

6.s898 Final Project: The User Interface of En-Roads

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December 1, 2019

1 Introduction

The vast majority of climate scientists (at least 97% [CNG⁺13]) have agreed that the world is warming significantly due to humanity’s carbon emissions. This warming could have drastic consequences worldwide. Likely consequences of a temperature rise of more than two degrees Celsius include significant sea level rise, an increase in frequency of massive tropical storms, as well as drought that threatens agricultural yields of key crops, such as wheat [MPP18]. However, carbon emissions are at the center of many technological advancements that define modern life. Our current transportation, electric power, and heating and cooling of buildings all cause significant carbon emissions, by burning fossil fuels. Even our production of buildings, vehicles, and food emits carbon. To add to the problem, the International Panel for Climate Change (IPCC) states that to curb emissions to below 1.5°C, which is likely necessary to avoid many of the significant effects of climate change, we will need to have net zero carbon emissions by 2040 or 2050 ([RSJ⁺18]).

This is a daunting task for many reasons. Sterman [Ste11] mentions that a major reason is the deficiency of our mental models to intuitively grasp details of the climate crisis that are so important. We are not good at understanding the terms “positive feedback” and “negative feedback,” as these phrases have been co-opted to mean “good” and “bad” responses. But understanding positive feedback is essential to appreciating the consequences of melting ice caps. As the ice caps melt, the albedo (or reflectivity) of the surface of the earth decreases, and trapped methane gas is released into the atmosphere, causing an additional net warming effect that contributes to melting more ice. We have difficulty distinguishing the *rate* at which greenhouse gas emissions are changing, as opposed to the total amount of greenhouse gases. Sterman notes that most people, including MIT graduate students, tend to instinctually feel that stabilizing net green house emissions at a positive value will solve the climate crisis. This behavior occurs even when the scenario is a simple example from everyday life, and also occurs to people with high STEM (science, technology, engineering, and/or mathematics) knowledge. For instance, when reasoning about a bathtub with a spout and a drain, many people feel that stabilizing the rate at which the spout puts water into the tub will

stabilize the water content [Ste11, Ste08]. This obscures the extremity of the action required to actually keep temperatures below 1.5° or 2°C . Finally, people are tempted to sit back and observe the severity of climate change before deciding whether to act. However, since there is a significant delay between emissions and warming, let alone the consequences of global warming, this is not a reasonable method for addressing climate change.

Due to the scale of the problem, individual climate consciousness is insufficient - one person's decision to turn the lights off is not directly significant in reducing the effects of climate change. The world needs political action, and it needs it quickly. Unfortunately, current action on the climate is insufficient. The Paris Agreement was projected by the IPCC to bring warming down to about 3.2°C [Kin15, Clé16]. As evidenced by the United States declaring its intention to pull out of the Paris Agreement, even this level of curbing climate emissions is controversial. Policy geared towards climate change faces many hurdles in the United States. One reason for this is that the United States will bear less of the burden of climate change than developing countries like India and China. Additionally, the existence of climate change has become a politically contentious issue in the United States, with belief in climate change correlated with party affiliation [LMRR⁺18]. Climate education for policy-makers and the public is necessary to enact climate change legislation, and in the challenge of these obstacles, it promises to be a daunting challenge, especially in the United States.

The most sophisticated, state-of-the-art climate models are not the best tool for encouraging political action. The models are computationally intensive, often taking weeks to run on supercomputers. Furthermore, the results are not presented in a form that is easily digestible: the IPCC's reports are often hundreds of pages. Even the summary for policy makers, as pointed out by Sterman [Ste11], is difficult to read and relies on the use of jargon. Additionally, many of these climate models only consider the climate, which is insufficient for policy-makers; policy-makers want to be able to gauge the effectiveness of policies, which is not possible without economic and societal models as well. So lies the conundrum: on one hand, we want a model that captures the climate, economy, and society, but on the other hand, we want it to be accessible to policy-makers and run efficiently enough to respond to policy changes immediately on a laptop.

The En-Roads climate simulator (<https://www.climateinteractive.org/tools/en-roads/>) was made to fit precisely this need. It features climate, economic, and societal models with transparent assumptions that the user can look up and adjust. It hides the mathematical details of the model away from the user, but still gives the user the power to adjust policies using sliders. The user can choose which policies to change, and observe their effects immediately, from the convenience of their own computer. We now discuss En-Roads and the specific ways in which the makers intended people to interact with it.

