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A picture is worth a thousand data points: Exploring visualizations as tools for connecting the public to climate change research

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Abstract: Data visualizations can serve as an integral component of online climate change research dissemination strategies, as they are effective and efficient ways for attracting diverse public audiences and delivering research information in a timely fashion. However, these visualizations can be highly varied in terms of form and ways of interaction, and this raises questions about the particular qualities of such media that influence their ability to connect with and inform diverse audiences. This study addresses these questions by building visualizations of secondary energy production and consumption trends in Canada and evaluating their impact through focus group methodology. Two visualizations were built that held contrasting features: an abstract, static visualization built in the form of a time-series graph and a dynamic, interactive visualization with a 'picturesque' design. The results indicate that the interactive visualization held higher potential for drawing in and maintaining audience interests, whereas the static visualization was more useful for users wishing to gain a more detailed understanding of the data. These findings suggest that both types of visualizations have complementary strengths, and collaboration between trans-disciplinary research teams and graphic artists can lead to visualizations that attract diverse audiences and facilitate different information needs and access.

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PUBLIC INTEREST STATEMENT

Data visualizations can benefit efforts in communicating climate change research and ideas online, as they provide an effective means for attracting different people and delivering research information in a quick and enticing manner. However, "visualizations" can be highly varied in terms of form and ways of interaction, and there is no "one size fits all" strategy for creating and employing them in online communication strategies. This study examines two different forms of visualization—a static graph and an interactive piece—to investigate which features are beneficial when visualizing data and attempting to connect with and inform diverse audiences. Understanding these qualities is useful for academics and researchers that are seeking ways to deliver important research information and messages to the broader public.

Subjects: Climate Change; Design; Energy; Environmental Communication; Environmental Studies; Flash; Mass Communication; Multimedia; Social Sciences; Visual Communication

Keywords: data visualizations; interactive media; online media; climate change; research dissemination; public audiences; scientific literacy; energy trends; visual design; sustainability

1. Introduction

Climate change is a complex, global issue, and thus climate solutions require widespread interest and participation (Few, Brown, & Tompkins, 2007). Modern digital technologies provide innovative new ways for creating tools for involving diverse groups and the broader public in climate action (Biggar & Middleton, 2010). In particular, advancements have been made in developing visual representations of information and data, and these "visualizations" have proven to be effective tools for communicating research around climate change and climate impacts (Nocke, Sterzel, Böttinger, & Wrobel, 2008). By adding a visual aspect to data and information, the cognitive requirements for understanding a message or idea can be greatly reduced (Keim, Mansmann, Schneidewind, Thomas, & Ziegler, 2008). This gives visuals a communicative advantage over text-based media in the way that they can convey a message using multiple senses, engage people on an emotional level and provide a degree of salience to the information presented (McDonald, 2009). Such an advantage is critical in climate communications, as visualizations can transmit the severity of certain impacts, such as wildfires (Schroth, Pond, Muir-Owen, Campbell, & Sheppard, 2009), and impress upon stakeholders (and the broader public) the imperative to act.

Alongside evolving techniques and software for developing visualizations, the proliferation of online communication platforms has provided new opportunities for sharing visuals and increasing the size and diversity of the audiences (Viegas, Wattenberg, van Ham, Kriss, & McKeon, 2007). This is particularly important in the context of climate change research, as it positions the use of visualizations in online communication strategies as key in mobilizing knowledge and increasing public understanding around both climate issues and our capacity for mitigating and adapting to these issues (Newell & Dale, 2015). However, methods in visualization are varied and new techniques are continually developing; consequentially, research assessing the most effective techniques for engaging different users is needed in this growing field (Wibeck, 2014). In addition, some visualizations, such as interactive tools, require specific technical expertise that not all researchers and organizations have access to (Viegas et al., 2007); therefore, "what is most effective" for engaging audiences must be also understood in context of "what is possible" for a particular organization or research group. The trade-offs in developing more sophisticated tools need to be considered.

This research was designed to explore the nuances around building and using different types of visualizations for dissemination of climate change research and knowledge, and it examines the trade-offs in building/using one type of visual tool over another. Two different visualizations with contrasting features were built: (1) an abstract, static visualization built in the form of a time-series graph and (2) a dynamic, interactive visualization with recognizable elements (e.g. buildings, landscapes, etc.). The visualizations were then explored and critiqued through a focus group. The objectives of this work were, firstly, to gain insights on the challenges and opportunities in developing various visualizations, and, secondly, to better understand the potential of different visualizations in connecting with diverse audiences and mobilizing public knowledge around climate change adaptation and mitigation.

2. Research context

This study is a part of a larger research project, Meeting the Climate Change Challenge (MC^3), which explores climate action and innovation within Canada (mc-3.ca). One of the major objectives of MC^3 is knowledge mobilization and research dissemination, and as a part of this objective, MC^3 has attempted to engage the general public through the use of popular social media channels. MC^3's efforts were preceded by previous work in this area, led by the second author's Canada Research Chair

(CRC) in Sustainable Community Development (2004–2014). As a part of this work, the first author developed a blog series hosted on the CRC website, entitled Patterns of Our Footsteps (https://www.crcresearch.org/visualizations/patterns-and-trends), which analysed data collected from public sources (i.e. from Statistics Canada, BC Statistics, World Data Bank, etc.) and presented the analyses to the public in clear, non-technical language. The visualizations examined in this study are derived from this blog, and the interactive visualization is currently hosted on the MC[3] website as part of the project's knowledge mobilization strategies (http://mc-3.ca/visualizations).

3. Visualizations and trade-offs

Visualizations can vary dramatically, ranging from abstract visuals that graphically convey numerical relationships and utilize people's spatial processing to make sense of these relationships (e.g. Marmo, Cartwright, & Yuille, 2010) to more realistic visuals that can be recognized as real-world objects and places (e.g. Sheppard, 2001). In addition, visualizations can differ in how one interacts with the media, and these forms of interaction can engage the body and mind in different ways. For example, a visualization can consist of a static picture where one simply views the image or it can consist of interactive media that allows the user to actively engage with it using a keyboard and/or mouse (Rada, 1995; Wagner, 2011; Ward, Grinstein, & Keim, 2010). Furthermore, visuals can vary in aesthetics, and their "attractiveness" can influence their ability to draw-in different audiences (Korkmaz, 2009) and the time they spend interacting with the media (Cawthon & Vande Moere, 2007). Ultimately, there is no "standard formula" for creating a visualization, and each type has associated strengths and weaknesses in both development and application of the tools.

The majority of the visualizations published through the Patterns of Our Footsteps blog (see Section 2. *Research Context*) are conventional time-series plots. Therefore, despite holding potential for evoking people's visual senses and pattern recognition for better information communication (Keim et al., 2008; Marmo et al., 2010), they are abstract, static, and do not explore the full range of features that can be employed through an interactive visualization. To provide a contrasting example, visualizations, such as Slover's (2013) interactive piece on the state of fisheries over the last 100 years incorporate dynamics and the ability to actively interact (i.e. through the use of buttons), thereby engaging audiences in different ways. Slover's visualization features an animated scene of large predatory fish and small prey fish, and as users click on buttons representing different decades, the fish composition changes accordingly. The scene in this interactive piece represents how fish composition has altered in response to fishing activity throughout the last century; thus, it essentially expresses the same information as in a time-series graph, but in an entirely different format. Therefore, although Patterns of Our Footsteps (i.e. static graphs) and Slover produced visualizations that convey the same type of information, the presentation formats are dramatically different and (thus) the visuals engage audiences in different ways. Ultimately, the decision to employ as either a static, abstract image (such as with the Patterns of Our Footsteps blog) or a dynamic, artistic tool (such as with the fisheries visualization) requires thinking about the trade-offs in incorporating certain features and design elements. Five such considerations are discussed in the paragraphs below.

