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Environmental Data Visualizations: Opportunities for Technical Communication Research

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Abstract

Environmental issues touch nearly every field. Technical communication researchers have advocated for multidisciplinary environmental communication research to effectively address the depth of environmental issues and speed at which environmental issues evolve. Visuals are often used in environmental communication to help clarify complex information. Using a multidisciplinary approach, the author utilizes secondary research to answer the question, 'how do data visualizations support environmental communication?'. This research illustrates the value of using environmental data visualizations to add credibility and to facilitate interpretation within environmental communication. Alignment among disciplines, however, is limited in other attributes of environmental data visualizations such as representing temporal or spatial data. This provides significant opportunities for technical communication researchers to expand the field's knowledge of environmental data visualizations and their function in environmental communication.

Keywords: data visualization, environmental communication, environmental visualization

Introduction

Environmental issues touch nearly every field. While some companies have been legally required to disclose environmental information for decades, issues like global climate change and the rise of conservation groups have led to an increase in writing about environmental issues in all sectors, including technical communication (Johnson-Sheehan and Morgan 2008).

The technical communication field is well-suited to participate in the development of environmental communication because it has the unique basis to understand an audience and influence environmentally conscious behavior (Coppola 1997). In recent decades, the development of environmental communication has grown beyond legally required documentation and narrowly focused conservation groups to broad environmental communication audiences and genres (Johnson-Sheehan and Morgan 2008). This growth in environmental communication and the expanded audience of the communication showcase the importance of technical communication's ongoing participation.

To meaningfully contribute, technical communication's understanding of environmental communication needs to evolve as environmental issues evolve. To achieve this, technical communication researchers must synthesize the field's knowledge with conversations occurring in other disciplines who are researching environmental communication. This approach builds upon technical communication research that investigated interdisciplinary research intersections of climate change communication. The researchers identified benefits for technical communication including the opportunity multidisciplinary research offers in identifying avenues for future research (Cagle and Tillery 2015).

Even when viewed through a multidisciplinary lens, environmental issues are extremely complex and can be difficult to interpret. Visuals aid in the interpretation of complex information by making the information easier for an audience to understand. They offer "a kind of cognitive short cut compressing a complex argument into one that is easily comprehensive and ethically stimulating" (DiFrancesco and Young 2010, 519). As a subset of visuals, data visualizations can be a key to communicating the complex components of environmental information, such as energy use and climate data. These are pieces of environmental information that cannot be clearly conveyed through words or photographs.

The communicative power of data visualizations is understood within technical communication. Their design facilitates comprehension through clarity (Kostelnick 2007). In technical communication research specific to environmental communication, Rude found the tables and graphs within environmental reports encouraged reading (1997). More recent research found visual elements were used in environmental reports as a rhetorical tool for claim-evidence relationships (Whithaus 2012). This starts to show a relationship between data visualizations and environmental communication. Multidisciplinary research expands this relationship by focusing on the complexity of visualizing the types of data prominent in environmental communication—temporal and spatial data. Expanding technical communication's research to look more closely at unique data visualization attributes within environmental communication provides an opportunity to advance technical communication's ability to meaningfully contribute.

Using existing technical communication, environmental communication, and data visualization research, I aim to answer the question 'how do data visualizations support environmental communication?'. Where existing research doesn't provide a complete answer, opportunities for future technical communication research will be identified.

What is Environmental Communication?

For the purpose of this research, I utilize the following definition of environment, "the complex of physical, chemical, and biotic factors (such as climate, soil, and living things) that act upon an organism or an ecological community and ultimately determine its form and survival" (Merriam-Webster 2019). This definition encompasses what Johnson-Sheehan and Morgan describe as conservation writing; an umbrella term for writing about ecology, biology, the outdoors, environmental policies, and ethics (2009). This definition also includes related terms and concepts found in existing environmental communication research such as, climate data, energy literacy, energy demand, renewable energy, and sustainability.

The history of writing about the environment can be traced back more than 200 years. This early writing was often observational information about plants and animals (Johnson-Sheehan and Morgan 2009). The National Environmental Policy Act (NEPA), passed in 1969, followed by the formation of the Environmental Protection Agency (EPA) in 1970, spurred the forms of environmental communication those in the field of technical communication typically participate in today. While it is impossible to capture all environmental texts that a technical communicator might construct or use in research, it is possible to gain a general understanding of these texts from the existing technical communication research. Rude identified the environmental impact statement as the most well-known type of environmental report and researched the function of energy reports in environmental policy making (1997). Johnson-Sheehan and Morgan suggested genres include analytical reports, articles, brochures, environmental impact statements, environmental management plans, essays, grants, natural resource inventories, newsletters, and website content (2008). Whithaus used reports written by environmental scientists to research claim-evidence structures in environmental communication (2012). Cagle and Tillery focused on climate change communication, primarily published in peer-reviewed journal articles (2015).

