesis is to create a visualization of carbon emissions that not only shows the relation in emission amounts between countries, but also visualizes the sources of emissions on a country-by-country basis, as well as visualizing future set goals (such as the Paris Agreement) and ways to achieve those goals.

By creating adjustable variables of the percentage of renewable energy, electric vehicles, and industry, the user of the visualization can interact with the visualization, and attempt to reach set goals to gain an understanding of what changes the world, or individual countries would need to take to reach their goals. Combined with visualizations of the emission sources, this is intended to give the user a well-rounded understanding of the current state of carbon emissions, in an intuitive and engaging way.

This thesis aims to create the visualization and do user studies with members from the target group (students age 13-15) to determine whether
the visualization achieves the goals it is intended to achieve.

1.4 Problem

The hypothesis of this degree project is that by building a visualization of carbon emissions (that can be interacted in different ways), members of the target group will be better informed regarding the current state of emissions, as well as different ways to reach various emission goals (such as the Paris Agreement).

1.5 Technical specification

The data is visualized with particle systems in the shape of smoke clouds on top of a world map, where the size of the cloud directly correlates to the amount of carbon emissions. The map exists in two layers, the macro layer (continents like Europe, Asia, Africa and the US) and the micro level (individual countries, focusing on EU28 as a relevant example for the proof-of-concept visualization).

The user can then interact with the model in several ways. For example, choose a target for carbon emissions (for the proof-of-concept, this is the Paris Agreement) and see how close to that target the countries are.

In addition, the user can change variables that affect carbon emissions, namely the percentages of renewable energy (starting at the world average of 22% [8]), electric vehicles, and industry (starting at 100% of industry remaining).

This means that the user can try to reach the Paris Agreement levels from today’s state of carbon emissions by manipulating variables, to see how the goal could potentially be reached, either on a country-by-country basis, or on a global basis.

The visualization needs to be intuitive enough that no prior knowledge is needed to operate it, and so that the user understands the data being visualized and what impact their choices have.
1.6 Delimitations

Due to the limited scope of the degree project, a full visualization containing every country, as well as every set goal and every projection is not feasible. Instead, the visualization will be treated as a proof-of-concept, with only a subset of countries and continents visualized. In addition, the visualization will focus on the current state of emissions and the most relevant set goal, which is the Paris Agreement, as it has 197 parties and has been ratified by 172. [2]

In addition, there’s a large number of variables that vary from country to country (such as what exact makeup their transportation is, in regards to diesel/petrol/electric vehicles etc), and due to the limited scope of the project, not all of these variables can be included for all countries. Therefore, the most important variables (total amount of emissions, sources of emissions and the sources distributions) will be included on a country-by-country basis, and the other variables (such as % of energy from renewable sources, % of vehicles that are electric and how much emissions are reduced by when increasing these numbers) be included as a global average. Implementing all these variables on a country-by-country basis would be a potential subject for future work.
Chapter 2

Relevant Theory

For this project, a robust understanding of several areas are required. These areas include:

- Emissions, where they originate from, the amounts from the different sectors, how they are affecting the environment and how they can be reduced.

- Renewable energy, how it’s collected, how much emissions they cause (and reduce), both in the real world currently and in theory.

- Electric vehicles, their effect on emissions (both in the real world today and in hypothetical scenarios with more/less renewable energy), and how widespread their use is.

- How these different areas affect each other. For example, if more renewable energy is used in conjunction with electric vehicles, what is the effect on transport emissions.

2.1 Renewable Energy

Renewable energy typically refers to wind power (collected by turbines moved by the wind), water power (collected by turbines moved by water), and solar (collected by solar panels from the energy of the sun). There are also less well known methods such as geothermal energy (collected from the heat generated by and stored in the earth), bio-
fuel (using fuel created by contemporary substances such as plants), and biomass (burning wood or similar substances). [9]

2.2 Electric vehicles

An electric vehicle is a vehicle that is driven purely on electricity, either generated by a battery somewhere on the vehicle’s body, energy generation such as solar panels, or with a persistent connection to a power source such as the power grid. [10]

There are several different types of engines, one design, the induction motor, works by converting the electricity to a dynamic magnetic field used to move a piston, which in turns causes the wheels to rotate and the vehicle to move. [11]

There are also several different types of electric vehicles, plug-in electric vehicle (PEV), which has a rechargeable battery similar to a mobile phone (sometimes referred to as Battery Electric Vehicle, or BEV), plug-in hybrid vehicles (PHEV), which has a rechargeable battery and a traditional internal combustion engine to use when the battery runs out, and hybrid vehicles which charge the battery from the residual energy of using the combustion engine, and Conventional Hybrid, which charges the battery with residual energy from usage of the gasoline engine. [12]

2.3 Emissions from energy generation

For this project, these types of emissions refer to burning fossil fuels such as oil and natural gas (referred to as non-renewable energy) or the construction and maintenance of solar panels, wind farms, etc (when referring to renewable energy).

2.4 Emissions from transport

Typically a result of burning fossil fuels in the forms of petrol or diesel in an internal combustion engine, such as the one found in a typical
car. In this project it is considered separate from energy generation in general. This is partly due to the fact that vehicles are generally disconnected from the energy grid, and partly due to fact that there are massive efficiency differences. A typical gasoline car for example, only converts about 17-21\% of the energy stored in the fuel to power at the wheels (comparatively, a electric vehicle converts about 59-62\%). [13] This is partly due to the fact that as engines grow smaller they sacrifice efficiency for size.

When changing from internal combustion engines to electric engines, there are two different sources of emission reductions. The first is the increased efficiency mentioned above. As the electric vehicle is charged with the energy from the grid, and has a higher efficiency doing so, which directly results in reduced emissions. The second emission reduction is related to the emission reductions of the energy generation. If energy generation becomes cleaner (by using renewable energy for example), the transport emissions are also reduced since the only emissions from electric vehicles are the emissions from the energy generation itself. Comparatively, an internal combustion energy does not get cleaner as it always uses the same fuel. [14]

2.5 Emissions from Industry

For this project, this category of emissions include energy generation (separate from the energy generation mentioned in section 2.3), and emissions from industrial processes. The first type is affected by switching energy generation towards renewable energy or nuclear, while the second is not.
Chapter 3

Method

This chapter will discuss primarily how the visualization was put together to ensure that all the relevant data was visualized in an intuitive way, how the interaction was designed, how the data was selected as well as the algorithms used and finally how the user studies were designed and executed.