Firstly, there are implications around the aesthetics of visualizations. Attractive images can draw in audiences (Cawthon & Vande Moere, 2007; Korkmaz, 2009). However, Lau and Vande Moere (2007) discussed a spectrum ranging from "data representation" to "artistic freedom" in visualizing data, and noted that representativeness and data accuracy could be sacrificed with increased degrees of artistic style and interpretation. Such considerations bring forward questions around how much style and creativity to implement in a visualization and whether information is being "lost" in the art.

Secondly, different visualization formats will hold different degrees of clarity or readability for different audiences. Although clarity is closely related to aesthetics in the way that good aesthetics can include clear, legible designs (Peters, 2007), it also relates to considerations around whether to use more complex design elements or simple abstract items. Visualizations with elements that can be identified as real-world objects have the ability to convey information in a salient manner to diverse audiences (Lewis & Sheppard, 2006). However, abstraction also serves a purpose and can be powerful in terms of utilizing people's spatial reasoning and pattern recognition when visually communicating trends (e.g. Marmo et al., 2010). Ultimately, the developer of a visualization must consider whether he/she is adding or detracting from a visualization's clarity when incorporating more complex designs and design elements.

Thirdly, the analytical power, or capacity for retrieving specific information and insights on data, of each visualization will vary with the format. As newer forms of visualizations are developed, it is important to critically interrogate whether these novel tools hold advantages over previous formats in terms of being able to gain deeper understanding of the data and trends (Plaisant, 2004). As Wibeck (2014) noted, methods and techniques in visualization comprise a rapidly developing field and testing is needed to assess the effectiveness of emerging visualization approaches. Accordingly, it is important to recognize that conventional but perhaps less "exciting" forms of visualizations have demonstrated their analytical power (e.g. time-series graphs), and novel visualizations need to be assessed to see if they have comparable abilities.

Fourthly, the decision to make a visualization dynamic or static brings forward certain considerations. Dynamic visual cues can lend to a visualization's communicative power by making them more vivid and understandable (Valkanova, Jorda, Tomitsch, & Vande Moere, 2013). However, conversely, a static visualization can be simpler in terms of reasoning and interpretation, and (thus) they can be a simpler communication vessel (Beck, Burch, Diehl, & Weiskopf, 2014). In addition, dynamic visualizations can be challenging to build and can require technical expertise (Viegas et al., 2007), which can be a considerable trade-off for researchers when selecting a dynamic approach to visualize data and communicate their research.

Finally, the decision to make a visualization interactive holds implications for both its development and application. Similarly to dynamic visualizations, interactive tools can be more time consuming and complicated to build (Viegas et al., 2007); however, interactive media can be more engaging as well, particularly to younger audiences (e.g. Yang & Coffey, 2014). The ability to engage and maintain audience interest is especially important in the context of communicating climate research online, as reaching diverse online publics through the vast amount of information available on the World Wide Web can be challenging (Anderson & De Palma, 2012). Therefore, interactivity could be an integral feature of climate visual communication; however, it is important to recognize that interactive visualizations are far less commonplace than static visualizations and understanding this potential still requires further research (Herring, VanDyke, Cummins, & Melton, 2016).

The visualizations examined in the current study are developed from the same data-set and (thus) communicate the same information; however, they contrast one another in terms of the five considerations discussed above. While one visualization is static, abstract time-series that can only be interacted with passively (i.e. viewing), the other is dynamic, artistic and can be interacted on with active engagement (i.e. by clicking buttons). The intention of this research is not to favour one approach to visualization over the other; rather, it seeks to gain a greater understanding around the trade-offs involved in building and employing different forms of visualization for communicating data and research trends.

4. Building the visualizations

A time-series graph included in a Patterns of Our Footsteps blog post, entitled *The Things That Energize Us* (Newell, 2013), was used for this experiment (https://crcresearch.org/crc-blog/patterns-our-footsteps-things-energize-us). The graph conveys trends in secondary energy production in Canada from various sources, throughout the period 1960 to 2010. The graph was considered particularly relevant to MC[3] because as a climate change research project, much of MC[3] research focuses on policy and innovation around energy use (e.g. Kristensen, 2012; Newell & King, 2013). Thus, it was selected for this experiment on building interactive visualizations for MC[3] dissemination, and the interactive piece built from the times series currently is hosted on the MC³ website (http://mc-3.ca/picture-electrical-energy-use-canada).

The following sections discuss the development of the visualizations involved in this study. The static visualization is (for the most part) a standard time-series graph, whereas the interactive visualization represents the unique contribution of this research; thus, more detail is given on the latter.

4.1. Static visualization

4.1.1. Published version

The time-series graph was built in MS Excel (v14.0) using Canadian secondary energy production data retrieved from the World DataBank archives (The World Bank Group, n.d.). A time-series plot was prepared for each of the six categories of secondary energy production—hydroelectric, coal, nuclear, natural gas, oil and all renewable sources. Energy production was expressed as terawatt-hours produced in given year (*y*-axis) and was plotted over a 50-year period (*x*-axis).

As the intended destination of the visualization was a public blog post, some effort was devoted to the aesthetics of the graph. Data points were interpolated, and individual points were removed from the graph to reduce visual "clutter" (e.g. Lambert, Bourqui, & Auber, 2010). In addition, a spline-type interpolation was selected (referred to in Excel as "smooth line") to create a more visually appealing smooth, continuous shape (Blaas et al., 2009). The resultant graph is displayed in Figure 1.

4.1.2. Study version

When revisiting the secondary energy production graph and data prior to building of the interactive visualization, the authors decided adding energy consumption to the interactive visualization was appropriate, as much of the MC³ research examines innovation and action around both producer (e.g. Newell & King, 2013) and user (e.g. Kristensen, 2012; Newell & King, 2012) ends. Energy consumption was calculated using data also retrieved from the World DataBank archives (The World Bank Group, n.d.). Consumption values were expressed as megawatt-hour per capita values.