1.1 En-Roads, Interactive Simulations, and Workshops

En-Roads was developed primarily to be used in role-playing exercises. In these exercises, a user who is trained with the En-Roads system (a *facilitator*) guides users through an interactive policy game. One instance of this is the *World Climate* exercise, where participants are split into different nations in a mock-UN debate. Each group decides policy initiatives they would like to enact and lobby against, and the groups discuss. By virtue of discussion, the participants decide on pledges that each of their groups are willing to commit to. Finally, the policies are entered into En-Roads, after which the participants can see the fruits of their labor. Alas, as noted by Rooney-Varga *et.al.* [RVSF⁺18] (who studied C-Roads, the precursor of En-Roads), these policies rarely ever get the temperature down to 2°C. Usually this first policy gets to around 3.3°C (similar to the projected outcome of the Paris Agreement under the default assumptions in En-Roads [Kin15]), to the surprise of those involved. This impresses the severity of the climate change problem upon participants of the exercise. They often question why their policies are not as effective as they thought, and the facilitator explains various dynamics of climate change that are present in En-Roads, like the “bathtub dynamics” of the climate. Finally, the groups convene again and come up with a new set of pledges, and try them out in En-Roads.

The *World Climate* process is highly popular worldwide, and has had great success in teaching participants about climate change. More than 42,000 people in 77 countries have participated in this process, and it has been integrated into official school curricula in Germany, France, and South Korea [RVSF⁺18]. Users who went through a role-playing game as documented above recorded high levels of engagement, and found that it was a good learning experience, would tell others about the experience, felt urgency to learn about how to address climate change, and felt motivated to address climate change afterwards ([RVSF⁺18], Figure 5).

En-Roads has also been used in non-role-playing policy workshops. In these, a facilitator who has been trained in hosting En-Roads workshops guides users through the En-Roads model. Users suggest policy changes to make, the facilitator makes the changes, and then the facilitator may help the users understand why certain changes affect the climate in the way they do. It is important that the facilitator be trained in using the En-Roads model, so that they can guide users to different parts of the application that would help them better understand the affect on the temperature that results from their actions. Just like in the *World Climate* exercise, the main purpose of the facilitator is to encourage interaction between the participants and guide the users in using the En-Roads application, rather than to explain climate policy to them. Indeed, this is perhaps the most critical part of learning from En-Roads - users learn about facts behind climate change by moving the sliders and talking with each other, rather than simply listening to facts that a facilitator tells them.

In both interactive simulations and non-interactive workshops, the basic format is that users decide what changes to make, the changes are made on En-Roads, the facilitator helps the users understand the changes using En-Roads. It is important to note that while the facilitator should *not* simply explain facts about climate change to the users, she is still crucial in helping the users interact with En-Roads.

However, people will not always use En-Roads in the presence of a facilitator. They will not even always use En-Roads in the presence of others. As of December 3rd, 2019, En-Roads was released to the public. People are encouraged to create simulations and share them with their friends and on social media. In this usage pattern, people use En-Roads *alone*. While the makers of En-Roads may make tutorials and documentation to explain usage to first-time users, users rarely look at documentation [GGJ⁺18a]. This motivates the main question that we study in this paper: what is the user experience of En-Roads like for a user who opens En-Roads for the first time when they are alone? Additionally, how can we improve the user experience, so that En-Roads influences lone users in similar ways to how it influences users in groups?

In this paper, we do not give definitive answers to this question. We do not even give statistically significant data for this question. Designing an effective user interface for interacting with climate change is an important question that is out of scope for this paper. What we did is talk to experts in human computer interaction, and conduct a user study with willing participants, to observe how they approached the site, what features they found and used, which they did not find, and what their thoughts and feelings were about the overall experience.

2 Some Preliminaries on User Interface Design

User interface (UI) design is an active area of computer science, and a subfield of human computer interaction. In this section we will focus on a few aspects of user design that are relevant to En-Roads. Users generally learn systems by using them, not by reading a manual [GGJ⁺18a]. In fact, this general principle is similar to the educational principle that guides En-Roads: throwing information at people is not an effective way to teach them about climate change. In the same way, according to basic principles of user interface design, throwing information at someone about how to use En-Roads is not going to be the most effective way to teach them how to use En-Roads, even if it is just because they will skip reading this information entirely. One could imagine that this is the case even if the information takes the form of a short video (as can be found on the new front page of the En-Roads simulator, <https://www.climateinteractive.org/tools/en-roads/>).