3.1 Development engine

For the visualization development, the Unity engine was chosen. This was due to several factors, the most important one being previous experience. Since the focus was on developing a complicated and intricate visualization, not having to learn new development tools was a large factor in the choice. Unity also had the advantage of being well-documented as well as having a large community to aid with problem solving and sharing ideas and solutions. Finally, Unity had all the required functions needed to complete this project.
3.2 Visualization design

Figure 3.1: The full initial screen of the visualization, showing emissions for the three major contributors: USA, EU28 and China.

The visualization was created with the “Visual Information-Seeking Mantra” in mind, namely overview first, zoom and filter, then details on demand. [15] It’s important for a visualization can display more information as needed, and remove it when not needed. [16, p. 317]

3.2.1 Map and View mode

First, a suitable map was purchased from an Internet vendor. The map was chosen based on simplicity, accuracy and resolution. The reason for having a simple map was to not distract from the rest of the visualization, and because humans tend to identify contours much faster than real life images. [16, pp. 336–343] The maps only purpose is to identify which country the emissions belong to, and to not be distracting. Since the map was a representation of reality, it also needed to be accurate.

Additionally, the map was designed with a small color palette, and the menu was chosen around those same colors, with differences in
shades. This creates a sense of unity in the composition. [17, p. 175]

Finally, because the design of the visualization was to have a 3D environment with a moving camera (as is standard in the Unity engine), the map needed to have a high resolution so that the camera could zoom closer without it having a negative effect on the visual quality of the map. In order to solve this, the map chosen was a vector map, which was then processed at a very high resolution (10000 x 7500 pixels) before being loaded into Unity.

The map was then split into two different modes, “Major Contributors” and “World”. When selecting “Major Contributors”, China, the USA and the EU were highlighted, and only their emissions were displayed. When selecting “world”, continent emissions were displayed (in this visualization, the continent emissions displayed were Asia, North America and Europe) while zoomed out, and country emissions were displayed when zoomed in (in this visualization, only the EU countries emissions were displayed).

Figure 3.2: The map when “World” is selected and the user is zoomed out. The major contributors view is shown in the image on the previous page. The UI is cropped out.
The only ways of navigating the map was panning (to move between regions at the same level of zoom) or zooming (to zoom in or out on the selected region). This was because these two operations help maintain a user’s mental model of data (in this case the world). [18, pp. 117-118]

### 3.2.2 Emissions and their size

To visualize emissions, the Unity particle system was used. The particle system was modified to resemble smoke (see Appendix 1 for specifications of the settings used), and then shaped into moving spheres before being placed on top of the map, in the middle of the country the emissions represented.

Spheres were chosen since the focus was to get an overview rather than an exact comparison (exact comparisons could be made with the information box discussed in section 3.2.3), and circles (or spheres) are an good way to achieve that goal, especially for a large number of values, which the user get when they look at individual countries. [17, pp. 40–43]
The particle systems were set to move rather than stay still in order to draw the immediate attention of the user, as humans tend to focus on moving objects before anything else. The particle systems represent the most important data (emission amounts), and therefore the users should focus on them first. [17, pp. 104–105]

Additionally, when similar objects (in this case the clouds) are shown with different sizes, that difference “pops out” via pre-attentive processing, highlighting the fact that the countries/continents that the clouds represent have different amounts of emissions. [18, pp. 40–47]

An argument could be made that the “emission clouds” could be represented in a simpler way (for example with flat textured circles rather than particle systems), however, more interesting visualizations can improve memory and recall of the data visualized. Since that was the goal of this visualization, a more elaborate design was given to the core data point, the emission amounts. [17, pp. 68–92]

When scaling the particle systems, the most important factor was to accurately depict the relation between different emission levels. For this purpose, China, the single largest emitter, was used as a baseline, with a 2x scale of the original particle system. Every other country was then scaled in relation to China (if, for example USA has 48% of the emissions of China, it would then be scaled at ($2 \times 0.48 = 0.96$) a 0.96x scale of the original particle system.

While some level of abstraction is acceptable (as the main factor was to depict relations between countries rather than exact emission amounts), this scaling system was not tested. In addition, comparing areas of circles or volumes of spheres is a relatively low-accuracy comparison method. [18, p. 55] Therefore, a necessary part of the project was to determine whether or not this method was accurate enough.

### 3.2.3 Emission sources

To display additional information about the emissions, a optional information box (or info box for short) was added. This box appeared when a country was clicked, and displayed more information about that specific country.
The info box contained what “ranking” that country had in the world in terms of emission amounts (with China being #1 and USA being #2), the percentage of the world’s emissions that originated in that particular country (with China for instance having 29% of the world’s emissions) and the country name, and additional information about that country’s emissions.

Additionally, the info box contained a pie diagram showing the sources of that country’s emissions, which was color coded to match the relevant adjustment slider (see section 3.2.5). A pie chart was chosen because it is very familiar to users. [17, p. 54] The color coding was done because it demonstrates a relationship between the field and the slider. [18, pp. 71–74] [16, pp. 190–192]

Finally, each box contained a “Lock values” button which could be used to make local changes for that country alone (see section 3.2.6).

### 3.2.4 Emission levels compared to goal

To show the current emission levels compared to the emissions level of the set goal, a gradient green-red bar was used.
Green was used to symbolize a reached goal whereas red was used to symbolize a emission level above the set goal. To show where the current level was, a black arrow indicator was added to the bar. This arrow gave a general idea of where the country’s emissions level were compared to the goal, but was not very exact.

If the user wanted to get an exact idea of whether or not the goal was reached, the previously mentioned information box contained a “traffic light” next to the country name, which showed red or green depending on whether the goal was reached or not.

### 3.2.5 Interaction (adjusting different emission sources)

Using the previously mentioned sliders, the user could change the variables mentioned in section 1.5, and see the effects that would have. They could also be activated/deactivated if the user wanted to only change a subset of them.

![Sliders](image)

Figure 3.6: Here Industry is deactivated and defaults to its starting value. Renewable Energy is decreased to 13% and Electric Vehicles is increased to 37%.
The sliders also included a text box which could be used to add a percentage directly, or just to get an exact reading of the current percentage. This was done to increase precision if the user wanted to enter an exact value or get an exact reading.