I define *environmental communication* as texts (i.e. reports, grants, studies) developed to convey information about the environment that the audience can use to take action. The advocacy for action is a significant difference between environmental communication and other kinds of communication (Johnson-Sheehan and Morgan 2008). It is also a key component of its function as technical communication. Environmental communication "rests on the assumption that before environmental problems can be solved, information must be gathered, and plans for action must be established" (Rude 1997, 77). Environmental communication should include an effective rhetorical purpose because "the traditional Aristotelian sender-receiver pattern which suggests information is passed like a silver bullet from writer to audience is demonstrably ineffective in environmental communication" (Coppola 1997, 17). Decision makers rely on environmental communication to assess the impact of specific actions and to provide forward-looking plans.

A challenge with making environmental communication actionable is that the audience is widespread and varied. Traditionally, reports developed to communicate environmental information, such as environmental impact statements, were not viewed by the public (Rude 1997). Today, both public and professional readers access environmental communication. Although it may be developed for a target audience, such as specific policy makers or stakeholders, environmental communication is likely to reach people beyond the target audience. These individuals may have business, public policy, or other political interests. This includes students, scientists, legislators, reporters, farmers, environmental activists, and interested citizens (Grainger, Mao, and Buytaert 2016; Johnson-Sheehan and Morgan 2009; Whithaus 2012). An example of actionable environmental communication is described in research conducted by an economics professor who found corporate sustainability reports were used by internal audiences to allocate resources and by external investors and stakeholders to evaluate the company's environmental performance as part of their investment decisions (Leszczynska 2012).

The information contained in environmental communication can be very dense. Developing environmental communication that will be utilized by multiple audiences creates a need to make specialized environmental information, generated by individuals such as environmental engineers or scientists, usable to broad audiences. Clarity, especially for a broad audience, is essential. Environmental science researchers suggest visualizations within environmental communication help a non-scientific audience complete a task or make an informed decision (Grainger, Mao, and Buytaert 2016). Data visualizations, as a subset of visuals, are a key component of taking complex environmental information and making it understandable and usable for the audience.

What is a Data Visualization?

A data visualization is a visual representation of data with the goal of facilitating the audience's ability to interpret, explore, and respond to the data. Similar to the long history of environmental communication, people have been visually representing data for centuries. Data visualizations quickly guide an audience through complex concepts and relationships even if they aren't familiar with the underlying data (Kuchinskaya 2018). They allow business leaders to see patterns in data and make better business decisions (Yoon 2017). Abstract quantitative data, such as a projection, is more comprehensible when it is viewed as a concrete visual representation of the data (Meitner et al. 2005). Data visualizations appear in everything from technical reports to brochures to monthly power bills (Kostelnick 2007). This ongoing use is a testament to their value in communication.

Many fields have studied how data visualizations function. Edward Tufte, a well-known data visualization researcher, indicated data visualizations should be clear and accurate without distorting data. Building on this research, Kostelnick, a researcher well-known in the field of technical communication, identified rhetorical benefits of using data visualizations to provide clarity. In his research, readers quickly understood data visualizations they viewed, and this quick comprehension gave them confidence in the data (2007). Advances in technology also continue to increase the value and use of data visualizations. The ability to create data visualizations has never been easier due to the availability of new software and technology (Grainger, Mao, and Buytaert 2016).

Advances in technology have also expanded the application of data visualizations to media beyond static displays. In the last two decades, online environments have made interactive data visualizations increasingly feasible. Interactivity gives the audience an opportunity to change their view of the data. Whether static or interactive, data visualizations have four elements: the designer, the user, the action of making the data visualizations, and the data visualization itself (Rawlins and Wilson 2014).

For the scope of this paper, I limit data visualizations to non-interactive visualizations intended to be read on a single surface. While interactive data visualizations are common, many typical environmental communication genres, such as environmental impact statements and analytical reports, are currently delivered in non-interactive formats. My focus on non-interactive data visualizations also follows the boundaries of a climate visualization research team who found insufficient research available to adequately incorporate interactive visualizations into their climate data visualization research (Daron et al. 2015).

Multidisciplinary Research Approach

To answer my research question—*how do data visualizations support environmental communication*—I searched for research at the intersection of technical communication, environmental communication, and data visualization research, see figure 1. I identified peer-reviewed technical communication articles containing the exact phrase ‘data visualization’ paired with terms from environmental communication such as energy, environment, climate, renewable, solar, and sustainability. This preliminary approach provided insufficient research to answer my question. With limited research available at this central intersection, I expanded my search to include peer-reviewed articles from fields outside of technical communication that were focused on data visualizations in environmental communication, see area ‘C’ in figure 2.