So we would like En-Roads to be usable by people who never seen it being used and who have not looked at any type of documentation or video about it. How do we test its efficacy in this

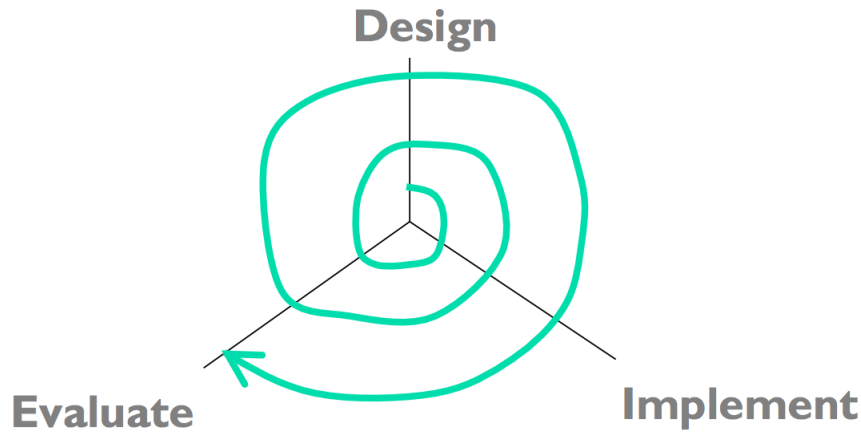


Figure 1: The spiral model of iterative user testing and design, from [GGJ⁺18b].

setting, and how should we go about designing En-Roads for this case?

UI researchers have developed a paradigm for this, centered around user testing. While many of these tests can be done remotely (e.g., gauging how much time does a user spends with their mouse hovering over a certain button, or asking a user a fixed set of questions about their experience), UI designers value directly working with the people who will use this interface. This is what we did in this project.

What can we get out of this approach, over the approach of Rooney-Varga *et.al.* [RVSF⁺18] that tested En-Roads by surveying thousands of people? For one, it is difficult to actually gauge what features of your webpage are important, or annoying, or in between, until you have a reasonable idea of how users actually use your system. This makes designing a static test that actually tells you everything you want to know about the user experience challenging. While such methods scale much better, the designer does not yet know if this is the actual information they want; it is akin to dropping your keys somewhere on the street and looking as hard as you can under the streetlight, because that is where the light is. To quote [GGJ⁺18b], “you won’t get it right the first time” - and we want to design tests with this in mind.

A standard paradigm for this is iterative testing, where we will have many iterations of designing the user interface, implementing it, and evaluating it. This can be very time-consuming, motivating the *spiral* model of iterative design (see Figure 1). By spending less time on initial iterations, the designer enables themselves to go through many iterations of design, implementation, and evaluation, while avoiding the trap of spending too much time on a design that has not been validated by users.

In particular, an important concept to keep in mind during user interface testing is that the user is always right, but the user is not a designer. What this means is that any problem that a user encounters when using your interface should not be dismissed as the user’s fault, because

the user is always right. However, user's may not be correct about everything they say they want about the interface; they are not designers, and different users may say contradicting things.

In this work, I will try to interpret the experiences of our users to make recommendations. My recommendations line up decently with some of the suggestions I received from users in concept, though not necessarily in implementation.

3 Set-up of User Study

What we do in this paper is a step of user evaluation with the current user interface of En-Roads. I had two main lines of questions that I asked users. The first of these was a more direct line of questioning, in which I gave some direct instructions to the users. The second line of questions, which I turned to after evaluating the results of my first line of questioning, was much more open-ended: in this, I attempted to interfere as little with the user's experience as possible, in order to gauge what it is like. For completeness, I list both sets of questions here. Note that I did not ask these questions verbatim, and I would additionally ask the user to explain their thoughts at times when they expressed particular frustration or enthusiasm during the process.

The first set of questions, which I asked to 6 people, was:

1. Do you believe that humans are causing climate change? If so, what do you think are good steps that society and/or individuals can take to address this?
2. En-Roads is an interactive climate simulator, where you can make changes to policies and immediately see effects on the climate. I'd like you to show me two different policies you think are reasonable and that decrease the temperature as much as possible, noting that the IPCC has a goal of limiting warming to 2°C by 2100, and justify them to me.
3. Show users interactive map of sea levels at (roughly) the temperature they had in their policies (the interactive map can be found here:
<https://choices.climatecentral.org/#12/40.7117/-74.0013?compare=temperatures&carbon-end-yr=2100&scenario-a=warming-4&scenario-b=warming-2>).