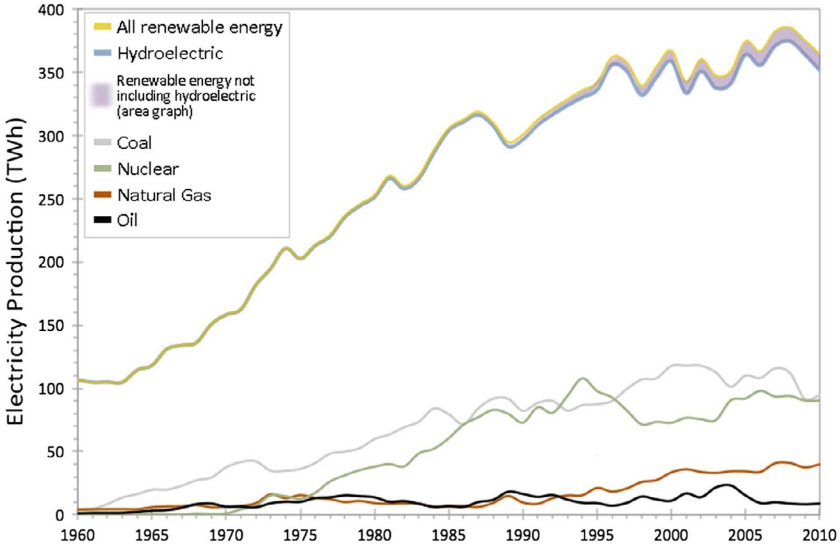
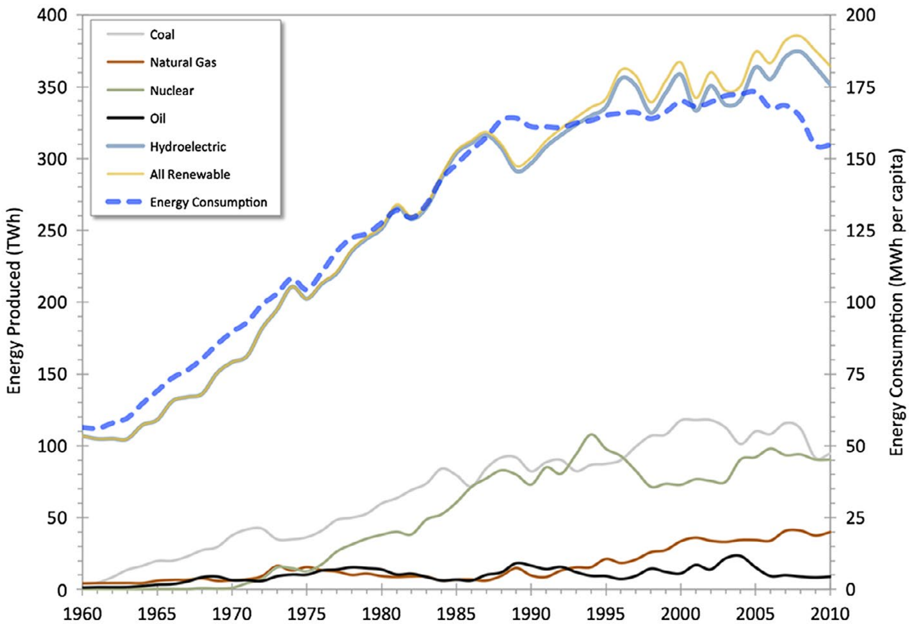


Figure 1. Times series visualization on secondary energy production in Canada from 1960 to 2010 published through the Patterns of Our Footsteps blog.

Note: The area between the "all renewable energy" plot and the "hydroelectric" plot has been filled in, using Adobe Photoshop (CS5), to highlight trends in non-hydroelectric renewable energy production.

Figure 2. Times series visualization on secondary energy production and consumption in Canada from 1960 to 2010.

Note: The time series graph was prepared for the focus group study and follows the style of the original graph prepared for the public display through the CRC Patterns of Our Footsteps blog.



This study compares the static visualization with the interactive visualization; therefore, the static piece was updated with the energy consumption trends. Consumption values were plotted on a secondary *y*-axis. The consumption plot was stylized in a similar manner to the other time-series, i.e. no data points and smooth curvature; however, a dashed (rather than solid) line was employed to better differentiate this trend from the production trends (Figure 2). This version of graph was used in the focus group study for comparison purposes, as it expresses the same trends as the interactive piece (i.e. both production and consumption).

4.2. Interactive visualization

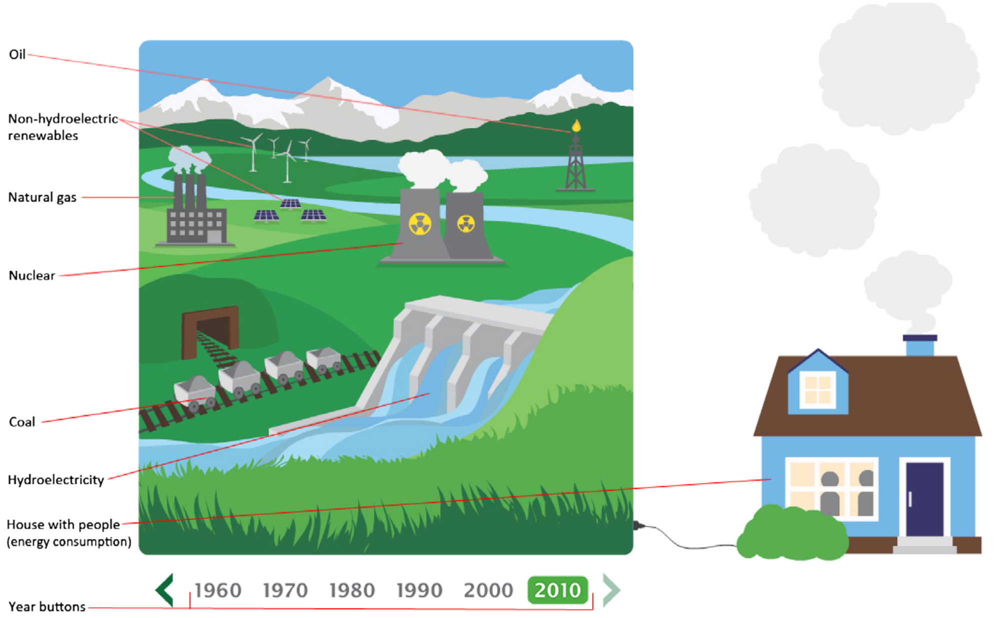
The interactive visualization was developed using Adobe Photoshop (CS6), Adobe Illustrator (CS5) and Adobe Flash Professional (CS6). Photoshop and Illustrator both were used for preparing the different visual elements; however, Illustrator was used more for this purpose because it is a vector-based program and this allowed for development of imagery that follows current design trends of simple, "cutout style" forms.[1] Flash Professional was used to compile the elements and add interactive features. Adobe programs were selected for this work, as it allowed for the development of a piece that could easily be embedded on a webpage and interacted with online (i.e. by the general public).

The interactive visualization takes the form of a "scene" with identifiable elements (i.e. can be recognized as real-world objects) that changes as users click buttons and interact with the elements. As the visualization is based on a time-series of secondary energy production and consumption (i.e. Figure 2), the visual elements in the scene consist of different energy operations, i.e. hydroelectric, non-hydroelectric renewables, coal, nuclear, natural gas and oil that are placed on landscape imagery. As shown in Figure 3, the elements that represent consumption per capita values comprise a house (placed next to landscape scenery) and silhouettes of people seen through the house windows.

To interact with the visualization, users can click on buttons representing different years or use the arrow buttons to, respectively, move forward or back a time increment. The elements appear and animate in a manner that attempts to "tell the story" (i.e. express the data trends) for a given year. A scene will take approximately five seconds for all the elements to appear, and then the user can hover over the elements to access pop-up bubbles containing numerical information on the level of

Figure 3. Labelled elements of an interactive visualization of secondary energy production and consumption in Canada from 1960 to 2010.

Note: Element labels are listed to the right of the figure, and labelling lines are featured in red.



energy production for each of the secondary energy sources and per capita consumption for a given year. This approach to visualization brought forward several considerations that influenced its development and often presented challenges. These considerations can thematically be described as imagery, interval and magnitude, and each of these are discussed in further detail below.