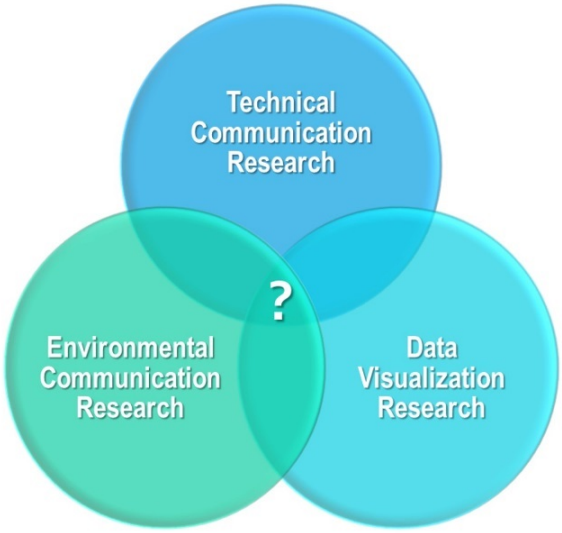

Figure 1–Research Question

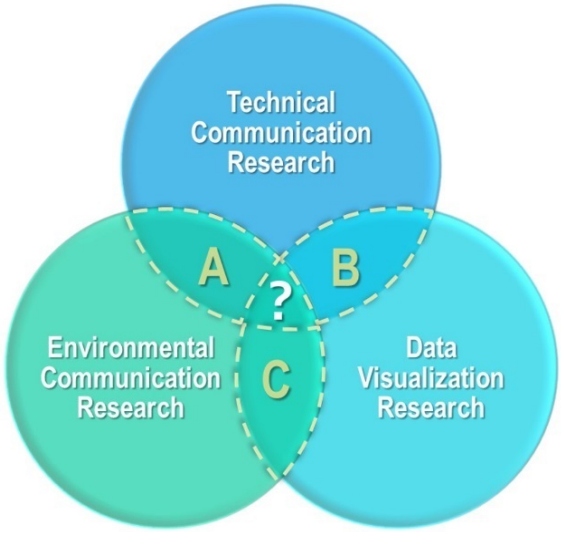

Figure 2–Research Intersections

When addressing issues that cross disciplinary boundaries, such as the environment, it is important for scholars to embrace interdisciplinary research (Meitner et al. 2005). Expanding my approach to include multidisciplinary research provided more opportunity to answer my research question. Using research from other fields to inform our own is one method technical communication researchers suggest we utilize to maximize resources (Cagle and Tillery 2015).

To ensure the research I utilized from other disciplines was appropriate to incorporate into the field of technical communication, I referred to research by Cagle and Tillery who contended that bringing research from other fields into technical communication had value. Their approach pulled together journals cited in *Technical Communication Quarterly* and the *Journal of Business and Technical Communication* with journals which they indicated were likely new to technical communication (2015). I utilized research published in *Environmental Communication* which appeared in Cagle and Tillery's list of journals cited in *Technical Communication Quarterly,* so would be considered a more well-known journal within the field of technical communication. My other primary sources, however, did not appear in that list so may be new to technical communicators–*Climate Risk Management, Energy Efficiency, Environmental Modelling & Software,* and *Frontiers in Energy Research.*

While the research from disciplines outside of technical communication focused specifically on data visualizations in environmental communication, it was not realistic to disregard technical communication's environmental communication research and data visualization research. Although technical communication researchers often study each independently, the body of research is extensive and should not be ignored when developing environmental communication. Therefore, my approach also utilized research from the secondary intersections within technical communication, see areas A and B in figure 2. This approach allowed me to look for multidisciplinary alignment and differences that could begin to answer my research question at the center.

To simplify terminology while maintaining the focus of my research, I utilize *environmental data visualization* as the descriptor for data visualizations used to visualize environmental data within environmental communication.

Benefits for Technical Communication

Pulling environmental data visualization research into technical communication from other disciplines can be beneficial for the field. In analyzing climate change communication, Cagle and Tillery identified three specific benefits of a multidisciplinary approach for technical communication: "(a) a broader context for our existing research; (b) new avenues for our future research; and (c) awareness of close overlaps between other fields' scholarship and our own" (2015, 147). A multidisciplinary approach to researching environmental data visualizations can bring all three of these benefits to the field of technical communication.