Users usually finished this process in about 15-20 minutes. Much of this time was spent trying to understand the interface. In the second set of questions, I gave the users more freedom, and they took up to 60 minutes to complete the task, completely of their own volition.

The second set of questions, which I asked to the rest (10 so far, I am continuing this as many people were unavailable and are becoming available):

1. Do you believe that humans are causing climate change? If so, what do you think are good steps that society and/or individuals can take to address this?

2. En-Roads is an interactive climate simulator, where you can make changes to policies and immediately see effects on the climate. I'd like you to mess around with it however much you want, and I'll take notes. I will refrain from talking to you during this, but if you have questions we can discuss them after the test is done.
3. Please give a best-case simulation that you think is plausible by 2100.
4. Please justify your choices to me. (In this step, I would particularly prompt users about sliders that they changed significantly, or that they did not change at all.)
5. Show users interactive map of sea levels at (roughly) the temperature they had in their policies, have them interact.
6. Ask what the user feels after the entire experience, and if they have any more thoughts or questions.

I have gone through this set of steps with ten users so far, and it took between 15 and 60 minutes for each user. While I did not record the time carefully for each interview, I would estimate the median time was at about 40 minutes overall. The majority of the time people spent was tinkering with the simulator (before I gave them any specific task). Both tinkering with the simulator and interacting with the sea levels took a considerable amount of time for the most involved users, while getting to a “plausible” scenario and defending it took relatively less time.

As a disclaimer, the set of people I have worked with is *not* a representative sample of any reasonable population. I worked with people I had access to, primarily friends of mine, were almost all (13 out of 16) MIT PhD students. Nevertheless, I think many of my recommendations based on these experiences are pertinent, but I will leave that up to the reader to judge. An excellent future direction is to test the stand-alone En-Roads experience with a more diverse audience.

Also, the final map is a projection of *equilibrium* sea levels, which will probably only reach us in hundreds or thousands of years. This was explained to users before they interacted with it.

4 Feedback from HCI Experts, Results of User Study, and Discussion

First, I will summarize my discussions with the various HCI experts I talked to, and discuss the various ideas that were brought up in these discussions.

I talked to four people who have ample experience with human computer interaction, and in particular with user interface design: Farnaz Jahanbakhsh and Lea Verou, who are PhD students

in David Karger’s group in CSAIL, Chris Lilley, who is technical director at the World Wide Web Consortium, and David Karger, who is a professor in CSAIL studying HCI.

Every expert brought up the fact that there is a lot going on in the simulation, and it is fairly overwhelming at first glance. I will list a subset of the ideas and feedback I heard from these experts, omitting repetitions. Note that all the experts had a fairly positive view of the En-Roads interface overall, though they felt that tweaks could be made.

Farnaz Jahanbakhsh. Farnaz Jahanbakhsh was the first expert who I showed the application to, and I tested my first set of questions with her. We realized that the drop-down menus for graphs were quite tricky - for context, the drop-down menus on the graphs can be accessed by clicking on the name of the graph, but clicking on the arrow next to the names brings up a *description*. Farnaz brought up that the buttons on the top of the interface are not very visible - she suggested that they be part of a more explicit menu bar in order to make it clearer to the user that these buttons serve the purpose of a traditional menu bar.

Lea Verou and Chris Lilley. I talked to Lea Verou and Chris Lilley together. They are both experts in HTML and CSS, and have both done extensive web development. They focused on the interaction of the “advanced settings” with the sliders, and also with the usage of colors in En-Roads.

When you are actively interacting with an element on a webpage, the element becomes *focused* - e.g., a button might become outlined in blue to indicate that it is the last button you interacted with. When you interact with the “advanced settings” for sliders in En-Roads and then return to the main menu, the “advanced settings” button (the triple dots) ends up being highlighted in blue, to indicate that you have changed some advanced settings that are not reflected by the sliders. They found this confusing, as this blue highlighting persists even after you have stopped interacting with that element, and suggested that perhaps a different color could be used. Additionally, they found it odd that setting advanced settings disables simultaneous usage of the basic slider. I believe this confusion could be improved with a hover tool-tip on the disabled slider explaining that it became disabled due to advanced settings; but probably better would be to eliminate it altogether by making the basic slider and advanced settings usable together if possible.