4.2.1. Imagery

Unlike a time-series graph that differentiates between secondary energy sources simply through colours and lines of plotted data, the interactive visualization was built as a landscape scene with elements that can be recognized as real-world and familiar objects. This required making the objects within the scene both differentiated and identifiable, meaning that the imagery, although simple and stylistic, is distinct enough that users recognize different elements as referring to different trends and is pictorially clear in terms of which trends each is representing. In the case of some of the secondary energy sources, differentiated and identifiable imagery was simple to achieve due to the energy source being associated with distinctly recognizable shapes and structures (i.e. turbines for wind energy and dams for hydroelectric energy) or being associated with iconic symbols (i.e. radioactive symbol on the nuclear plant towers). However, some energy sources were more difficult to distinctly represent, particularly since the visualization was constructed using simple vector-based shapes, which presented some difficulties for sufficient differentiation. For example, coal, oil and natural gas plants developed using the vector-based design produced elements that had similar "forms", i.e. column structures extending from rectangular structures with "cloud-like" shapes rising from the structures. Therefore, to increase the distinctiveness of the elements and allow the user to more quickly and clearly identify each element with a specific energy source, coal was represented with coal carts and oil was represented by an oil refinery tower (with a gas flare). This allowed for imagery that is more distinctive in both shape and animation.

Another consideration around imagery is the layout. Rather than arranging the elements as separated, disassociated entities, the visualization was built as a coherent scene, in a manner similar to the aforementioned fisheries visualization (Slover, 2013). This necessitated thinking about image composition to ensure that all the elements could be clearly seen and "make sense" as regards their "place" is in the scene. To this end, the image was arranged in a landscape scene consisting of foreground, middle ground and background, as this allowed for placement of elements in a manner that is clear, coherent and facilitates understanding. To elaborate, the visualization consists of a hilly landscape with a river travelling in from background to foreground, and by setting it up in this manner, the hydroelectric dam can be placed in the foreground on the river and the other energy operations can be located on the hills aside the river, giving the impression of a logical, easy-to-interpret picture.

The conveyance of energy consumption trends through the interactive visualization also required imagery and layout considerations. Energy consumption was calculated as per capita values, and accordingly, consumption elements consisted of people living in a house with lights that turn on after all the energy production elements appear in the scene (i.e. during the two seconds of animation after a year button is clicked). Consumption trends involve different unit measures than production trends; thus, the energy consumption elements were distinctly positioned outside the landscape scenery. However, although energy consumption and production aspects are kept distinctly separate, the authors aimed to conceptually illustrate that energy production and consumption patterns are linked. To achieve this, they included an electrical wire running from the house, which plugs into the landscape image after the production elements appear and before the house illuminates. This visualization element and animation figuratively conveys the relationship between a secondary energy production source and the end user of the energy.

4.2.2. Interval

In a time-series graph, temporality can be represented clearly and in a single image by plotting data along a continuous time axis (i.e. the *x*-axis). However, in a visualization constructed as a scene, only one instance of time can be represented at a given moment, and consequently, data and trends must be expressed through discrete intervals. This creates limitations around the amount of data that can be featured in a scene-based visualization, and requires decisions around which intervals and instances should be captured through the scenes. Ideally, as many of the data points available would be included in an interactive scene-based visualization; however, time and resources often will not permit this level of inclusion. Developing animated scenes requires far more time and resources than is required in plotting a time-series graph, and in the case of this research, building 50 animated scenes (i.e. one for each year) was not feasible.

After considering the time and resources available for the project, the visualization was built with 10-year intervals between scenes, resulting in a total of 6 scenes. There was considerable discussion about the most appropriate time intervals, and the necessary trade-offs between fine and larger grain data. Limiting the scenes to 10-year intervals resulted in certain shortcomings in the visualization's communicative power; namely, it obscured mid-decade patterns and trends. For example, a spike in nuclear power in the mid-1990s can be seen in the time-series graph (Figures 1 and 2), but because it is a mid-decade phenomenon, it is not captured in the interactive animation.

Two actions were taken to address some of the issues concerning mid-decade obscuration. The first was to include notes in the webpage text above the visualization on certain mid-decade occurrences. For example, it has been noted on the webpage that significant non-hydroelectric renewable production did not emerge until the mid-1970s. The second action was to express values as three-year mean averages, centreing on a respective decade. This allows values to capture data before and after a specific data year, making it more representative of overall trends.[2]

4.2.3. Magnitude

The visualizations illustrate relative trends in energy production and consumption; therefore, how best to capture and convey the relative magnitudes of production and consumption levels was a key consideration for the interactive piece. In a time-series graph, magnitude is relatively easy to portray, as it is simply a matter of plotting the data along the *y*-axes. However, when creating visualizations as scenes or pictures, consideration must be made around how to display scale and changes in magnitude through modifying the pictorial elements. It is worth restating that users of the interactive visualization can hover over certain elements to see values and thus gain numerical information on changes in levels of production and consumption; however, as the piece serves as a visual data representation, the authors deemed it important to represent differences and changes in magnitude through the imagery as well.

To visually express that secondary energy production has increased or decreased from year-to-year, certain elements associated with each of the energy operations were scaled in the scene according to a respective year's data. The scaled elements were specifically selected for their ability to be modified without compromising the visual clarity and/or logic of the scene. For example, increasing the size of the dam could risk obscuring middle ground elements and/or confuse the user as to whether the dam has been built-up or moved; therefore, increases in hydroelectricity production are instead represented through rises in the water.

Determining the degree of scaling was challenging. For the trends and patterns to be communicated visually, the scaling needs to effectively convey how the different energy sources compare to one another in terms of production, e.g. hydroelectricity is a significant secondary energy source in Canada and oil is not as significant. In addition, the scaling needs to illustrate how energy production compares from year-to-year and changes over time, e.g. hydroelectricity production increased dramatically from 1960 to 2010, whereas this increase is not as significant with oil. However, visually capturing these comparisons and attempting to scale images relatively can create complications and prove ineffectual. For example, referring again to hydroelectricity and oil, hydroelectric production was approximately 90 times that of oil in 1960; thus, representing this directly (i.e. a hydroelectric element 90 times larger than the oil element) would result in either one element being too large or one being too small for the scene.

An alternative option that was considered was to scale elements in a manner that they increase and decrease relative to their own "base year", i.e. their lowest non-zero production year. However, this option was prone to producing visually misleading results, due to a fairly large variation in the baselines. For example, 2010 levels of hydroelectric production were 3.3 times those of 1960 levels, whereas 2010 levels of oil energy production were 7.4 times those of 1960 levels. This actually represents increases of 244.7 terawatt-hours and 7.6 terawatt-hours, respectively; however, visually, it would appear as if oil energy production has increased much more dramatically than hydroelectric production over the last decade.

To address the scaling challenges discussed above, elements were subsequently arranged in the scene where larger overall producers (with higher base year values) were displayed more prominently. This involved placing the hydroelectric dam in the foreground, coal in the "fore-to-middle" ground, nuclear and natural gas in the middle ground, and then other renewables and oil towards the background. A scalar system was then devised that allowed for scaling of elements both relative to their own trends and relative changes in overall energy production. The first step in developing this system involved identifying the year of minimum production for each energy source to set this as the source's base year value. Then, the minimum, non-zero energy production value among all energy sources for all years was identified, and this served as the basic unit of comparison for relative magnitudes. All other values were divided by the number to determine the magnitudes relative to the basic unit of comparison. Finally, the resulting relative magnitude values were placed on a scale from 1 to 10, with the base years set to 1 and the maximum possible magnitude set as 10.