Of these benefits, I believe the most significant opportunity with environmental data visualizations is finding new avenues for technical communication research. The environmental data visualization research I reviewed from outside of technical communication pointed directly to areas where the understanding of environmental data visualizations should be expanded through research. Daron et al. suggested a need to focus on how audiences interpret spatial and large sets of data being used to communicate climate information (2015). Grainger, Mao, and Buytaert recommended future research where non-scientific end users help understand the

impact data visualization design has on end users (2016). Herrmann, Brumby, and Oreszczyn hypothesized that data visualizations with disaggregated data would help homeowners understand their energy use, however there is currently no evidence to support this hypothesis (2017). Technical communication researchers have the opportunity to advance this multidisciplinary conversation by taking the gaps identified by other researchers into account when they develop environmental data visualization research.

Benefits for Non-Technical Communication Disciplines

Not only are there benefits for technical communication, collaboration can also be beneficial for the fields whose research we integrate or expand upon. A forest management research team explains one benefit of multidisciplinary research may be a combined understanding of science and societal values because it isn't feasible for any one individual to be up-to-date on the full body of research from every discipline (Meitner et al. 2005).

Multidisciplinary visualization work, such as between designers and scientists, has been found to significantly contribute to audience interaction with the information presented to them. Collaboration was mutually beneficial because both disciplines brought unique design strategies and worldviews to the visualization process. The outcome was an innovative visualization that accurately conveyed the scientific message (Grainger, Mao, and Buytaert 2016).

A research article in *Climate Risk Management* explained the need for expertise in developing environmental data visualizations and looked to other disciplines for this expertise. The research team indicated that multidisciplinary expertise could expand the awareness of how environmental data visualizations are interpreted and could offer a variety of design approaches to help communicate climate data to many audiences (Daron et al. 2015).

Integrating technical communication's research with environmental data visualization research from other disciplines can be especially helpful for scientists. There is pressure on them to ensure data visualizations are attractive and tailored to specific audiences (Daron et al. 2015). Scientists, however, are often eluded by the ability to convey accurate and useful information to non-scientist audiences and are rarely given training about how to develop visualizations. Since this skill is challenging for scientists, one environmental research team suggested they learn from professional environmental communicators (Grainger, Mao, and Buytaert 2016). Technical communicators are certainly professional environmental communicators so a collaborative, multidisciplinary approach can benefit scientists aiming for clarity and usability of data. As technical communicators, we are trained to create "messages that interact with our audience's attitude and knowledge" (Coppola 1997, 22).

Environmental Data Visualization Research Conversations

Using this multidisciplinary approach to answer my research question, I synthesized the research by looking for alignment and differences. I identified two primary areas of alignment; data visualizations add credibility to environmental communication and data visualizations aid audiences in environmental communication interpretation. Along with the areas of alignment, I recognized a primary difference between the technical communication research and the research from other disciplines. This difference was a focus on the nature of the data visualized in environmental communication, specifically temporal and spatial data. A significant opportunity exists for technical communication researchers to join this conversation and extend the existing research.

Alignment in the Research Conversations

Understanding areas of alignment is important for technical communication. One benefit of understanding alignment is that it identifies areas that could be deprioritized when developing future research. For example, in investigating climate data visualization interpretation with a community in Africa, a research team found age and gender had no significant impact on interpretation of data visualizations (Daron et al. 2015). Earlier technical communication research aligned with this and suggested environmental communication audience analysis should go beyond using age or gender as attitude forecasters (Coppola 1997). This alignment can guide technical communication researchers to prioritize other areas ahead of studies focused on environmental data visualization interpretation related to age or gender.

Add Credibility or Support a Claim

Technical communication researchers contend that an environmental data visualization can add credibility and support a claim. Quantifiable information was used to develop environmental data visualizations displayed in energy reports. The environmental data visualizations served as sound claims to create the basis for arguments, thus advocacy. They became sound, or credible, by synthesizing key findings and incorporating styles that encouraged reading (Rude 1997). Whithaus extended Rude's research by investigating the role visuals take in forming an argument in environmental communication. Using a modified version of Toulmin's model of argument, Whithaus found visual and numeric elements, in conjunction with linguistic forms, aided in constructing arguments. The findings suggested visual elements were used, most frequently, as evidence to support a claim made in linguistic form (2012).

The ability for environmental data visualizations to support claims or enforce credibility aligns with research from other disciplines. Corporate sustainability reports that contain accurate and complete data were found to build trust and credibility with key stakeholders (Leszczynska 2012). In research regarding scientists developing environmental data visualizations for a non-scientific audience, it was found that adding forecasting uncertainty to environmental data visualizations increased user trust. Including this uncertainty was found to be essential because removing it or oversimplifying the data creates an environmental data visualization that is unable to facilitate action, a key function of environmental communication (Grainger, Mao, and Buytaert 2016). Researchers also found, for environmental data visualizations with forecast or prediction data to be credible, the data must come from scientific models (Meitner et al. 2005).