On the subject of colors, they also brought up the possibility of using different colors on the sliders. One example for this that we came up with was that, perhaps, the elements can be color coded so that red or orange indicates a setting to the slider that contributes to a rise in temperature (keeping the other sliders fixed), while blue indicates a setting that causes a fall in temperature. This could additionally be used for the large number that governs temperature change.

David Karger. David Karger brought up many interesting points about the bigger picture of the interface - he was focused more on the overall user experience, and macro-level choices of what to display on the application to best express what users actually care about.

The first point he made is that the costs and impacts on individuals are very opaque. The words “highly taxed” and “highly subsidized” are meaningful from the point of view of how difficult it would be to enact policy, but do not actually convey what the effects on end users are. In essence, he wanted the application to answer questions like “What does the tax mean for me and my life?” for individuals using the application. In addition, he brought up the idea that the webpage could do more optimization for the users, to help them find the scenarios they might be interested in without relying on them first figuring out everything the interface has to offer.

5 User Evaluation and Recommendations

Inspired by our discussions with the experts, we first talk about what most users want to get out of En-Roads at a high level. I believe it is plausible that users are most concerned with the following two questions. First and foremost: 1) What will be the damages of climate change for us and future generations for any given policy?, and 2) How much will addressing this temperature rise cost me?

En-Roads refrains from answering 1) in monetary terms - this requires converting environmental effects of climate change to economic damage, on timescales ranging from tens to hundreds of years. As John Sterman mentioned to me after his lecture to the class ([Ste19]), estimates of damages from climate change measured in dollars are highly speculative. Indeed, we saw in John Deutsch’s work presented to us in class that there were many uncertainties involved in measuring costs due to damages, and that the costs could be wildly different depending on one’s assumptions.

So instead of giving an economic estimate of damages resulting from climate change, En-Roads gives us the results of climate change in less controversial forms, including temperature rise, sea level rise, and ocean acidification, and lets the users make their own judgment as to how concerned they are about that scenario. To address 2), En-Roads provides cost information in the set of “Financial” graphs, including the market price of electricity, and the net revenue from taxes and subsidies that the user selects.

However, this is currently very easy to miss; as we noted above, many users we talked to did not find these costs addressed in En-Roads, but thought they were incredibly important.

So what are my user interface recommendations? We can characterize them into a few types.

1. **Rearranging existing information.**
2. **Cosmetic fixes and improvements.**

3. Changes to inspire hope.

4. Aiding in exploration.

These types cover the issues I would most likely to see fixed in En-Roads. Note that they are not necessarily disjoint; for example, use of colors to indicate temperature could be under “cosmetic fixes” and also under “aiding in exploration.”

1. Rearranging existing information. A lot of good information is on the En-Roads page, but much of it is not in places that users or experts were able to find. One example is the reset button - there are currently two ways to reset the simulation in En-Roads. One is to go to the “Simulation” button on the top menu bar, under which you can reset the simulation, and the other is to hit the “Reset Sliders” button. Both these options were fairly unclear to most users and UI experts, and some users who wanted to reset the simulation resorted to moving the sliders back manually. To remedy this, I would recommend taking out both these methods for resetting, and replacing them with a single “Reset” button on the top menu. Then, the “Simulation” button on the menu can be replaced with “Assumptions” or a shortened version of this. Since the reset button was frequently used, we feel like this would be a considerable improvement to the user experience. Out of the 16 users I have talked to so far, three successfully found and used the reset button of their own accord, and six reset their simulations manually when they wanted a reset.

As mentioned at the beginning of this section, another feature I think should be moved into more prominence is the set of financial graphs. The financial graphs are incredibly useful for a user; they give much better idea of the sacrifices that a user would have to make if their policies were enacted. While the emphasis in En-Roads is currently on the target temperature in 2100, users are also interested in the costs they would incur in the new future. This type of information is accessible via En-Roads in the form of two graphs, “Market Price of Electricity” and “Net Revenue from Taxes and Subsidies.” My recommendation is to make a separate category for financial graphs to emphasize them.

Currently, there are too many categories of graphs for the financial graphs to stand out. But many of the categories are similar; categories like “Primary Energy Demand Totals” and “Primary Energy Demand Types” can be lumped under a single category, “Primary Energy Demand.” The same goes for “Final Energy Consumption Totals” and “Final Energy Consumption Types,” as well as “CO2 Emissions” and “Greenhouse Gas Emissions.” By lumping these together, we emphasize the financial graphs better.