The scalar system was used to guide the changes in elements from year-to-year. For example, nuclear energy production had a scalar value of 3.6 in 2000, and thus, in the 2000 scene, the steam emerging from the turbines was raised 3.6 times that of its base year (i.e. 1960). However, in some cases, scalar values had to be used as more approximate in scaling elements. For example, magnitude differences in coal energy production was represented by adding and removing coal carts; thus, rather than featuring fractions or "part-carts", scale values such as 3.9 (i.e. 1990) would be rounded up and (thus) translate to four carts.

Magnitude was also an important consideration for the energy consumption aspect of the visualization, and in some ways, this was more complicated to visually communicate. Secondary energy consumption was measured in per capita values; therefore, as per capita consumption increases, fewer people are using more energy. Within the visualization, this relationship translates to decreases in the numbers of people featured within a scene as consumption levels increase. Although conceptually sound, this was visually confusing, as it (to some degree) gave the false impression that there are less people placing energy demands on the grid. Two actions were taken to address this issue. Firstly, more information was added to the pop-up bubbles that appear when scrolling over the house/people elements. This information provides consumption levels of that year compared to the year of lowest consumption (i.e. 1960), which allows for a clearer articulation of the consumption trends. Secondly, smoke clouds emerging from the house chimney were scaled in accordance with the consumption levels of a respective year. The scaling of the clouds allowed for a visual representation of magnitude, and seen in conjunction with changes in the number of people in a house, it better captures the idea that less people are requiring more energy. However, it is important to note that the authors were hesitant to implement this second action, as the scaling of the smoke cloud was intended to be taken metaphorically, but could run the risk of people regarding it in a more literal sense, i.e. that electrical energy production has a direct influence on smoke arising from a fireplace.

5. Focus group

A focus group was assembled in which participants engaged with both types of visualizations and provided feedback on their relative strengths and weaknesses. The focus group consisted of 11 participants, within the Royal Roads University's Bachelor of Arts in Professional Communications programme.[3] Recruitment was done through an in-class announcement, requesting voluntary participation from the students and they were further advised that they could withdraw at any time. An ethical review was approved for this data collection. The participants that joined the focus group had no prior involvement in the research project, and they encountered the visualizations for the first time during the focus group session.

The rationale for the focus group selection is threefold. Firstly, Royal Roads follows an applied research and education model in which practice and theory are integrated in the classroom, as most of our learners are adults returning to school while working full-time. The opportunity to critically examine a communications tool while studying modern communications and technology was congruent with our pedagogical methodology. Secondly, the invitation to participate was extended to communication students in the final stages of their coursework; therefore, although the focus group was small, the participants were a sample (Tongco, 2007) that could engage in an analysis of the visualization tools based on an informed opinion on what constitutes effective modern communication tools and techniques. Thirdly, the communication students have diverse backgrounds and professional interests, and therefore, the assessment of the visualization allowed us to sample diverse perspectives, albeit from a smaller sample. To the knowledge of the authors, none of the participants had expert knowledge in climate change and energy research prior to engaging in the focus group.

The group was composed of 64% females and 36% males, predominately young adults with 73% falling within the age range of 20–25, 18% within the range of 26–30, and one participant over the age of 50. Due to the small sample size, results were not considered representative of the broader public; however, this methodology follows research that employs small-sized groups primarily for qualitative data and analysis (Munday, 2006), which has been previously used in other studies on visual communication tools (e.g. Lewis & Sheppard, 2006). In addition, because communication students in the final stages of their programme were targeted for this study, this method aligns with other research involving small focus groups of people with knowledge relevant to the topic understudy (Onwuegbuzie, Dickinson, Leech, & Zoran, 2009).

The focus group began with a discussion around the background of the research and purpose of the experiment. The participants then were asked to explore the two visualizations, which were presented to them as standalone media without complementary webpage text (for the purposes of assessing the media without having to account for the quality of supporting information). The participants then completed a questionnaire (Appendix A). The first part of the questionnaire asked them to answer questions about secondary energy production and consumption within Canada over the last 50 years, while using the visualizations to guide their answers. The second part asked participants to provide feedback on the strengths and weaknesses of both visualizations, drawing on their experiences from using the visualizations to answer questions on production and consumption patterns. A discussion period followed that allowed participants to elaborate on their written feedback.

It is important to note that one participant opted not to respond to the majority of questions in the written questionnaire, but provided feedback in the focus group discussion. This is reflected in the sections below, and accordingly, sections that refer to numbers and percentages of questionnaire responses are based on a sample size of 10, rather than 11.

5.1. Responses to energy production and consumption questions

Participants were allowed to freely explore the visualizations and use whichever one they preferred to answer the questions. Prior to engaging in the exercise, they were asked to rate both their perceived statistical understanding and their comfort with computer technology (on a scale of 1–10) to get a sense as to whether either of these factors had a bearing on their preference for and selection of visualization. Both ratings of perceived statistical understanding (M = 7.6, SD = 2.95) and technological comfort (M = 6.1, SD = 3.03) varied from participant-to-participant. However, when asking participants whether they primarily used the interactive or static visualization for answering questions and exploring the data and trends, there was a strong tendency towards the interactive piece with 70% noting they used it to answer questions and 100% noting they used it for data exploration. In examining responses from the three participants that used the static visualization for answering questions, no clear pattern could be seen among their perceived statistical understanding and technological comfort and thus no relationship between these factors and visualization selection was assumed.

The primary objective of asking participants to answer questions on Canada's secondary energy consumption and production patterns was not to test the participants' knowledge base; rather, to determine how effective the visualizations were in delivering information. In order to do this, the analysis was conducted in two steps. Firstly, the responses were examined in terms of how consistent they were with the interactive visualization, rather than for correctness. The interactive visualization was selected as the reference point for this analysis because all participants indicated they explored this visualization at some point. In addition, the interactive visualization is an experimental form of visual media investigated in this study; therefore, its capacity for drawing people in and delivering information was of greater interest than that of the time-series. The second step was to engage in a qualitative analysis of the inconsistent answers by identifying what makes them inconsistent with the interactive visualization. The results of this analysis are summarized in Table 1.

A common inconsistency relates to the identification of energy categories. As seen with the first question, two participants identified "all renewable" as an energy source distinct from hydroelectric, and as seen with question five, two participants listed "renewable energy" as the highest producer of energy rather than specifically hydroelectricity (which is featured as a distinct element in the interactive visualization). It should also be noted that of those who did respond to question one in a manner consistent with the interactive visualization, only one participant specified that the "renewables" category referred to non-hydroelectric renewables, such as wind and solar energy (as featured in the interactive visualization). The reasons for these observations likely relate to how the energy categories are worded and displayed in the visualizations. In the static visualization, "all renewables" are featured as a separate plot from the "hydroelectric" category (despite encompassing hydroelectricity), and appears as if two participants listed the legend for the time-series graph verbatim when responding to question one. In the interactive visualization, non-hydroelectric renewables are described as just "renewables" and are not verbally differentiated from hydroelectric energy,

Table 1. Percentages and descriptions of responses to questions on Canadian energy production and consumption patterns that are inconsistent with the interactive visualization

Number	Question	Inconsistency (%)	Notes on inconsistent responses
1	What are the six energy sources of Canada's total energy production?	20	• All renewable listed as an energy source distinct from hydroelectric • Only one respondent identified the specific types of other renewables (i.e. solar, wind)
2	What is the Terawatt energy production of oil in 1980?	10	• Response referred hydroelectric production rather than oil-based production
3	When was the highest amount of consumption per person in the last 50 years?	40	• Two responded with the year 2005 • One responded with the year 2008 • One responded with the year 1960
4	When did renewable energy (non-hydroelectric) production begin in Canada?	30	• One responded with "before 1960" • One responded with the year 1960 • One responded with the year 2000
5	Which source produced the most amount of energy in Canada over the last 50 years?	20	• "Renewable energy" identified as an energy source distinct from hydroelectric

and therefore, the participants that described the non-hydroelectric renewables simply as "renewables" likely adopted the visualization's wording. It is difficult to definitively ascertain whether these answers indicate that the participants were misled by the visualization and did not understand that hydroelectricity is considered renewable energy or if this was simply a matter of copying what they see. It is commonly understood by the general public that hydroelectricity is renewable energy and participants likely are assuming that using the term "renewable" referring to non-hydroelectric renewables is a "given"; however, this observation does show how lack of specificity in the visualization can lead to an equal lack of specificity when users are asked to relay what they have learned.