To give an indication of what the changes would do, the sliders were color coded to match the relevant field of emission sources (see section 3.2.3 to see the different sources and their colors), so for instance the “Renewable energy” slider was color coded to match the “Energy” field, since that is what would be impacted most by adding or removing renewable energy.

Sliders in combination with input boxes was chosen over having only input boxes because the objects themselves (in this case the sliders) should suggest their purpose, in this case to be dragged in order to manipulate some value (that value was further color coded to indicate what the user was manipulating). [17, p. 189]

The other two sliders were “Electric Vehicles” (color coded to the “Transport” sector) and “Industry” (color coded to the “Industry” sector). The industry slider started at full value and decreased, since it represented removing X% of industry rather than increasing (as was the case with renewable energy and electric vehicles).

Colors for the different categories were chosen to be optimal for this type of labeling, that is they were distinct, with unique hues, on every background they appeared on. They correspond to the 12 recommended colors for coding. [16, pp. 123–127]

The start values of the different sliders were set to the reflective of the current situation, or at least a close approximation (except for the industry, which was set to 100% as it represented what percentage of industry the user had removed).

When the sliders (or input boxes) were manipulated, the “emission clouds” currently displayed changed size accordingly over the course of a few seconds. This has the effect of making the changes “pop out”, making the users highly aware of what effects their changes had. [18, p. 51] This immediate response also makes sure that the users understand that there is a correlation between their manipulation of the sliders and the amounts of emissions (“emission clouds”). [18, p. 147] Finally, the reason the changes are made over a few seconds and not
immediately is so that the users don’t miss the changes due to change blindness or inattention blindness. [18, pp. 177–180]

3.2.6 Global and local interaction

The interaction mentioned in section 3.2.5 could be applied in two different ways, globally and locally. When applying the changes globally, they affected every country that was not currently locked. When applying the changes locally, they affected only the particular country whose information box (see section 3.2.3) was currently opened. This was done automatically whenever an information box was opened, and reverted back to global changes as soon as the information box was closed.

To lock a country, the user pressed the lock button on that particular country’s information box. To unlock, it was pressed again. When a country was locked, the only way to change that country’s slider values was to click it and open the information box.

To remove all locks, the “Reset All” button could be pressed (this also reset the slider values to their start values). If the user pressed “Reset Shared” instead, all sliders were reset to their initial values, but the locked values were unaffected.

3.3 Algorithms

There were several algorithms designed, in order to calculate the new emissions once the user had made changes to the levels of renewable energy, electric vehicles or industry. They were based on data for the reduction rate of doing that particular change compared to the average (for instance, renewable energy generation compared to average energy generation yields an approximately 90% reduction in emissions [19] [20], while electric vehicle yields an approximately 54% decrease in comparison to the average vehicle). [21]

The reduction rates were then combined with data on the different emission sectors for that particular country (see section 3.2.3) to determine how the country’s emissions (as well as the relative sizes of that
country’s emission sectors) were affected by the change.

The algorithms used are as follows:

First energy emissions are calculated by adding emissions from energy generation and the energy part of industry emissions.

\[
E_e = E_{eg} \ast E_{ie}
\]

Where \( E_e \) is total energy emissions, \( E_{eg} \) is emissions from energy generation and \( E_{ie} \) is emissions from industrial energy generation.

Then the amount of saved emissions from renewable energy is calculated. The input percentage of renewable energy is reduced by 22 as that is the starting percentage for renewable energy.

\[
S_r = (I_r - 22) \ast P_r \ast E_e
\]

Where \( S_r \) is saved emissions with renewable energy, \( I_r \) is the user input percentage of renewable energy minus the starting point and \( P_r \) is the percent reduction for renewable energy.

Next, the amount of energy emissions left in the industry sector is calculated.

\[
L_{ie} = (E_{ie}) - ((I_r - 22) \ast P_r \ast E_{ie})
\]

Where \( L_{ie} \) is amount of emissions left from industrial energy generation.

Next, emissions reduction for Electric Vehicles in the transport sector is calculated, factoring in the amount of renewable energy.

\[
R_t = P_t + ((1 - P_T) \ast (I_r - 22) \ast P_r)
\]

Where \( R_t \) is the emissions reduction factoring in the amount of renewable energy and \( P_t \) is the percent reduction for electric vehicles themselves.
Then the emissions saved with usage of electric vehicles is calculated.

\[ S_t = I_t \times R_t \times E_t \]

Where \( S_t \) is emissions saved from the transport sector, \( I_t \) is the user input percentage of electric vehicles, and \( E_t \) is the total emissions from transport.

Next, emissions saved from reducing industry is calculated.

\[ S_i = I_i \times P_i \times (E_{ip} + L_{ie}) \]

Where \( S_i \) is emissions saved from industry, \( I_i \) is user input percentage of industry remaining, \( E_{ip} \) is total emissions from industrial processes, and \( L_{ie} \) is remaining emissions from industrial energy generation.

Then we can finally calculate the total amount of saved emissions by simply adding the amount saved from each sector and removing it from the amount we started with.

\[ S = S_r + S_t + S_i \]

### 3.4 Evaluating the project with the target group

Once the visualization was finished and all the data was added, the next step was to evaluate the visualization to see if it achieved the goals set for the degree project and the visualization itself.

#### 3.4.1 User studies

The evaluation method chosen was user studies with members of the target group (students in year 7-9, aged 13-15). This was because this was the most effective and accurate way to evaluate the visualization,
since the objective of the thesis group is to inform. Why this particular target group was chosen is expanded upon in section 3.4.3.

The user studies were designed based on structural analysis, where every task had the purpose of testing some aspect of the visualization to see if it achieved what it was meant to achieved, and was intuitive enough that the users understood its function on their own, or by testing it for themselves. At the same time, the users were asked to report on their understanding and their perceptions. This type of structural analysis is especially appropriate in the study of computer interfaces and visualizations. The tools used were semistructured interviews (with rating scales) and tasks (with task analysis). [16, pp. 398–400]

With a large enough number of user studies, the results would be statistically significant enough to determine whether or not the visualization had achieved its goal. The more user studies that could be done the better, but the number set for this degree project was between 10-20, depending on availability of users that wanted to participate.