Another suggestion that was brought up after my talk in class by Vanshika Jain was the possibility of a search bar for graphs. I view that as a good possibility (certainly I think it would be a useful addition to the current user interface if the search), but maybe it is something to revisit

after doing other re-organization.

2. Fixing cosmetic issues. There are small cosmetic issues with some features of the En-Roads application, which hinder users from discovering everything En-Roads has to offer. En-Roads displays a lot of information. Users can change the sliders, they can toggle advanced settings, and they can access a multitude of graphs. But small issues with the user interface can prevent users from accessing some of this information, even if they want it, and sometimes even if they want it and *know* they want it. I will focus here on the overwhelmingness of the application, the menus bar, drop-down menus, information symbols, and tool-tips, which I believe are the most hindering for a current user.

Just about every user and expert thought the application was overwhelming at first. All the sliders are nice, because they each allow the user to control a meaningful subset of policies, but users generally tended to focus on one set of policies at a time. Hence, we recommend letting users minimize tabs of policies - that is, minimize all the policies under either “Energy Supply,” “Transport,” and “Land and Industry Emissions.” This would let users focus on one set of policies at a time, rather than having them all showing always. For example, one user, although she played with the sliders a lot, completely forgot to set energy efficiency or electrification for transport in her underlying scenario. When I asked her why, it took her some time to realize what I was pointing to, and she remarked that she had somehow completely missed its existence. I believe these kinds of oversights could be helped by having a somewhat less overwhelming interface; my hypothesis is that it was just difficult for her to see that there was a slider unset amongst all the others. Another possibility, which was brought in Section 4, is to make use of different colors on the sliders - for example, red meaning that this slider is causing the temperature to get hotter, and blue meaning it is causing it to get cooler. Varying the color usage could have the effect of making the overall interface easier to take in.

Fixing the constant sensory overload that En-Roads could have additional benefits. Many users did not use the toolbar on top, even when they were looking for a reset button, either for the sliders or for the graphs. As mentioned in Section 4, something that would help is making the menu bar clearer - for example, by highlighting the buttons in gray, like a traditional menu bar. This might help users register that there is a menu bar on top just like on other applications, even though their focus is on the main screen.

The graphs in En-Roads are accessed via drop-down menus - either from the menu bar, or by clicking on the names of the graphs themselves. We have already discussed why we think users did not click on the menu bar much, but what about clicking on the name of the graph to get a drop-down menu? This was a much more common way to access the graphs, but it also had its

flaws. The fact that the arrow next to the name of the graph did *not* bring up the different graph options, while clicking on the name of the graph *did*, was quite unintuitive. While most users who clicked on that area eventually did find out that clicking on the arrow and the name do different things, it often came as a surprise. Also, some users did not find out that they do different things: some users clicked on either the name of the graph or the arrow next to it first, and then assume that the other button does the same thing¹. This is despite the fact that the current user interface highlights the name in gray when it is moused over, indicating that it is a different button from the arrow. I believe the reason for this not being so effective is because the arrow is fairly small, so people do not notice that it is not highlighted along with the text.

I would suggest fixing this in two ways. One, the arrow and the name should be part of the same button. Two, the job of the arrow should be done by an information icon - much like what is used in one part of the “Advanced Settings” sections of En-Roads (accessed via the triple dots). It might be even better if it were accompanied by a hover tooltip. Of course, the information icons could cause too much clutter, in which case a hover tooltip might have to suffice; it is hard to say before seeing it implemented.

The information symbols and tooltips go farther than the drop-down menu for graphs. The use of an arrow to drop down descriptions is prevalent throughout the “Advanced Settings” sections, used to explain each of the advanced settings. To keep the theme consistent, if we change the arrows to information symbols for the graphs menu, it should also change in each of these settings, and hover tooltips could also be useful here. Additionally, to see the description of an item, a user needs to click the triple dots. There is no hover tooltip indicating that users should click there for a description, so some users expressed frustration at not knowing what things meant. However, eventually, almost every user (14 out of 16) managed to click on the triple dots and realize how to look at descriptions and advanced settings.

The graph tooltips should additionally be larger. Currently, they are exceedingly narrow, which makes it very difficult to hover over graphs to see the values - even a small hand twitch would bring the user’s mouse off the curve, getting rid of the tool tip. This is a problem, since multiple users were interested in understanding nearer-term outcomes of their policies, say, in the year 2060. This is very natural behavior, as people are particularly interested in seeing outcomes that will effect them and their children. En-Roads provides this information, but in a way that can be frustrating.