Another area where responses were inconsistent with the interactive visualization concerned the third question, which asked "when was the highest amount of consumption per person in the last 50 years?" Two participants responded with the year 2005 and another with the year 2008. These inconsistencies demonstrate the challenges in capturing mid-interval trends in the interactive visualization (see Section 4.2.2 Interval). The participants that responded consistently with the visualization noted that consumption was highest in 2000. However, according to the more detailed data (and static visualization), the actual peak consumption lies between 2000 and 2010, and it appears as if the participants that indicated the years 2005 and 2008 attempted to convey this. Such an observation aligns with earlier stated concerns around attempting to convey detailed information on time-series trends using scene-based visualizations that are limited by the intervals between scenes.

Other inconsistencies that are more difficult to explain include three participants, respectively, stating that non-hydroelectric renewables emerged in Canada in 2000, 1960 and "before 1960". Some of these responses might be based on personal understanding, independently of the participants' experiences with the visualizations. However, the participant who referred to the year of 1960 responded inconsistently to the second and third questions (i.e. 1960), consisting in the only individual to do so in the former case (i.e. question 2). The participant rated her perceived statistical understanding as low (i.e. a rating of "1") and noted she used the static time-series to answer the questions; therefore, it is possible that the response inconsistencies relate to these factors, rather than the actual design of the interactive visualization.

5.2. Strengths and weaknesses of visualizations

Following the questions on Canada's energy patterns, participants were asked to provide feedback on the two visualizations in terms of their usability and appeal. Participants provided these details in part through the questionnaire and in part through the focus group. This feedback was thematically coded (Seidel & Kelle, 1995) using a framework defined through the five considerations discussed in Section 3 (*Visualizations and Trade-offs*)—aesthetics, clarity, analytical power, dynamics and interactivity. After coding the data, qualitative analysis was performed, specifically looking for user-end strengths and weaknesses for each of the visualizations.

5.2.1. Aesthetics

Two participants commented on the attractiveness of the interactive visualization in the questionnaire, noting this to be one of its strengths. In contrast, another noted the aesthetics of the static visualization to be one of its shortcomings, specifically referring to it as "ugly". These sentiments were echoed in the discussion session following the questionnaire, characterizing the interactive visualization as aesthetically more appealing and the static visualization as unappealing. These findings are complementary to the earlier observation that 100% of participants selected the interactive visualization for data exploration (Figure 4). Thus, aesthetics play a key role in attracting audiences to a visualization (Korkmaz, 2009) and maintaining their interest in retrieving information (Cawthon & Vande Moere, 2007).

> [The static visualization is] ugly and hard to read. (Participant 8)

In light of these findings, it is worth noting that the static visualization was developed solely by the first author, and was done with only minor attention to aesthetics (see Section 4.1.1 *Published version*). However, the interactive visualization was developed with the third author, who has multiple years of experience in graphic design; thus, it was developed with much more attention to aesthetic design. The results of this study indicate that this meshing of expertise, data analysis and design experience, was crucial for enhancing audience outreach and user experience, highlighting the potential for graphic designers and artists in research dissemination, especially with the emergence of "big data" (Boyd & Crawford, 2012).

5.2.2. Clarity

Visual clarity is closely related to aesthetics (Peters, 2007); however, this aspect was coded separately from aesthetics to investigate whether the multitude of complex elements and animation in

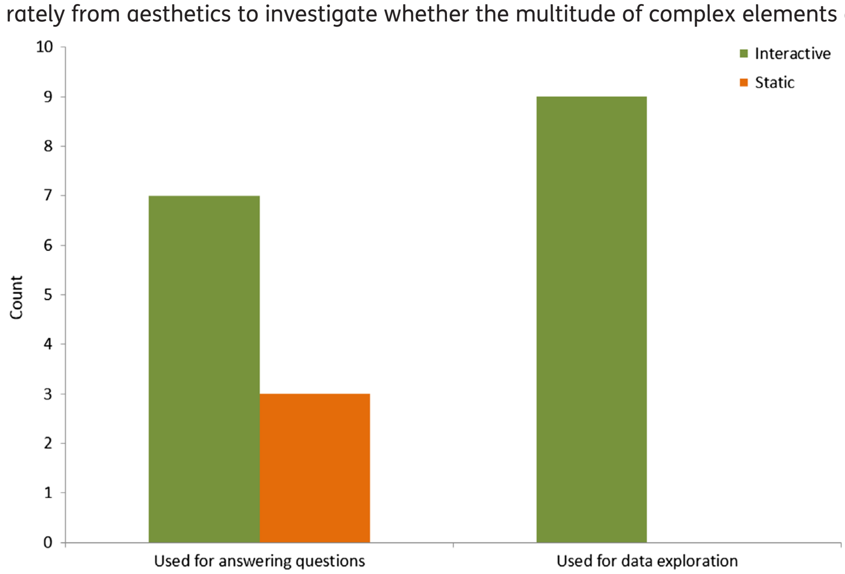


Figure 4. Participants' selection of visualization types for answering questions on Canada energy trends and exploring Canada energy data.

the interactive visualization made it more convoluted than a simple time-series graph (regardless of whether it was considered more attractive). However, contrary to this supposition, clarity was considered to be a strength of the interactive visualization and commonly noted as a weakness of the static piece. Responses from four participants in the questionnaire contributed to this finding, consisting of descriptions of the interactive visualization as "simple", "clear to understand" and "easy to see". Questionnaire responses from five participants supported the contrasting opinion on the static visualization, noting the graph colours as "difficult to differentiate", "hard to read" and "hard to understand". This point emerged again in the focus session, where participants critiqued the colour scheme and readability of the static graph. Such findings once again demonstrate the role graphic designers can play in research programmes, as this field of expertise includes understanding how to clearly "speak" to different audiences using visuals (Barnard, 2005).

> [The interactive visualization is] very simple, clear to understand. (Participant 3)
> The interactive presents the information more simply. (Participant 7)

The interactive visualization received some criticism concerning clarity; however, this primarily related to a lack of instruction on how to use and access the data. As noted in the beginning of Section 5 (*Focus group*), the visualizations were presented to the participants as standalone media without supporting or complementary text; therefore, the participants did not receive the benefits one would if exploring the visualization embedded on a webpage with instructional text. This finding indicates that instructional text is particularly important for novel interactive visualizations because, unlike time-series graphs that have a fairly standard and recognizable format, the interactive pieces can be unique in design, format and methods for interaction.