3.4.2 Tasks and motivations

First, the users were given a short interview designed to give an approximate idea of their current knowledge of the current situation of carbon emissions, they were also asked to rate their current knowledge on a scale from 1-10.

The pre-interview questions were as follows.

What do you know about climate change? How would you rate your knowledge from 1-10?

The rating was not meant to be used as a representation of their knowledge, but rather to judge whether the rating increased after using the visualization, showing that the student felt their knowledge had increased.

Which country in the world (and if that question was correct, the EU), do you think has the most emissions?

This question was also meant to be compared to the same question asked after the test, to see if the students had learned the answer with
the visualization.

*How do you think we can reduce emissions? What ways are there?*

Similarly, this question was also to be compared to the same question asked afterwards.

Then, the users were asked to perform a series of tasks on the visualization. These tasks were as follows:

1. **While looking at Major Contributors (US/China/EU), based on the visual only, rank them from biggest to smallest in terms of emissions, and state their relative sizes**

This question was designed to show that the users could tell size differences, and also size relations. So if they judged China to be the biggest particle system (or “smoke cloud”), and USA to be the second biggest, they also needed to qualify that statement (e.g. “USA is 50% the size of China, and the EU is 30% the size of China”).

2. **Go to “World” and then zoom in on the EU. What are the three countries with the biggest emissions, and in what order?** This question was designed to see firstly how easily the user could navigate the visualization, and then how well they could see size differences when it wasn’t obvious. The two largest emissions in the EU are easy to see visually (Germany then the UK), but the third, fourth and fifth are very similar in size. So, the users needed to use the information boxes in order to get this question correct.

3. **Go back to “Major Contributors” and use the lock function on each country, and try to balance their pie diagram sectors as closely as you can.**

This question was designed to see if users understood the lock function, and to see if they understood the pie diagram and the relation between the emission sectors and the changes they could make (e.g. the relation between the energy sector and renewable energy).

4. **Reset all the changes you made, and set the target to the Paris Agreement for 2030. Now try to reach the goals set by all the major contributors, by making as few changes as possible.**

This question was designed to see if the users understood how to reset their changes, and to see if they understood the arrow and the gradient bars. It also was designed to give them some perspective on how the
different changes affected the countries differently, and how hard the various changes were to reach. The reason the “making as few changes as possible clause” was added was to that the users didn’t just max out every slider as the task would then have been very easy and much less constructive.

5. Reset your changes again, and go to Sweden. Use the lock function and try to reach the goal for Sweden alone.

This question was designed to again show that the users could navigate the visualization (hopefully even easier than before), that they now understood the lock function completely, that they understood the gradient bar and the goal set, and finally to give them some insight in what Sweden’s pie diagram looked like and what that meant for our emissions in particular. Sweden was chosen since it’s the country we live in, which hopefully makes it more relevant for the user.

Once all the tasks had been completed, the user was given a post-interview similar to the pre-interview, designed to judge their knowledge in climate change and see if anything had changed, and were once again asked to grade their knowledge on a scale from 1-10. Finally, they were asked some additional questions on the visualization itself, if there was anything they thought was hard to understand, that they would have liked to see included, or simply had additional questions about.

The questions in the post-interview were as follows.

*What did you think of the project?*

Asked first to get the student to reflect on their experiences.

*Which countries (World/EU) do you think has the most emissions now?*

This question answer was intended to be compared with the same question in the pre-interview to see if the answer had changed, which would indicate increased knowledge.

*What ways are there to reduce emissions? What was the most important?*

Also a question to be compared to be previous answer.

*What did you think when trying to hit the Paris agreement goals? Was there any difference between different countries?*
This question was intended to judge whether the user now understood the differences in emission sources/target levels between countries.

*Did you feel like anything was missing? Would you add any features?*

Critical feedback on the visualization design itself, specifically the GUI/User interface.

*Did you understand the sliders and how they worked?*

Since manipulating variables is a major component of the visualization, it was vital that the way of interacting with those variables (via sliders) was intuitive enough that all the students understood the concept.

*Do you have any other thoughts or questions?*

More critical feedback, this time left more open.

### 3.4.3 Target group motivation

The target group was students in grades 7-9, aged 13-15. There were several reasons this particular target group was chosen. The main reason was their technical aptitude, a student aged 13-15 could reasonably be expected to be able to navigate a menu on a computer, and be expected to understand all information presented (as all information was written in English), while also being a baseline for the rest of the population. Another reason was the difference in experience. From a student in grade 7 to a student in grade 9 there was a 2 year difference in studying, which meant that grade 9 student was more likely to have some previous experience than the student in grade 7. Finally, availability, as students they gathered each day at their school to study, which meant an easy location for a user study.

Since the entire adult population can be expected to have completed grades 7-9 (but not necessarily any other education as it’s not mandatory), if the visualization was effective for the target group, it would likely be effective for the adult population as well, though this of course would need further study to prove.
3.4.4 User study setup

The user studies were conducted at a Montessori school in Stockholm, Sweden, with an allotted time slot of five hours, from 10 (10 am) to 15 (3 pm). The studies were conducted in a secluded room with one student at a time, to ensure that no other students could look at the visualization or hear any questions or answers before it was their turn to participate.

The entire length of each study was recorded (audio only) with a Samsung Galaxy S6 (except for the very last user study as that student did not consent to being recorded, and pen and paper was used instead to write down that students answers).

The pre-interviews and post-interviews were conducted face to face, with the questions written down on paper to make sure that all questions were asked. For recollection of the answers, the recording was used.

The tasks were performed on a laptop, running a dual-boot of Windows 10 and Ubuntu (for the tasks, the Windows 10 boot was used). The tasks were also written down to ensure they were all included, and the students were encouraged to do a “think-aloud”, where they stated their thought processes as they attempted to complete the tasks. User logs were generated automatically and contained the clicks and their respective timestamps for each user study.

The hardware of the laptop is included below.

<table>
<thead>
<tr>
<th>Processor</th>
<th>AMD A10-8700P 4 Core, 3.2 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphics Card</td>
<td>AMD Radeon R8 M365DX, 2GB VRAM</td>
</tr>
<tr>
<td>RAM</td>
<td>8G</td>
</tr>
<tr>
<td>Harddrive</td>
<td>256GB SSD</td>
</tr>
</tbody>
</table>
Chapter 4

Results

This chapter will discuss the results from the user studies. The results are split into three sections, representing the interview given before the tasks, the tasks themselves, and the interview given after the tasks were finished.