I can see fixing this in one of two ways. One would be simply to make the tooltip hover zone larger, so that users can hover over the temperature more easily. Another might be to make the entire graph show tooltips on the vertical axis. In the case of multiple curves being shown in the graph, it could show tooltips for all the curves at once, color-coded. At the moment, the color-

¹All the HCI experts I talked to stated that this was also their intuition before clicking.

coding in the tooltip is not useful - I only ever get a tooltip when I'm hovering over a single curve, and the only value that shows up in the tooltip is the value of that graph. I have a preference for the second solution, but could see a case for either.

There is a slight bug with the sliders that occurred many times during my testing and user testing. Roughly, it occurs when the user first opens a fresh copy of En-Roads, and slides a slider while putting their cursor elsewhere on the screen and releasing when their cursor is off the slider. The mouse release does not register and the slider continues moving with mouse movements until the user clicks back on the slider to stop it. I have been able to reproduce this bug on Safari - it is possible that the behavior is different on different browsers. There may be other settings where this bug occurs, but it seems to always occur when no other slider has been touched on En-Roads.

Finally, a very minor point, there are various small typos and other errors in the "Advanced Settings" menu for each of the sliders. The biggest issues I found are that the description for "Coal CCS R&D breakthrough cost reduction" is simply "description", and if you go to the advanced settings for "Economic Growth" and go to the "GDP Per Capita By Region" graph, it is blank (although the same graph is also accessible via the graphs menu and via the advanced settings for "Population," and is not blank in these places). Additionally, the descriptions are often inconsistent in terms of having a period at the end or not. This should all be easily addressable with thorough interface testing.

3. Changes to inspire hope. After my experiment, many of the subjects reported feeling depressed, sad, or indifferent². This is probably not primarily the fault of En-Roads. First, the people I talked to were all people who believe in anthropogenic climate change. Second, I asked the question when people had just finished interacting with the map of sea levels, which was the final step of the study. As most of the users lived in Boston, the map was not very encouraging: even at 1.5°C by 2100, most of the Boston-Cambridge area was under water. Recall that the map was of equilibrium sea levels, which are hundreds, maybe thousands, of years away, and this was explained to users before they interacted with it.

But even still, this points to some concerns for En-Roads. When En-Roads is used in a workshop setting, the facilitator is explicitly instructed to make sure that the participants are hopeful afterwards. En-Roads shows the users that there still is a path to stay below 2°C (even 1.5°C). In addition to this, the facilitator emphasizes that there have been great technological breakthroughs in the last few years, particularly in renewable energy technology. These advances, along with natural economic processes, have brought the price of renewable energy down drastically, faster than many people would have anticipated.

²Eight users reported feeling scared or sad, two reported feeling indifferent or believing the maps were as-expected given their knowledge, one reported that the map helped them understand what 2°C meant, and one reported being happy that their future home was not underwater. Other users had no comment on the sea levels.

But when a user is interacting with En-Roads alone, they do not get any of this interaction. So there was no part of the En-Roads experience that left people feeling hopeful. But hope is very important in climate communication: if we are going to be motivating people to take action about climate change, they need to feel hopeful that their action can change something.

To this end, I believe it would be useful to have a link to top actions individuals can do to address climate change. Ideally, this should not only include actions like eating less meat and taking fewer flights, but also should include ways to influence policy, and make these ways easier. For example, it could link to a tool to look up relevant legislation that is up for consideration in your state, or give other tips on how to pressure policy makers into addressing climate change, directly or indirectly. For example, Bill Wehl ([Wei19]) suggests that graduates of universities conspicuously choose companies that are greener for the environment, and that additionally lobby for climate change in countries that they operate it (if applicable). En-Roads could link to advice like that, possibly coming from sources outside of Climate Interactive and Ventana Systems. Making short-term co-benefits of policy actions (like improving health by decreasing pollution) stand out more could also serve to increase hope, since it might make various policy actions seem less unreasonable.

When a user finishes understanding the basics of En-Roads and starts to deeply investigate scenarios, En-Roads can be fairly alarming. At the very least, it did not make most users feel empowered. While some users were optimistic about our ability to immediately enact multiple useful policies, the general feeling from users I talked to was one of sadness and powerlessness - sad because significant climate change felt inevitable given the current political climate, and powerless because they recognized that large-scale policy change is needed, but did not know what they could do about it.