Facilitate Interpretation

Significant research has been done in many disciplines to understand how data visualizations are interpreted. The results showcase the complexity of interpretation including several differing perspectives. There are three lenses that are useful when considering varying interpretation research perspectives. One is a functional view where researchers attempt to define universal design principals that can facilitate consistent interpretation. Another is an adaptive view where researchers study the influence of situational factors—such as audience, purpose or context—on interpretation. The third is a social view which extends interpretation research to consider the learned experiences of an audience such as their education or the popular culture they have been exposed to (Kostelnick 2007).

Even though interpretation research remains ongoing, it was evident from existing research that environmental data visualizations are used to facilitate interpretation of complex environmental data. In an environmental report analyzed by a technical communication

researcher, wind intensity maps were found to make the wind intensity data accessible for an audience of nonspecialists (Rude 1997). Another technical communication researcher studied data visualizations on a broader scale and found they helped an audience make decisions (Rawlins and Wilson 2014).

This technical communication research evidence is in alignment with the other disciplines' research. Scientists use environmental data visualizations to support their scientific communication. A research team stated visualizations that balanced clear communication of environmental data with an audience's preferred appearance provided opportunity for accurate interpretation of the visualization (Grainger, Mao, and Buytaert 2016). Household smart energy meters provided data in a graphical format with the intent that the data would be clear, easy to understand, and would enable homeowners to change energy consumption behavior (Hermann, Brumby, and Oreszczyn 2017). Landscape data visualizations have been used for several decades in forest management communication. Technology advancements in recent years have increased their realism. The advantages of this increased realism have made landscape data visualizations essential in forest management communication (Meitner et al. 2005).

While multidisciplinary research alignment highlights the value of using environmental data visualizations to facilitate interpretation, interpretation is very complex. Results from existing research prove that our understanding of interpretation is not yet conclusive. For example, an environmental data visualization designed to increase trust and credibility doesn't guarantee the audience will correctly interpret the data. In one study, the audience extracted different messages from average rainfall data visualizations even though the data was the same (Daron et al. 2015). Understanding why this occurs and how to increase consistent interpretation should remain a focus for technical communication researchers.

Primary Difference from the Research Conversations

The difference I identified was not a contradiction between technical communication research and research from other disciplines but rather a noticeable difference in focus on the nature of the data. Throughout the non-technical communication research, strategies for conveying temporal and spatial data were consistently referenced. In my review of the technical communication research, this terminology and associated strategies were not apparent. I suggest a more thorough understanding of this focus, and its implications on environmental data visualization development and interpretation, should be a focus for technical communication researchers.

Temporal Data Considerations

Choosing the type of environmental data visualization that will best convey a message is dependent on the nature of the data (Daron et al. 2015). Temporal data is time dependent and is a necessity within environmental communication. "Perhaps one of the differences between geographic and environmental visualization is the need to incorporate more strongly the temporal domain" (Grainger, Mao, and Buytaert 2016, 302).

Visualizing temporal environmental data is complex and poses unique challenges (Grainger, Mao, and Buytaert 2016; Herrmann, Brumby, and Oreszczyn 2017; Kuchinskaya 2018; Meitner et al. 2005). Time-series graphs are one common tool for communicating environmental data that changes over time (Daron et al. 2015; Grainger, Mao, and Buytaert 2016; Herrmann, Brumby, and Oreszczyn 2017; Wilson 2016).

A challenge in conveying temporal data in an environmental data visualization is selecting the appropriate timeframe. It may be necessary to show a sequence of visualizations to appropriately represent changes over time such as monthly temperature outlooks shown in figures 3 and 4. Placing this information on a single visualization would require averaging the data and would not allow the audience to see the difference between the March and April temperature outlook. Likewise, using this format for a daily data visualization could overemphasize day-to-day temperature changes, causing the audience to take unintended action.

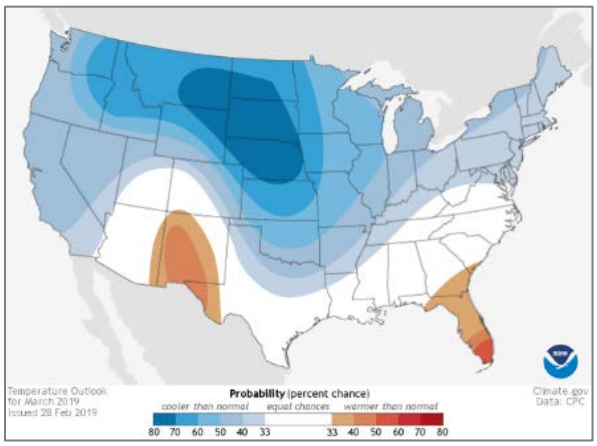

Figure 3–March 2019 Temperature Outlook
(Source: NOAA 2019, Data Snapshots)