In total, 10 students took part in the user studies, distributed according to the table below.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Male students</th>
<th>Female students</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

4.1 Pre-interview

For the pre-interview, users gave themselves a knowledge grade of 1-10, and were asked questions to determine what they knew in advance. Specifically, their knowledge on major emitters and ways to combat climate change.

Overall, the theme of the responses was limited but mostly correct knowledge. More specifically, every student either knew or correctly guessed that China was the highest emitter, with 2 students out of 10 confidently stating China, 2 guessing China, and the other 6 stating “either China or USA”. In addition, 5 of the students were asked if
they knew the biggest emitter in the EU, with 1 correctly guessing Germany, 1 incorrectly guessing France and 3 having no idea.

As for questions regarding ways to combat climate change, the same theme emerged of limited but mostly correct knowledge. Specifically, every student asked named at least one way of combating climate change that was represented in the visualization, with transportation being the most commonly given answer (with 7 of the students as part of their answer giving some way of reducing transportation emissions). Clean energy was also given as an answer by 4 of the students. 1 student mentioned the meat industry, which is related to both industrial and agricultural emissions as well. Only 1 of the students had a comprehensive knowledge of ways to combat emissions before using the visualization, and stated that the reason for this knowledge was having a father that was actively working in the field.

After having been asked the questions, the users gave their rating of their own knowledge, which was an average of 6.1/10.

4.2 Tasks

4.2.1 Task 1

The first task was comparing sizes between the emission amounts of the three major contributors (USA, EU28, China) based only on visually inspecting the smoke cloud. Every student (10/10) was able to correctly determine the order of the emission amounts (China > USA > EU28), but not all students were able to correctly determine the relative sizes.

In reality, using China as a starting point (100%), the US has a relative size of 48% and the EU28 a relative size of 33%. For the task, since the question was asked broadly (with answers being given such as “half as big”, “a third” etc), an acceptable answer for the US was 50% (or one half of China), and for the EU28 33% (or one third of China).

Only 3 out of the 10 students gave an exactly correct answer (China 100%, US 50%, EU28 33%). 5 out of 10 students gave the correct size of the US, while 3 out of 10 gave a correct size of the EU28 (the same 3
that had the perfect answer).

The most common mistake was giving relative sizes that were too small, out of the incorrect answers, only 1 student gave an answer that was too large (China 100%, US 50%, EU 40%), and all the other incorrect answers (6/10) were too small on either USA, EU, or both.

The average answer for the relative size of the US was 42.9%, and the average answer for the EU was 25.9%. This meant that the average error when visually estimating sizes was 7.1, with the average error of the US and EU28 being 7.1 and 7.1 respectively.

Figure 4.1: US compared to China had a pretty even distribution, with most estimates being correct.
3.0 CHAPTER 4. RESULTS

Figure 4.2: EU28 compared to China had more split estimates, which 33% being the correct estimate.

4.2.2 Task 2

The second task was to compare emission amounts between countries that had emissions (and therefore smoke clouds) much more similar in size, and therefore requiring the user to make use of the additional information in the information box to give a correct answer.

As in task 1, every single student was able to correctly name the top three emitters in the EU28, in the correct order (Germany, UK, Italy). Every single student was also able to name the first two (Germany, UK) based solely on visually inspecting the cloud sizes, similarly to task 1. However, 9 out of 10 students could not tell the difference between the 3rd and 4th largest emitters (Italy and France) visually with any certainty, and therefore made use of the information box when giving their answer. 1 student was able to determine the size visually, but still used the information box to verify their answer.

The difference between Italy and France is very small (with Italy be-
ing the 19th largest emitter with 0.98% of the world’s emissions, and France being the 20th largest emitter with 0.91% of the world’s emissions), meaning that the visual difference is very slight, as you can see from the image below.

![Image of the three biggest emitters in the EU](image)

Figure 4.3: The three biggest emitters in the EU (Germany, then the UK, then Italy)

### 4.2.3 Task 3

This task entailed using the lock function in the information box on the three largest emission contributors and then trying to balance the circle diagrams of the emission sources with the sliders (Renewable energy, electric vehicles, industry). There were four sectors of the circle diagrams (Energy, Transport, Industry, Other), and due to the nature of the emission sources of the three major contributors, a perfect balance (25% energy, 25% transport, 25% industry, 25% other) was never possible, so the task for the user was to get as close as possible.

Every single student was able to finish the task by correctly using the lock function for all three major contributors. Every student was also able to get reasonably close to the optimal solution for each emitter in the task. In the graphs below you can see the average performance of the students compared to the optimal solution for each major contributor.

Deviation is given in percentage points (abbreviated as pp).
### 4.2.4 Task 4

In this task, the students were asked to find global percentages of the three variables (Renewable energy, electric vehicles, industry) that reached the Paris Agreement goals for the three major contributors. In order to prevent the students from simply maxing out each of the variables, they were asked to try to find the smallest change that still resulted in reaching the goal for all three of the major contributors.

There were various strategies to reach these goals depending on which of the variables the students preferred adjusting. The only variable that could not reach the goal alone was Electric Vehicles, as China only had a 6% transport sector.

The most common approach was to have at least 50% renewable energy (with the average being 65.9%, slightly inflated due to one student having 100% renewable energy and not adjusting the other two variables), and then add either electric vehicles (average being 26.9%) or remove industry (with the average being 67.7%, down from 100%), or both.

3 of the students relied on almost exclusively renewable energy (at 100%, 87%, 85%), while two more relied on only renewable energy and industry (63%/63% and 52%/40%). The other 5 had a mix of all three variables, with 2 focusing heavily on electric vehicles (89%, 81%) and the final 3 having a more evenly distributed percentage.

In regards to the optimal solution, most of the students made more changes that were necessary. The optimal solutions (in the sense of percentage points of changes made) depends on what distribution is chosen. Here are some examples of optimal solutions (total changes given as percentage points, abbreviated pp).

Note that optimal in this sense means that no field could be decreased while still reaching the Paris Agreement for all three contributors.
To achieve the least amount of changes, Renewable energy should be the main focus. The EV sector made very little difference as China was the bottleneck to reaching the Paris Agreement goals, while having a very small transport sector (6%).