4. Aiding in Exploration. These changes are a bit more speculative, and were inspired both by my background and by my discussion with David Karger. There is a lot going on in En-Roads. While En-Roads allows users to play with sliders and advanced settings, there is no way that users can try out all the combinations of policies, or even most of them. Furthermore, the effectiveness of one policy is *dependent* on the setting of the other policies. For example, at the status quo setting, if one maximizes the electrification of buildings, it actually *increases* the temperature by 0.1°F (from 7.3°F to 7.4°F). But if we first make electricity generation more green, by maximizing the carbon price, coal tax, and renewable subsidies, then maximizing building electrification *decreases* the temperature from 5.3°F to 4.9°F.

This type of dependency ended up becoming apparent to some users, with four out of the sixteen users I talked to explicitly remarking on this as they played around. Out of the remaining users, I am unsure how many realized this, as it is not something I asked. Ten of the sixteen users

started out their experimentation by maximizing and minimizing one slider at a time, resetting the slider, and then moving on to another slider. This type of experimentation was used to gauge the influence of each slider on the climate, which was then committed to memory by the user as they moved on to making various scenarios. During this initial phase, some users commented that they thought the different sliders were independent in the model, probably since they were able to move one slider at a time without the others moving with them.

One suggestion we have is to somehow display *gradients* of the temperature (or whatever impact is being displayed) with respect to the slider on each slider. This idea was my original motivation to investigate En-Roads, and works towards Karger’s idea that the interface could do more to help the user explore the space of scenarios that achieve a certain temperature. One user I talked to suggested the gradients idea to me without my prompting, and two other users who I mentioned the idea to thought the idea would be helpful in navigating the interface. However, one of these users expressed concern that it would “make the interface overwhelming.”

Karger suggested that there could be ways to implement this that would not clutter the interface; for example, the size of the knob on the slider could be made larger or smaller depending on the size of the gradient (in the cooling direction, to make this well-defined). This seems promising to me; it could really help the user realize that something *is* changing about the other sliders even when they only change one, without having to interact extensively with the interface.

Another idea is to have “canonical” ways to achieve a certain temperature, measured in terms of other metrics; for example, what is the way to get down to 2°C that maximizes tax revenue? What about a way that minimizes the market cost of electricity in 2040? En-Roads does not currently support easy ways of making these types of queries.

In general, there is a fine line between helping the user with optimization and hindering the freedom that the user currently has with En-Roads. This is why I view UI changes in this section as speculative, but things that the makers of En-Roads should consider.

6 Future Work and Conclusions

In this project we investigated the climate simulator En-Roads, looked at its education goals, and evaluated the user interface with respect to these goals. There is still a lot of work to be done in this vein, especially since all UI changes should themselves be evaluated and tested; even if a change is well-thought-out and helps solve a legitimate problem, it may introduce new problems and clutter.

Lea Verou and David Karger brought up the notion that the user interface for En-Roads could be open-sourced, so that user interface designers could contribute to it. While the makers of

En-Roads are right to be worried that the model could be tampered with, letting experts play around with the interface and suggest changes to the developers of En-Roads could be useful. It would also allow En-Roads design to be integrated into university curricula. Verou and Karger are considering the possibility of making an En-Roads inspired project for their course on user interface design next semester, 6.s082. Even if this does not go through, this could be an excellent, mutually beneficial arrangement between UI designers and climate simulation designers.

I believe En-Roads has the ability to revolutionize how we educate people about the climate. The user interface is already very good, but can be improved. However much the user interface improves, though, there is no substitute for learning with other people. That is why I believe another avenue to improve En-Roads's reachability is to turn the interactive role-playing experiences into an online game. People can indicate their preference in being a participant or a facilitator, and be matched with other players across the world. This could reach people who do not have a group of friends who are interested in doing this with them, and greatly increase the reach of En-Roads into communities of climate skeptics.

7 Acknowledgments

I would like to thank all the course staff for 6.s898 for this illuminating course and for their encouragement throughout my project selection process. In particular, Ron Rivest strongly encouraged me to do this project and suggested the initial steps I should take, like contacting David Karger's group at MIT, reaching out to John Sterman, and talking to users. Additionally, I would like to thank John Sterman, who generously responded to my inquiring emails and put me in touch with other people at Climate Interactive to follow up with them about changes in the future, and Bill Weihl, who talked to me and another student after lecture about ways to affect climate policy as individuals.

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