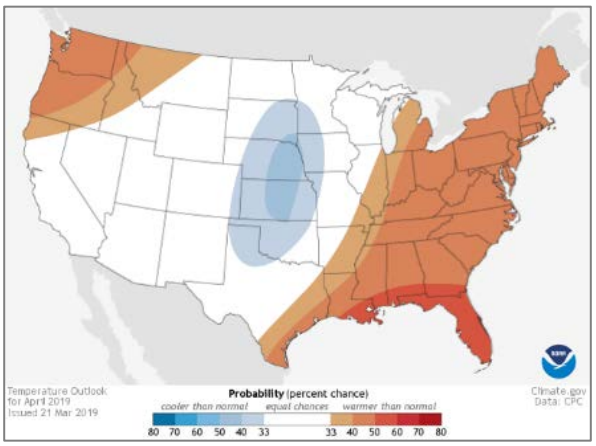

Figure 4–April 2019 Temperature Outlook
(Source: NOAA 2019, Data Snapshots)

Energy data is another form of temporal data and is presented by energy type (i.e. natural gas, coal) over the timeframe of a year, quarter, or month–typically on a bar chart or line graph. Newer forms of energy, such as renewables, benefit from showing more frequent time intervals because the generation is weather-dependent (Wilson 2016). Presenting annual renewable energy data hides short-term weather changes, see 'wind' in figure 5. This visualization averages annual generation from wind so the only visible changes are year-over-year. In reality, there is month-to-month variability that can be seen when the data is displayed monthly rather than averaged, see figure 6.

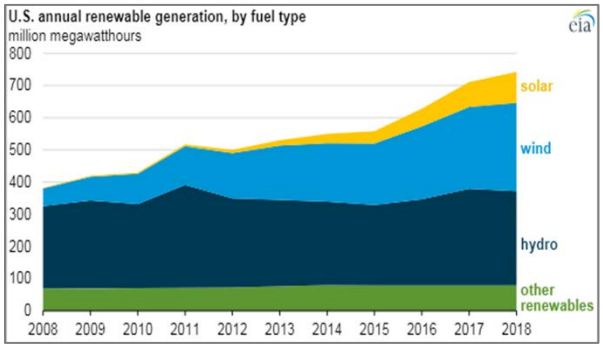

Figure 5–U.S. Annual Renewable Generation
(Source: U.S. Energy Information Administration, 2019)

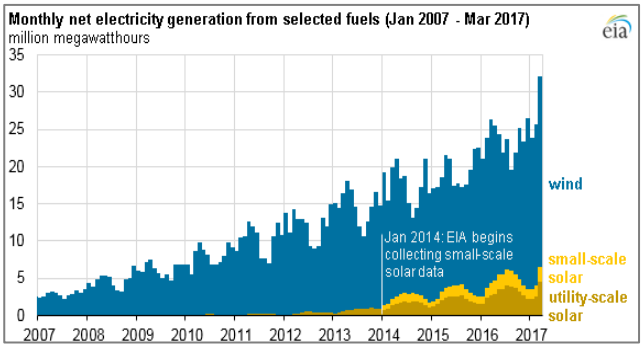

Figure 6–Monthly Net Electricity Generation
(Source: U.S. Energy Information Administration, 2017)

Although the existing research didn't outline a definitive solution for selecting the appropriate timeframe, research is ongoing in this area. An energy researcher suggested that the traditional time-series graphs should be adapted for displaying energy information. The researcher's suggested solution was the shared axes energy diagram (SAED), see figure 7. According to the researcher, the SAED can provide "insights into the seasonality and volatility of supplies and demands, which is becoming more important with the increased deployment of weather-dependent electrical renewable energy generation" (Wilson 2016, 4). The SAED is a visualization that promotes whole systems analysis and has been used by the Scottish government and the Institute of Mechanical Engineers.