With these optimal solutions in mind, here is the average solution the users made, and the optimal solution for that distribution.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Renewable</th>
<th>EV</th>
<th>Industry</th>
<th>Total changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average solution</td>
<td>65.9%</td>
<td>26.9%</td>
<td>67.7%</td>
<td>102.1 pp</td>
</tr>
<tr>
<td>Optimization</td>
<td>62%</td>
<td>23%</td>
<td>72%</td>
<td>90 pp</td>
</tr>
<tr>
<td>Excess change</td>
<td>3.9 pp</td>
<td>3.9 pp</td>
<td>4.3 pp</td>
<td>12.1 pp</td>
</tr>
</tbody>
</table>

In addition to the average distribution being inefficient (by including EV and industry), the average solution changed 12.1 percentage points more than was necessary, which meant the average solution was 11.9% larger than the optimal solution for the same distribution.

**4.2.5 Task 5**

For the final task the students were asked to lock Sweden, and attempt to reach the Paris Agreement goal set, while taking the emission sources into account.
Sweden’s largest emission source is transport, and the goal of the task was to show that the students understood how to read the circle diagram and the emission sources (thus understanding that transport was the largest source), that they understood the correlation to the variables (thus wanting to adjust the electric vehicle-variable more than in the previous example), that they could use the lock function without being told how, and that they could reach the Paris Agreement goal as closely as possible without being prompted. When trying to reach the Paris Agreement target, the average value of the electric vehicles variable was 58.6%, compared to the 26.9% average value from task 4. The second largest emission source of Sweden is energy, which saw an average value of 46% compared to the 65.9% of task 4, and the smallest sector the users could influence, industry, saw an average value of 89.3% (down from 100%), compared to 68.7% in task 4.

Here is an image depicting the average change and the effects those changes had on Sweden’s emission sources.
4.3 Post-interview

The purpose of the post-interview was to see if the users had gained new knowledge, if that new knowledge affected their own opinions on their knowledge of climate change (via their self-rating) and if they had any feedback regarding problems they had with the visualization itself.

When discussing which countries had the most emissions in the world and in the EU28, every student gave a confident answer of China (in the world) and Germany (in the EU28).

When discussing ways to reduce emissions, every student named at least two of the three methods of emission reduction in the visualization, with 9 students mentioning renewable energy, 10 students mentioning industry emissions, and 9 students mentioning transport/electric vehicles.
When asked if they had noticed any difference in emission sources between countries (or differences when trying to reach the Paris Agreement), every student said that they had. When asked for examples of these differences, every student mentioned differences in industry emissions (with China having a lot more with nearly 50%, and US and China both having more than the EU28). 5 mentioned energy emission differences, with 4 of them naming EU28 as having more energy emissions than the other two major contributors. 3 students mentioned Sweden having more transport emissions in particular.

The students were also asked about their opinions on the visualization design of having sliders adjust the variables, and all students said they understood the concept well.

As for problems with the visualization design, one student mentioned having trouble navigating the menus/map system, and one student mentioned having trouble closing the information box. There were no other mentions of things that the students found hard to understand, but there were two students that asked for additional features. These were having a circle wireframe appear in the cloud when the information box was opened, to make the visualization of the emission sizes more exact, and the other was having the world percentage of emissions written directly on the cloud rather than in the information box.

Finally, the students were asked to once again rate their own knowledge, and they now gave themselves an average score of 7.62/10 (compared to the initial score of 6.1/10).
Chapter 5

Discussion and conclusion

This chapter will be a subjective analysis regarding the results from the previous chapter. The tasks mentioned in section 3.4.2 were judging relative emissions visually (task 1) with numbers from the information box (task 2), as well as understanding and balancing emission sources (task 3), understanding the different requirements to reaching the Paris agreement, and finally the specific requirements for reaching the Paris agreement for our country, Sweden.

5.1 Results of user studies

5.1.1 Size differences

When it came to judging size differences, it was clear that the users could distinguish which particle system was larger, given at least a somewhat significant difference. The users only needed the additional help of the information box when the difference was smaller than 10%, as was the case between Italy (0.98% of world emissions) and France (0.91% of world emissions).

However, when it came to judging the exact difference visually the users struggled. When reviewing the results for task 1, every user had the correct order of countries but only a few of them had the correct size percentages, though most were reasonable close (with the worst estimate for USA/China being 33% instead of 48% and the worst
estimate for EU/China being 15% instead of 33%). The average for USA/China was 37.9%, with the real number being 48%, and the average for EU/China was 25.9%, with the real number being 33%.

This still constitutes an acceptable error margin since the goal of the visual particle systems was not to give an exact understanding, but rather give an estimate, and rely on the information box for exact numbers. This could be seen in task 2, where the users had to compare the sizes of very similarly scaled particle systems. Every single user got the correct response (which was Italy being the third largest emitter in the EU), by using the information box. Only one user was able to tell it was Italy without using the information box.

5.1.2 Emission sources

As for emission sources, all users were able to understand the purpose of the circle diagram/pie graph, and understand what the different pie graphs represented. I was initially worried that it would not be intuitive enough, but every single user understood the significance of the relative sizes of the different slices, and could recall differences even after the visualization was closed. This shows that the diagrams were an effective way of showing the differences in emission sources.

This was clearly seen in Task 5, when the students showed that they clearly understood Sweden’s emission sources as they took them into account when trying to reach the Paris Agreement.

In general I think the color-coded, dynamic pie graph clearly communicated what it was meant to communicate. Every user quickly grasped the connection between the sliders and the pie graph, which meant that it was an intuitive way of displaying the information.

5.1.3 Local/global changes

Some users had some initial confusion when attempting task 3, in particular when it came to locking and changing individual countries. They grasped the concept very quickly (as in a short sentence of explanation), but the initial confusion might pose a problem if there is no assistance nearby.
Once the users had grasped the concept of locking and making individual changes, the actual execution was very straightforward and none of them had any issues whatsoever when locking/changing the EU and China, as well as when locking Sweden in task 5.

There was a little confusion about the information box making individual changes. In the current design, the user makes local changes whenever the information box is opened, and “saves” them by locking the country. After having conducted the user studies, I feel that a better design would be to do global changes even when the information box is opened, and only do local changes when the lock button is pressed.