5.2.3. Analytical power

Contrary to aesthetics and clarity analysis, analytical power was considered a strength of the static visualization and a weakness of the interactive visualization. Six participants noted in the questionnaire that the static visualization held the advantage of being able to present all data and trends in the same image. In addition, another participant commented on the ability to "pinpoint [values] on the graph", referring to the level of precision the graph offers in examining data. In contrast, participants noted in both the questionnaire and discussion group that the scene-by-scene format of the interactive visualizations created challenges in attempting to understand the specificities in trends for each of the energy sources and how these trends compare with one another.

> Easier to pinpoint on graph. (Participant 6)
> The graph displayed everything at once. (Participant 9)
> I can see all the information at once. (Participant 11)

These findings aligned with the concerns the researchers had for the interactive visualization, regarding both intervals and magnitude. In terms of intervals, participants noted during the discussion session that the interactive visualization did not make trends from decade-to-decade (and within decades) obvious, which ultimately affected their ability to understand the temporal nature of the data. In terms of magnitude, participants noted (also during the discussion session) that the sizing of visual elements from scene-to-scene, according to their scale of energy production, did not effectively convey increases and decreases in said production. However, participants did note that operations where elements were added or removed (e.g. coal carts) adequately conveyed scale changes; thus, this suggests that changes in visual elements need to be "dramatic" (i.e. presence or absence of elements) rather than subtle modifications (i.e. slight increases or decreases in size of elements) to effectively communicate data and trends.

5.2.4. Dynamics

The animation incorporated into the interactive visualization was considered both a strength and weakness in different ways. In terms of strengths, one participant noted through the questionnaire that the animated nature of the interactive visualization gave "a sense of changes during [the] time [span]", and this sentiment was supported during the group discussion. Therefore, albeit the interactive visualization might fall short at the level of detail and precision for changes over time (see Section 5.2.3 *Analytical power*), it was considered effective for conveying temporality. In this way, the interactive visualization demonstrated potential for communicating the nature of the trends, if not details on the trends themselves. Such a finding indicates that animation can play a strong role in conveying the time-series character of a visualization, and perhaps the animation could be designed to address weaknesses of the interactive visualization concerning its analytical power. For example, when clicking on a button for a particular year, the animation could capture the fluctuation in production and consumption throughout the previous decade leading up that year, thereby illuminating mid-decade trends.

> [Interactive visualization] gives a sense of changes during this time. Illustrates how energy consumption has grown. (Participant 1)

In terms of weaknesses, three participants noted in the questionnaire that the time it took for all elements to appear in a scene each time a year button was clicked (i.e. five seconds) was time-consuming and created delays in retrieving the information. This point was also reinforced in the focus group. Such a finding suggests that careful consideration needs to be given to animation time in order for it not to feel "rushed" while also ensuring users do not feel frustrations from delays. In light of the discussion above around the potential of using animation to illustrate trends within intervals, this could be complicated and requires thinking about how to allow an animation to tell a "story" without disrupting the user experience. A potential solution to this issue would be to allow the user to bypass the animations and move directly to a scene using an alternate series of buttons.

> Waiting for the animation to load each time is time consuming. (Participant 7)
>
> It took longer to get informed from [the interactive visualization]. (Participant 9)

5.2.5. Interactivity

Feedback on interactivity related to the ability users had to actively interact (i.e. click buttons) and initiate changes (i.e. trigger animations) and the experience this provided. Overall, the participants noted that this feature greatly contributed to the visualization's capacity to engage and maintain user interest. The implication of this feedback is that interactive visual media is better suited for engaging public audiences. Such a finding is complemented by the earlier observations that 100% of the participants primarily used the interactive visualization (rather than the static visualization) for exploration of the data and trends (see Figure 4). In addition, some of the participants commented on how the interactivity (and accordingly power for engagement) increases educational capacity, e.g. one participant noted that this was "effective for learning" and another noted that it assists with "remember[ing] the information". In addition, another commented on how the interactive visualization can appeal to broader groups, specifically noting "children would play with animation". These findings suggest that although more specific analysis and comparisons can be made with the static time-series (see Section 5.2.3 *Analytical power*), the interactive animation was a far more effective attractor, informing them on (at least) "bigger picture" trends and ensuring that they retain information. Such an insight is significant in the context of this research, as a research objective was to interrogate how to engage and inform broader publics on climate change research using visuals.

> Interactive is more interesting and useful, as I'll remember the information more. (Participant 8)

Although interactivity was considered beneficial for the most part, it did create challenges around information retrieval, in a similar manner to that seen with dynamics. In the interactive visualization, users had to click buttons to access data for certain years and scroll-over elements to see data for the different energy production methods. Participants noted this created delays in retrieving information when using the interactive piece; whereas, in contrast, all information was available upfront when viewing the static visualization.

> Slow to get information, lots of mouse work to get info. (Participant 10)

6. Discussion

No “perfect recipe’” exists for developing a “best” visualization for research dissemination and communicating data trends to broader audiences. When attempting to engage public audiences around critical sustainability issues such as climate change, one must consider the potential trade-offs that exist in both building and using one form of visual media over another. The findings of the focus group indicate that a major strength of the interactive visualization was its aesthetics and design; by contrast, this was noted to be a weakness of the static visualization, one participant going as far to say that it was “ugly”. This finding relates to the fact that the interactive piece was built with artistic elements and demonstrates the potential that integrating the arts with data visualization can have in terms of reaching diverse audiences. Previous research has similarly advocated for this form of integration in climate communications. For example, Holmes (2007) described a digital piece mounted on the National Center for Supercomputing Applications (Urbana, IL) that displays the carbon footprint of the building and number of trees required to absorb this footprint. She describes the display as ‘public artwork’ as it incorporates aesthetic tree imagery, and posits that these aesthetics make for a more interesting conveyance of data.

The potential trade-offs in incorporating art and aesthetics with data visualization is that it can create challenges around accurately representing the data. Lau and Vande Moere (2007) discussed a spectrum that dichotomized data representation and artistic freedom, and discussing climate communications as an example, they warned that highly interpretive visualizations with little data representativeness can lead to misuse and diminished trustworthiness of scientific visualizations. In a similar vein, visualizations that contain real-world elements can be more aesthetically engaging and have communicative salience (e.g. a map-based visualization showing wildfire spread (Schroth et al., 2009)); however, Sheppard (2001) and Lewis, Casello, and Groulx (2012) also caution around the misuse of these in climate communications in terms of communicating data inaccurately, whether advertently or inadvertently. This challenge became apparent in the building phase of this research, particularly with the scaling of the chimney smoke clouds (above the house) in accordance with the consumption levels of the respective year. Although the scaling did express magnitude, the imagery was not abstract and (thus) posed the risk of inaccurately communicating that electrical energy production has a direct influence on smoke arising from a residential fireplace. In contrast, the use of less-artistic abstract imagery in the static visualization contributed to data representativeness, which, in turn, lent it analytical power. The time-series graph was noted to be useful for examining specific data points, allowing for closer comparisons and better understanding of trends.

Other trade-offs involve the incorporation of interactivity and dynamics. In a study on online visualizations as tools for climate communications, Herring et al. (2016) found evidence that interactive tools can engage audiences and increase concern towards climate impacts. Aligning with this observation, the findings from this research indicate that interactivity has the potential to better engage more diverse audiences, contribute to learning and maintain interest in the information communicated. Similarly, dynamics were found to enhance the visualization’s capacity for engaging and communicating information, particularly in terms of how it expresses a “sense of temporality”. Ultimately, these findings position dynamic, interactive visualizations as powerful tools for attracting, maintaining the interest of, and communicating complex information to diverse audiences.