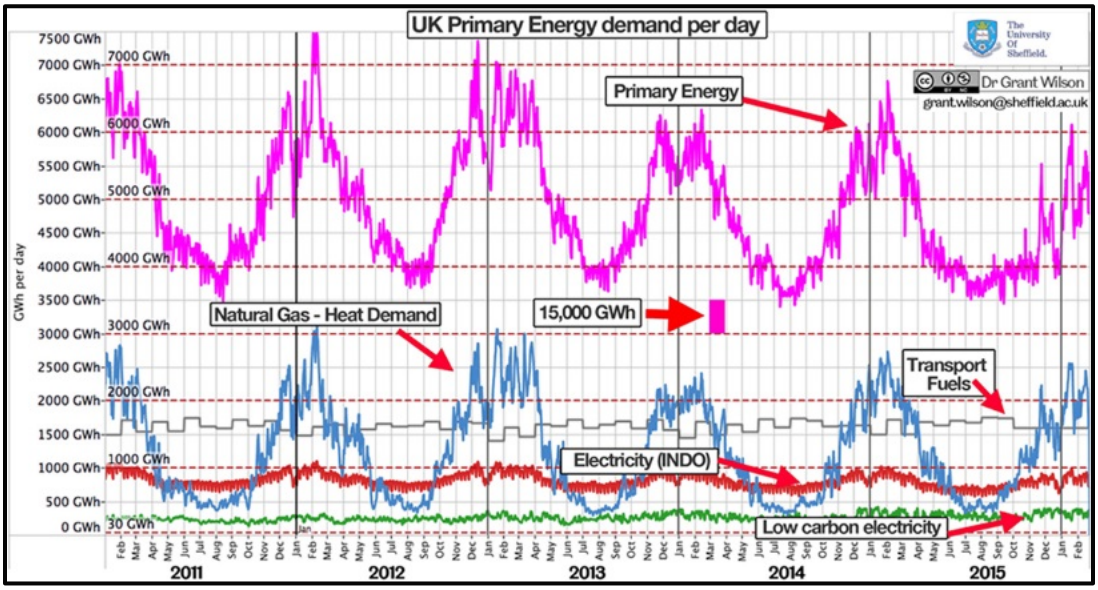

Figure 7–Example of a Shared Axes Energy Diagram
(Source: Wilson 2016)

Spatial Data Considerations

Temporal data is not the only type of environmental data that warrants additional research. Spatial data represents specific places, spaces, or locations. When adapted graphs or charts aren't sufficient to convey spatial environmental data, environmental communication often relies on geographic or photographic visualization. These are still data-driven but allow the user to more readily 'see' data, often by providing a connection to a specific place. One example of this is a map overlaid with environmental data, such as in figures 3 and 4. Spatial environmental data visualization maps could be used to show rainfall amounts, temperature variation, or terrain changes such as growing bodies of water or reduced forestation.

Environmental data visualizations can also be rendered using data to create photorealistic views of landscapes or spaces. They can illustrate several timeframes or the impacts of various conservation strategies. These types of environmental data visualizations are especially useful when viewed side-by-side to facilitate an audience discussion or to help an audience make decisions between strategies. This increased realism can also increase the accuracy of the audience's interpretation (Meitner et al. 2005).

Avenues for Future Research

The unique nature of environmental data visualizations, paired with unanswered questions from existing research, provides an opportunity for technical communication researchers. Household energy monitoring researchers specified that "there are no clear design requirements to develop the energy monitoring visualization" (Herrmann, Brumby, and Oreszczyn 2017, 1706). This is just one example of a gap identified in existing environmental data visualization research.

Future technical communication research should aim to inform and expand the field's current research, especially to understand how data visualizations function in environmental communication. My review of multidisciplinary research reveals several areas for researchers to consider as they develop future studies.

The Data

The primary opportunities for technical communication researchers involve the data utilized to create environmental data visualizations. Temporal data is crucial in environmental communication. Existing research does not comprehensively identify how visualizing a specific timeframe may impact interpretation. Expanding research to identify methods for selecting the most appropriate timeframe based on the type of data and the intended use would be a logical opportunity for technical communication researchers.

Along with investigating temporal data, an area that needs more research is how aggregated versus disaggregated data impacts environmental data visualization interpretation. A research team investigated households' interpretations of their energy use through environmental data visualizations. They provided homeowners with a whole home metering device and gave them access to energy visualizations. When the researchers asked questions about energy use and the visualizations, there was a lack of interpretation on the part of the homeowners. They were unable to relate specific details from the visualizations to their energy use. In addition, the researchers conducted interviews prior to, and after, the metering. The homeowners showed no change in their comprehension of their energy use. Upon concluding the study, the research team hypothesized that aggregating data for the whole home may have caused the lack of interpretation. The researchers suggest additional research is needed to determine whether disaggregated data, showing an energy data visualization for each appliance rather than the whole home, would improve interpretation (Herrmann, Brumby, and Oreszczyn 2017). The idea that aggregating or disaggregating data in environmental data visualizations may impact interpretation is an area for future research.

Another result from the household energy use research was that homeowners were biased by unusual activity. They often jumped to peaks in the data visualizations rather than comprehending overall trends. From this, the researchers suggested the risk of misinterpretation could be reduced by avoiding placing too much focus on unusual activity, especially when showcasing typical activity (Herrmann, Brumby, and Oreszczyn 2017). While knowing that minimizing unusual activity in environmental data visualizations can aide with interpretation, the research was not comprehensive enough to establish whether this phenomenon is consistent across audiences or data types. Technical communication researchers could repeat this research with different audience and data types to see if patterns develop that can expand the field's understanding of environmental data visualization interpretation.