However, once the users understood the design paradigm (open information box means local changes), they had very little difficulty in adapting to that paradigm. However, it was not what they intuitively assumed. Since the goal is to create a stand-alone visualization that can be used without assistance, the intuitive design is the better one, even if the current design is not difficult to understand or adapt to.

### 5.1.4 Reaching goals (the Paris Agreement)

Some users were initially confused about the purpose of the gradient bars/the black arrow, they quickly grasped the purpose once they were asked to try and reach the Paris agreement.

The risk is that first-time users will be intimidated by the bar/arrow. Since the goal is for the visualization to stand on its own, it might be necessary to include a tutorial or guide in order to not intimidate any users from using the visualization.

Once the users grasped the purpose of the bar/arrow they were very quick to adapt. Something that was interesting to note was that the users themselves correlated this task to task 3, where they were asked to balance the emission sources. Since they had previously discovered that China had a very large industry sector, they were more inclined to adjust the industry slider when trying to reach the Paris Agreement for China in particular.

The users also immediately grasped the purpose of the “traffic light” in the information box, using the bar/arrow to get a general sense of
how close they were to the goal, and using the “traffic light” to con-
firm whether or not they reached the goal, and make smaller adjust-
ments.

This confirms that the bar/arrow is intuitive to use, once it’s been un-
derstood. The initial confusion that some users have merits further
study. A second user study may be required with users who get no
assistance what so ever, to ensure that they still grasp the significance
of the bar/arrow as well as the traffic light.

To further illustrate this point, in task 5, none of the users needed any
assistance with any of the functions. They could navigate to Sweden,
open the information box, lock the country (to adjust it locally), and
reach the Paris Agreement while taking into consideration the partic-
ular makeup of Sweden’s emissions (that our energy and transport
sector are both fairly large). All of the users preferred to manipulate
Sweden’s renewable energy and electric vehicle sliders, indicating that
they understood the connection between the sliders and Sweden’s cir-
cle diagram.

One final thing to note is that when users were trying to reach the Paris
Agreement with minimal changes (task 4), they tended to favor chang-
ing all fields, despite that the smallest change possible was achieved
when changing only renewable energy. This is likely due to the fact
that the different emitters have different energy source distributions
(the US is heavy on transport, the EU is heavy on energy, and China is
heavy on industry), but since China was the major bottleneck, chang-
ing transport was mostly pointless.

In addition, the users also made more changes than was necessary,
even when accounting for the inefficient distribution (with the average
answer making 11.9% more changes than were necessary). However,
considering that the users were using the visualization for the first
time with no prior knowledge, having the average answer be 11.9%
too large is acceptable, especially when considering that the answer
was never too small (which would indicate that the user failed to reach
the Paris Agreement for some country).
5.2 Method criticism

There are two main areas that could potentially be criticized, the data used and the accuracy of the algorithms that were created and implemented.

5.2.1 Data

While the data always came from trusted sources with authority on the subject (such as the European Commission and the Environmental Protection Agency), there were several cases where the data was mismatched and where some compromises occurred. In this visualization, there are two occurrences of this happening.

The first is a 2-year difference between some of the different datasets. Namely, the data on emission amounts is more recent (2014/2015), whereas the data on emission sources per country is older (2012/2013). This means that the data on emission sources is slightly outdated, and could potentially be wrong. However, the data on emission sources was intended to give a general idea of how emission sources differ between countries, and so some I considered some slight inaccuracy acceptable. Obviously a more recent study on emission sources is preferable but none was found. A potential improvement on the visualization would be to either use completely new data for everything, or to verify the accuracy of the dated data.

Secondly, there was a mismatch in the emission data, also between emission amounts and emission sources. The emission amounts data was available in CO2, which was what the visualization was aimed towards, so that data was used. However, the data for emission sources was only available in GHG (Greenhouse gases), which includes other gases that also contribute to climate change. The reason I deemed this an acceptable compromise is that CO2 accounts for more than 90% of all GHG, and most of the other GHGs are emitted from the same sources as the CO2 is. In the very worst case, this meant that the emission sources (and only the emission sources) were 10% inaccurate. Realistically, the error margin was likely only a few percentage points since all GHG have similar sources, which I deemed an acceptable error margin as the emission sources, like the emission amounts,
was meant to give the user a general idea rather than knowledge of the exact numbers. Ideally, the emission source data would be in CO2 only, but such data was not available and a compromise had to be made.

5.2.2 Algorithms

The algorithms themselves were discussed in section 3.3. The criticism that could be made towards the algorithms is their accuracy. The reason for this is that their accuracy is very hard to test in depth, as there is very limited data on how changes to renewable energy or electric vehicles would affect every country.

In addition, to simplify the visualization, and allow the user to change the variables globally, the amount of renewable energy and electric vehicles had to be averaged for the world, which meant that different countries would be misrepresented. A potential change would be to have local percentages for these variables, but this was decided against because it would make the local/global changes very confusing for the user. This could potentially be implemented and the results compared with the existing results, to see if the added accuracy would be worth the added complexity.

Another aspect is that not every country has the same types of transport or energy generation. The emissions saved by switching to renewable energy or an electric car is dependent on what the energy types (nuclear, coal, natural gas, et cetera) and the vehicle types (diesel, petrol, hybrid, et cetera) that particular country had to start with. Due to the scope of the degree project, including all these variables for every country was not feasible, and were instead averaged to give a simpler, more cohesive visualization.

With more resources, all these variables could be included rather than averaged to give a more accurate representation of how changing renewable energy, electric vehicles and industry would affect individual countries. However, considering the scope of the project as a proof-of-concept, this level of accuracy was not needed in order to determine whether this type of visualization was effective at increasing knowledge.
5.3 Future work

Due to the visualization being a proof-of-concept, there are two different types of possible future work: developing the proof-of-concept to a complete product, and expanding on the scientific analysis.

5.3.1 Regarding the visualization

To develop the visualization, the main things required are more data and more work. At the moment, only the three major contributors (China, USA, EU28), their respective continents (Asia, North America, Europe) and the countries within EU28 are included. For a complete visualization, every continent and every country should be included.

