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Environmental visualizations: Framing and reframing between science, policy and society

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ABSTRACT

Visualizations are influential in the interaction between environmental science and policy. Research on framing in environmental visualizations (visual framing) is expanding. These studies typically focus on 'static' images; the visualizations themselves. However, framing already occurs during their production through the choices made by their producers, and visualizations may be reframed while traveling across boundaries between science, policy and society. So far, visual framing during the production process and reframing during their circulation remains relatively unexplored and undertheorized, a gap which the current research aims to address. As an empirical case, we studied visualizations produced by a boundary organization, the Netherlands Environmental Assessment Agency (PBL). We conducted interviews, focus groups, and a media-analysis. Our results show that although producers of visualizations were aware of potential framing through the objects depicted or simplifications in data, they were less aware of conceptual and ideological levels of visual framing and potential reframing when their visualizations circulate. Visual framing during production involved trade-offs in clarity, correctness and relevance, and contrasting perspectives among producers on intended audiences. When visualizations circulated, they were republished by multiple audiences and modified in various ways such as adjusting color, form and aggregating data. These reproductions and modifications resulted in different and contrasting frames compared to the original images. We demonstrate that environmental visualizations are powerful framing devices that can easily transcend the boundaries between science, policy and society. We thus highlight the need for boundary organizations to acknowledge visual framing effects in influencing these science-policy-society interactions.

1. Introduction

As environmental issues pose significant societal challenges, relevant scientific knowledge is deemed crucial to inform policy-making processes. An important way in which environmental scientific information is conveyed is through visualizations, such as data visualizations, infographics, maps and photographs. Because environmental issues such as climate change are long-term, complex and large-scale processes that are not directly observable, images are exceptionally powerful in "visualizing the unimaginable" (Schneider and Nocke, 2014, p. 2). Thereby, visualizations are influential in shaping how environmental issues are understood and have significant influence in (environmental) governance (Morseletto, 2017; Schneider and Walsh, 2019; Uggla, 2018). Visualizations contribute to the authority of scientific concepts, ideas and knowledge claims and can therefore become influential in environmental policy-making (Morseletto, 2017). However, rather than a linear model flowing from science to policy, in practice the science-policy interface is characterized as a dynamic two-way interaction (Wesselink et al., 2013). In fact, it constitutes not just interactions between experts and policy-makers, but involves a multitude of actors (Turnhout et al., 2019). For instance, media representations play an increasingly prominent role in interactions between science, policy and society (O'Neill et al., 2015). Although visualizations can summarize large amounts of complex information, presenting a clear and

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understandable message necessarily involves selection and aggregation (Wardekker et al., 2008, 2013). Thereby, either deliberately or not, visualizations emphasize particular aspects while neglecting others and can become powerful 'framing devices' that shape the understanding of environmental problems in policy and society. A growing body of literature focuses on 'visual framing': the process in which particular aspects of a phenomenon are, either deliberately or not, made more salient and thereby promote particular evaluations, interpretations and decisions (Brantner et al., 2011). Visual framing has been studied by various scholars, who particularly analyzed media images (e.g. Clancy and Clancy, 2016; Fahmy, 2010; O'Neill, 2013; O'Neill and Smith, 2014) and scientific data visualizations (e.g. Wardekker and Lorenz, 2019; Mahony and Hulme, 2012; McMahon et al., 2016).

Framing in visualizations produced by scientific organizations that provide policy-relevant knowledge, so-called 'boundary organizations' (Guston, 2001), is of particular interest in this regard. Especially considering their central position in the coordination and interaction between science and policy.

For example, the 'burning embers' diagram by the Intergovernmental Panel on Climate Change (IPCC) has greatly influenced the understanding of climate change risks in political debates (Mahony and Hulme, 2012). Visualizations produced by boundary organizations can function as 'portable representations': environmental issues are represented in a way that is meaningful for experts from various epistemologies as well as policy-makers and are portable in the sense that they might transfer from their original context and reinterpreted by various actors (Lidskog, 2014). Visualizations are not only reinterpreted, but may in fact be edited, reworked and republished by their audiences (Schneider and Nocke, 2014). During their 'travel', visualizations can be framed or reframed in new or contrasting ways, either through editing or by being placed in different contexts. This points to the importance of not only considering framing in the original visualization, but also their framing and reframing during their circulation. Moreover, during the production of visualizations, various choices are made by scientists, editors or designers, such as types of data, level of detail, colors and form (Dasgupta et al., 2015). Framing is thus inherently involved during the production of visualizations through those choices. In a more general sense, images can be viewed as "dynamic and contested spaces where various 'actors' battle to shape public understanding and engagement" (Boykoff, 2011, p.3).