Secondary Opportunities

The nature of environmental data and its impact on interpretation provides the primary research opportunity for technical communication researchers. There are, however, additional opportunities I came to identify through my review of existing research.

Global Context

Technical communication's environmental communication has been heavily focused on communication practices and documentation in the United States. Coppola utilized a New Jersey pollution document (1997). Rude mentioned a few global entities, such as The World Commission on Environment and Development, however, the specific environmental reports analyzed were developed by the Union of Concerned Scientists which is a United States based and founded organization (1997). Johnson-Sheehan and Morgan outline the history of conservation writing starting with an English naturalist but quickly move into referencing United States based authors, followed by United States based conservation societies (2008). Cagle and Tillery started to expand the conversation by incorporating global research (2015). This offers a beneficial view, especially when researching global issues like climate change.

The environmental communication research from non-technical communication disciplines offered a more global perspective. Very few of the researchers themselves are based in the United States. They are located in Canada, Poland, Switzerland, and the United Kingdom. One of the more significant aspects highlighted in the research was the reporting framework. While technical communication researchers pointed to NEPA and the EPA, a researcher in Poland suggested the Global Reporting Initiative (GRI) was a key reporting framework for corporate sustainability reports and that more than 75% of Global Fortune 250 companies followed the guidelines (Leszczynska 2012). Technical communication researchers need to be aware of this and should utilize research methods that represent a global perspective.

Placement

The location of environmental data visualizations within environmental communication is another area with limited focus in existing research. Where the environmental data visualization is placed within a report, newsletter, or other environmental communication may impact the interpretation or the function of the data visualization. In the environmental science writing analyzed by Whithaus, it was noted that claims, and the evidence to support the claims, were often closer together within the writing when both were constructed using linguistics. When the claim was linguistic, but the evidence was visual, there was a greater separation (2012). The research conducted by Whithaus, however, was limited to two documents. Research regarding placement and its impact is limited so would be a beneficial area for technical communicators to explore further.

Non-Interactive

Although I established a boundary of non-interactive data visualizations for the scope of this research, data visualizations are increasingly interactive, and this interactivity increases the opportunity to display data in new ways (Kostelnick 2007; Rawlins and Wilson 2014). It is evident that technology advancements will continue to increase the use of data visualizations that can be manipulated by the audience. Understanding how this interactivity alters interpretation and the function of the data visualization within environmental communication would be another research opportunity.

Sources and Tools Available

Before undertaking research, it may benefit technical communication researchers to understand sources of data and tools being used to create environmental data visualizations. Environmental data visualizations aren't necessarily created from scratch. An example from the research covered previously in this paper is the SAED, used for conveying different forms of energy in a single environmental data visualization. For additional information about the SAED's benefits and how to create a SAED, technical communication researchers should refer directly to the research article "Energy Data Visualization Requires Additional Approaches to Continue to be Relevant in a World with Greater Low-Carbon Generation" (Wilson 2016).

Another useful source is climate.gov, a website developed out of a collaboration between the Climate Program Office, the National Centers for Environmental Information, the Coastal Services Center, and the Climate Prediction Center. Climate.gov provides links to software packages and tools that can be used to create climate data visualizations (NOAA 2019, Visualizing Climate Data).

Conclusion

People have been writing about the environment for hundreds of years. What started as observational writing about plants and animals evolved as environmental issues evolved. Today's environmental communication has roots tied to the passage of NEPA in 1969 and the formation of the EPA in 1970 but has expanded significantly in recent decades to include a multitude of genres and a far-reaching audience.

The importance of environmental communication and its expansion in recent decades has not gone unnoticed by the field of technical communication. Researchers have investigated rhetorical strategies, argument formation and genres within environmental communication. The extensive reach and complexity of environmental communication, however, provides additional opportunity for technical communication researchers.

Environmental communication is complex and environmental data visualizations are a key component of making this complexity clear for an audience. Technical communication, and other fields who research environmental communication, have established the value of environmental data visualizations for adding credibility and facilitating interpretation. At the same time, existing research does not completely answer the question, 'how do data visualizations function in environmental communication?'.

I suggest technical communication researchers should extend the field's research by delving deeper into the impact environmental data has on audience interpretation and on an audience's ability to take action. The following questions are suggestions for future technical communication research:

- How does the specific timeframe of the environmental data impact the audience's interpretation of the visualization?

- How does aggregating versus disaggregating environmental data impact an audience's ability to act on the information?

While the research I have compiled is not all-inclusive, it brings together key components of current environmental, data visualization, and technical communication research. The synthesize of this research offers technical communication researchers a direction for future research. With an increased understanding of environmental data visualizations, technical communicators can actively incorporate the visualizations into environmental communication in a way that utilizes the full potential of the visualizations.

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