This brings with it the potential problem of performance issues, since every country has a particle system (the smoke cloud representing emission amounts) and a small GUI (the bar/arrow representing the status of reaching the eta goal) that are both updated at least once a frame, adding more countries means potentially introducing performance issues. There was no major performance issue problems in this visualization, but it is something to keep in mind.

Furthermore, the issue of mismatched data will also increase as more countries from different parts of the world with different methodologies are included and made to fit the same mold. As was mentioned in section 5.2.1, there are already minor issues with mismatched data, and that problem will continue to increase as the amount of countries represented increases.

A possible way of achieving this would be to develop the visualization into a website with an interface for inputting more data, essentially crowdsourcing the data and part of the work required.

In terms of visualizing emission sources, one student wanted the impact of the meat industry to be more clearly labeled. This could be accomplished by splitting the “Other” section of the pie graph into more clearly labeled sections, such as “Agriculture”, “Waste Management”, etc. These could then be further split. The reason against doing so is that it will create a lot more complexity when reading the pie graph
initially, and since only one out of the ten users requested it, the general simplicity of the visualization should be taken into account.

A possible way to implement it would be to have it as an optional display. For example, if the user wanted to see a breakdown of a particular sector, they could click the section they are interested (for example “Other”), and it would split up into several smaller sections that represent what that section was made up of.

Lastly, this visualization was deliberately made very simple. The smoke clouds are one-dimensional in the sense that they only convey the amount of emissions. Now that this version of the visualization has been proved effective, a possible next step would be to make it more complex and see if it still is an effective tool.

Examples of this type of increased complexity could be to color-code the smoke clouds, where a darker cloud means more emissions per capita. Another example would be to color-code the countries themselves to red or green depending on if they have reached the Paris agreement or not (or even some gradient in between to show how close the respective countries are for the current settings). One more possibility would be a drill-down style to the sliders or the information box, where the user can click the pie chart to get a further breakdown of emission sources, and then get multiple sliders to address these different emission sources.

5.3.2 Regarding scientific analysis

This degree project proved the visualization to be effective for one target platform, one set of tasks and one target group. To ensure that the visualization is indeed effective, all of these three fields could be expanded upon.

To try the visualization for different platforms, it would first need to be ported to that specific platform. For computer based platforms this is fairly trivial, as Unity is easily portable, and the same tools (mouse and keyboard) are available. However, it is harder to port the visualization to platforms that lack these tools. The most relevant example of these types of platforms are smartphones and tablets.

The infrastructure required is already built in. All camera movement
is done with mouse dragging, which can be replaced with finger dragging on a touch screen. Menu navigation and opening the various countries information boxes is mouse clicks, which can be replaced with touches. The zoom is operated either with the scroll wheel (which can be replaced with pinching on a touch screen) or clicking the zoom buttons (which also can be replaced with touch).

The main issue there is to change the code so that it accounts for touch-based actions instead of mouse-based actions, and making it work for smaller screens. Some level of accuracy is needed to open the information box for the correct country and to operate the sliders, which could be significantly more difficult on a smartphone as the screen is smaller.

As for the tasks, their motivation is discussed thoroughly in section 3.4.2. These tasked proved to be very effective, but as the goal of the final visualization is to have the users be able to use it without supervision, the tasks should not be mandatory. One option is to have the information learned from performing the tasks present in some other way (e.g. with a tutorial or with a clickable question mark interface on the relevant places). Therefore, a potential future study could be performed in order to determine how much information and guidance the user needs to be able to operate the visualization on their own.

Finally, the target group. As mentioned in section 3.4.3, the target group was chosen because it was deemed the most suitable for a single user study. However, if more user studies were performed it would be constructive to try using different target groups. Both younger and older students could perform the user study to see if the effectiveness increases or decreases based on age. Significantly older adults, perhaps with limited technical experience, could also perform the user study to see if there is a point where the effectiveness starts to decline due to the platform.

These user studies could also be combined, to see if there is a difference in the additional information required based on the target group (i.e., maybe younger students need more help to understand the visualization, whereas older students barely need any at all).
5.4 Conclusion

In short, my conclusion is that the goal of the degree project was reached.

The first objective was to create a visualization of carbon emissions that communicated data on emission amounts (both generally and individually), emission sources, and the target emission levels set by the Paris Agreement, as well as let the user manipulate the data interactively by changing amounts of renewable energy, electric vehicles and industry. Chapter 2 describes in detail how this visualization was designed and created.

The second objective of the degree project was to test this visualization with members of the target group to see if the design of the visualization was effective at communicating the information, and intuitive enough that the members of the target group could complete the tasks. Chapters 4 and 5 discusses why and how these user studies proved that the visualization reached this goal.

With both these objectives achieved, the hypothesis stated in the thesis problem of section 1.4, namely that the visualization would be able to better inform members of the target group regarding the current state of emissions and ways to reach emission goals, has been proven to be correct, for the chosen target group and the chosen platform, using the chosen tasks. In order to determine if the visualization reaches the objectives for every target group (and for other platforms and other tasks/no tasks at all), future studies are required.
Bibliography


Appendix A

Unity Particle System Settings
Appendix B

Sources for carbon emission data

B.1 World emission amounts and targets data sources

All visited on 24/01/2018.

EDGAR Trends in global CO2 emissions 2015 report

Carbon Brief’s Paris climate pledge tracker INCD database
https://docs.google.com/spreadsheets/d/1LtaBOv70pvXVPDgLUGtTKnSxojfZy7jx06bTSaM/edit?usp=sharing

What are Europe’s biggest sources of carbon emissions? World Economic forum

Air and greenhouse gas emissions by industry, OECD

CO2 Emissions, Global Carbon Atlas
http://www.globalcarbonatlas.org/en/CO2-emissions
B.2 Country emission data sources

USA


China

Evans, Simon, Climate pledge puts China on course to peak emissions as early as 2027, Carbon Brief, visited on 24/01/2018


EU28

All EU28 data taken from the United Nations Framework Convention on Climate Change, UNFCCC. All links visited on 01/24/2018.

Austria
https://unfccc.int/files/ghg_emissions_data/application/pdf/aut_ghg_profile.pdf

Belgium
https://unfccc.int/files/ghg_emissions_data/application/pdf/bel_ghg_profile.pdf

Bulgaria
https://unfccc.int/files/ghg_emissions_data/application/pdf/bgr_ghg_profile.pdf

Croatia
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