Despite the dynamic character of visualizations, most visual framing studies focus on so-called 'found images' in news media or scientific reports (e.g. Mahony and Hulme, 2012; O'Neill, 2013; Wardekker and Lorenz, 2019), typically performing content analyses to identify dominant frames and thereby take a 'static' approach. So far, framing during the production and circulation of images is largely unexplored and remains undertheorized. Considering their role in the dynamic interaction between environmental science, policy and society, it is important to better understand how environmental images are framed throughout this dynamic interaction: *How are environmental visualizations framed and reframed during their production and circulation?*

To answer this question, we analyze framing during the process of producing visualizations and during their reception and use by various audiences (circulation). We propose a conceptual framework for a dynamic approach to visual framing and reflect on possible implications for the interaction between science, policy and society. We study environmental visualizations created by the Netherlands Environmental Assessment Agency (PBL) to apply this framework. PBL is a boundary organization that provides assessments and policy analyses to inform particularly the Dutch government in a wide range of topics related to the environment, nature and spatial planning policy. It aims to be policy-relevant, while independent and scientifically sound and is active in science-policy interactions at local, national and international levels. PBL has a dedicated visualization team and their visuals have evolved over recent years, experimenting with a broad diversity of visualizations to increase the accessibility, communicative and deliberative value of PBL's scientific studies for a wider range of publics (Kunseler, 2017). At the same time, PBL remains an important source of expertise and cannot risk losing its appeal to science-based expertise to objectify and scrutinize value-based statements in policy and politics (Pesch et al., 2012). This makes PBL an interesting case to study visual framing.

In the following sections, we first elaborate on existing literature on visual framing in environmental science and policy and present our analytical framework of a dynamic approach to visual framing (section 2). This is followed by the methodology we applied for our case study (section 3), results in which we applied the framework (section 4) and discussion and conclusion (section 5 and 6).

2. A dynamic approach to visual framing in environmental visualizations

2.1. Visual framing in environmental science and policy

Visual framing is far less studied than textual framing, though similar principles of selection, inclusion and exclusion apply (Rodriguez and Dimitrova, 2011). 'Frames' can be understood as 'organizing principles' that actors use to structure and give meaning to the world (Reese et al., 2001; Scheufele, 1999) and 'framing' is defined as the selection of aspects of a phenomenon that are made salient (Entman, 1993). Frames can define the problem at stake, identify the causes for that problem, induce moral evaluations and suggest possible solutions (Ibid.). Thereby, framing can influence environmental governance processes, as particular action orientations are emphasized or relevant stakeholders are identified (De Boer et al., 2010; Metze, 2014). Visual framing has been studied in various domains, such as political conflict (e.g. Fahmy, 2010) and genetic engineering (e.g. Clancy and Clancy, 2016). Framing has also been studied in environmental visualizations, predominantly in the field of climate change (e.g. O'Neill, 2013; Wardekker and Lorenz, 2019). Paradoxically, while visualizations always involve framing, portraying a *version* of reality, viewers perceive them as direct 'windows of reality' that can be influential in environmental discourse (Seppänen and Väliverronen, 2003). Another distinctive feature of visualizations is their ability to transcend geographical and linguistic boundaries, allowing for portrayal of strong ideologies, prejudices and moral evaluations than would not be accepted in textual form (Jasanoff, 2001; Messaris and Abraham, 2001; Metze, 2018).

2.2. Visual framing in multiple phases and on various levels

Rodriguez and Dimitrova (2011) provide a commonly used framework for visual framing analysis, distinguishing between four levels: visualizations as (1) denotative systems, (2) stylistic-semiotic system, (3) connotative system or as (4) ideological representation. The first level entails the concrete objects or elements that are shown in the image (Rodriguez and Dimitrova, 2011). For example, O'Neill (2013) found that climate change imagery in news media often depicted politicians and smokestacks. The second level involves stylistic conventions and their social meaning, such as cultural understandings of colors or camera position (Rodriguez and Dimitrova, 2011). For example, depicting refugees as full-shots of large groups rather than close-ups with recognizable faces, visually framed migration as a national security threat rather than a humanitarian challenge (Bleiker et al., 2013). The third, connotative or conceptual level entails the ideas or concepts that are conveyed, which can be identified by analyzing symbols and metaphors (Rodriguez and Dimitrova, 2011). For instance, conceptual aspects could entail whether climate change is framed as psychologically distant or close phenomenon or as risk or opportunity. The fourth level involves the ideological representation that is portrayed: e.g. what interests are served, which voices are heard and which ideas dominate (Rodriguez and Dimitrova, 2011). Conceptual and ideological levels of visual framing are difficult to analyze from the image alone, because it involves culture-bound and personal interpretation, but can be identified using

other levels as proxy. For example, O'Neill (2013) found that climate change was visually framed as a contested and politicized issue, derived from the objects depicted (concrete level) as well as the use of close-up images (stylistic level).