The obvious trade-offs around incorporating dynamics and interactivity in visualizations involve the fact that they are more challenging and time-consuming to design and build (Viegas et al., 2007), and such trade-offs were observed in this research. This will become less of a consideration as software and techniques in visualization advance; however, other trade-offs were observed surrounding the ability to retrieve information, which are perhaps more difficult to reconcile than the ones previously mentioned. In particular, participants noted animation and button-clicking to be time-consuming, creating delays in information/data retrieval. Similarly as discussed above, this indicates that while dynamic and interactive tools might be more engaging, static visualizations might provide more detailed insights on specific data. This is a significant trade-off in climate communications, as communicating climate research requires both engaging diverse publics and effectively conveying complex information (Nerlich, Koteyko, & Brown, 2010).

The discussion above illustrates the need for optimizing both engagement and analytical power, and accordingly, discussing one type of visualization as "better" than another might not be appropriate. Instead, communication strategies could involve multiple types of visualizations employed in a complementary fashion. For instance, an interactive visualization could attract audiences at an aggregate level to explore overall trends relevant to climate change and climate action; however, the visualization could then hyperlink (through embedded buttons) to time-series graphs for a more in-depth examination of the data. For example, the most recent assessment report from the Intergovernmental Panel on Climate Change (IPCC) (2014) includes a time-series graph on trends in greenhouse gas contributions over the last 160 years from land use and forestry and the combination of fossil fuel combustion, cement production and flaring emissions. An interactive visualization could be developed around this time-series, including visual elements such as forests and fossil fuel sources (e.g. vehicles, energy production), and this could then be used as an initial attractor for broader engagement and information on the broader trends whereby sources are increasing their influence on climate change. The visualization could also include a button on which users click to access the original time-series graph to examine increases and decreases in emissions more in-depth as well as gain insights in greater detail into more specific time periods. By offering both a generalist and a specialist way to access data, the user would be able to drill down more deeply according to interests and data needs, which may contribute to the literacy of far wider audiences. In support of this line of thought, Valkanova et al. (2013) conducted a study on user interaction with dynamic, interactive visualization of electricity consumption, and found that while most appreciated the simple and 'clear' interface, some requested a function that allows access to more specific data.

Another possibility for optimizing the communicative potential of visual media would be to take a 'hybrid approach', improving on the weaknesses of one type of media by borrowing from the strengths of another. As discussed, the major strengths of the interactive visualization were that it was attractive, dynamic and interactive; whereas, the static visualization was considered "ugly", did not benefit from the temporality animation can convey, and lacked the engaging quality of interactivity. However, featuring recognizable elements such as the landscape and energy operations was not specifically cited as a strength of the interactive visualization; therefore, it is possible that an abstract visualization in time-series format can be made just as engaging if created as an interactive, dynamic and aesthetic piece. For example, Roston and Migliozzi (2015) produced a time-series visualization that displays different trends in natural and anthropogenic phenomena in comparison to increasing global temperatures to illustrate that it tightly correlates with increases in greenhouse gases. The visualization is in the format of an abstract time-series graph; however, it involves user interaction (i.e. clicking buttons) and animation, which increases ability to engage audiences and convey a sense of temporality. As another example, Venturini et al. (2014) developed a graph that displays the relative prevalence of topics discussed within the various conferences of the United Nations Framework Convention on Climate Change from 1995 to 2013. This graph was constructed as an abstract time-series; however, it has been posted online as a visually interesting, interactive piece on where users can click and highlight different trends (Baya-Laffite et al., n.d.).

7. Conclusions

Although findings of this study are not statistically representative of the broader public, they support ideas from other research on visualization tools and techniques, and highlight the importance of making climate research visualizations interesting and attractive in order to increase the potential for engagement among diverse audiences. This presents a clear role for greater collaboration between graphic designers and artists in research dissemination and knowledge mobilization to broader public(s). To a certain degree, such a role has been explored by graphic artists in recent years, as the proliferation of public data sources has allowed artists more opportunities to creatively express data trends (Viégas & Wattenberg, 2007). However, as discussed above, there can be a trade-off between artistic freedom and data representation (Lau & Vande Moere, 2007). Therefore, to fully realize the potential of integrating art into data visualization, further experimental collaborations should be conducted where artists are included as an integral part of research teams, rather than researchers and artists working independently to communicate data patterns and trends. Such a consideration is particularly important in research around critical sustainability issues such as climate change, as it is through such trans-disciplinary approaches (Brandt et al., 2013; Dale, Newman, & Ling, 2010) that efforts towards communicating critical research findings to the public sphere can be most effective and increase engagement. Granting councils should include funding for these novel collaborations, especially if the explanatory power of big data is to be optimized to wider public(s) and communicated beyond the educated elites.

These findings could apply to a wide variety of disciplines; however, they were obtained within the context of climate change research, on the basis of the understanding that climate change is a critical global issue that, by necessity, requires actions on multiple tiers, informing and changing human behaviour and decisions at the micro, meso and macro levels. Within this context, the outcomes indicate that art, design and aesthetics are key components of applied interdisciplinary research programmes committed to widespread research dissemination and knowledge mobilization, as well as informing evidence-based decision-making. Some scholars have referred to this as the 'production of useful knowledge' (Kates et al., 2001; Raven, 2002). Artists can be integral members of the research teams, specifically graphic designers in data visualizations. Moving towards sustainable development is a complex challenge that requires trans-disciplinary solutions and implementation that necessitates input from multiple disciplines and sectors (Dale et al., 2010) and also society at large (Brandt et al., 2013). In addition to the incorporation of the arts and humanities disciplines, the integration of professional designer practitioners to apply their talents so as to better engage, inform and enhance literacy among the wider public(s) on this critical issue and field of research should be promoted. Engaging both the heart and the mind leads to greater action on the ground, further emphasizing the importance of designing aesthetically attractive data visualizations (Dale, 2001; Peavey, 1994).

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Notes

1. These design trends are known by the third author, as she is a professional in the graphic design industry.
2. It should be noted that there were challenges with this technique, as data were not available for 1959 and 2011. As a consequence, the initial and last scenes only represent two data points.
3. The majority (91%) of participants' primary occupation could be classified as that of undergraduate students; however, one of the participants was also a course instructor at Royal Roads University, in addition to being a student in continuing studies courses.

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Appendix A.

Part 1. About yourself
Sex: Male [ ] Female [ ] Other [ ]

Age: ___

In the two questions below, circle what number you feel describes you best [1-Low to no comfort and 10-Very Comfortable]

Statistical understanding**:** 1 2 3 4 5 6 7 8 9 10

Comfort with computer technology**:** 1 2 3 4 5 6 7 8 9 10

Part 2. About the visualizations
Take a few minutes to explore the two following tools, and then answer the questions below:

Static visualization: https://crcresearch.org/y

Interactive visualization: https://crcresearch.org/z

About Canada's electrical energy production and consumption

(1) What are the six energy sources of Canada's total energy production?
(2) What is the Terawatt energy production of oil in 1980?
(3) When was the highest amount of consumption per person in the last 50 years?
(4) When did renewable energy (non-hydroelectric) production begin in Canada?
(5) Which source produced the most amount of energy in Canada over the last 50 years?

About the visualization tools

(6) Which visualization did you use more to answer the questions above (if this differs for certain question, please indicate)?
(7) Which visualization did you use more to explore the data and trends?
(8) Describe the pros and cons of each tool?
(9) Any additional thoughts or comments?