Visual framing can be considered a specific 'branch' within visual analysis. In visual research, four stages ('sites') in which visualizations convey meaning can be distinguished; the site where the image is made ('production'), the image itself ('visual image'), the stage where visualizations travel ('circulation') and the stage where it encounters its users or viewers ('audiencing') (Rose, 2006, 2016). A similar distinction is made by O'Neill and Smith (2014, p.74) when analyzing the different 'moments' of communication: production - visual - consumption. Importantly, this does not constitute a linear, but rather a dynamic process in which visualizations freely migrate through various media, are continuously adjusted and in which audiences of visualizations become re-producers.

2.3. A new framework for understanding visual framing from production to circulation

We combine the frameworks of Rose, 2006, 2016 and Rodriguez and Dimitrova (2011) to better understand how environmental visualizations are framed and reframed from their production to their circulation (see Fig. 1). Building on Rose, 2006, 2016, we distinguish between different stages in which environmental visualizations are framed. However, where Rose, 2006, 2016 classifies the image as a stage in itself, we argue that the image should not be detached from their production as the image inherently involves the original intended framing by its producers. Similarly, the image is the item being circulated. Furthermore, we view the stage where visualizations interact with their audience ('audiencing') as an inherent element of circulation rather than a stage in itself, since visualizations tend to reach a wide range of intended and unintended audiences that may or may not use and reframe the images. As shown in Fig. 1, we thus distinguish between production and circulation as two stages of visual framing. Both stages involve the image itself and the interaction with audiences. Furthermore, based on Rodriguez and Dimitrova (2011), we distinguish between four levels of visual framing and argue that the levels on which visualizations are visually framed and reframed are determined by the two stages (i.e. production and circulation).

2.3.1. Framing during production of visualizations

As argued by Rose (2016) "All visual representations are made in one way or another, and the circumstances of their production may contribute toward the effect they have" (p. 27). The production stage involves the practices, conditions and technologies involved in producing the image (Dasgupta et al., 2015). This not only entails *how* the visualization is produced (visual technologies, editing processes, choices in composition, etc.), but also *who* is involved (skills, expertise, perspectives, etc.). In the case of photographs, this entails for example the type of camera used, skills of the photographer and available editing technologies (Rose, 2006, 2016). We view the production processes and the image both as interlinked parts of the production stage, yet a distinction between these can be made in terms of the levels of visual framing. The image itself contains the first two levels of visual framing: the concrete level ('denotative system': Rodriguez and Dimitrova, 2011), such as the objects and data that are presented, and the stylistic level ('stylistic-semiotic': Rodriguez and Dimitrova, 2011), such as color and contrast. Note that numerical and textual elements, such as titles, variable names and legend captions, also contribute to visual framing (Brantner et al., 2011; DiFrancesco and Young (2011); Hullman and Diakopoulos, 2011; Powell et al., 2015). The conceptual level ('connotative system': Rodriguez and Dimitrova, 2011), such as the ideas, symbols metaphors conveyed, and the ideological level ('ideological representation': Rodriguez and Dimitrova, 2011), are more culture-bound and susceptive to personal associations and interpretation. These levels are less obvious or perhaps less inherent in the image itself; they are shaped by the actors involved in the production process and their epistemologies, cultural background and expertise[1] . These actors include researchers, editors and designers with varying skills, expertise, cultural backgrounds and epistemologies, who make choices in what, how and to whom to visualize (Dasgupta et al., 2015; Hullman and Diakopoulos, 2011). The characteristics of those actors thus influence how meaning is conveyed through the images (conceptual and ideological level) and the outcome of production, the image itself, involves the concrete and stylistic levels of visual framing (Fig. 1).

2.3.2. Framing and reframing during circulation

As Rose (2016) states "It is hard to imagine an image of any kind that does not move away from the place in which it was produced" (p. 34). The extent to which visualizations circulate is influenced by the technologies and communication channels and networks that allow visualizations to travel (Rose, 2006, 2016). After environmental visualizations are produced and communicated, they may reach various intended and unintended audiences. These audiences perceive and interpret the images, or also use, republish or even remake the images. Audiences' interpretations are largely influenced by the cognitive, perceptual and cultural characteristics of the viewer (Hullman and Diakopoulos, 2011; Morseletto, 2017; McMahon et al., 2016). Moreover, audiences are not 'passive receptors' but actively make sense of visualizations. Therefore, it matters *who* is making sense of the image, *why* and *how* (Rose, 2006; O'Neill and Smith, 2014). Or as Berger (1972) stated, "We only see what we look at. To look is an act of choice" (p. 8). Therefore, a distinction can be made between the image itself as object that is communicated (concrete and stylistic levels of framing) and how audiences interpret, make sense of and give (new) meanings to the visualizations (conceptual and ideological levels).

As Schneider and Nocke (2014) explain, "images might start to travel independently, detached from their original background. Images start to migrate from one sphere to another. They might keep their basic groups, trigger different associations and offer new perspectives" (p. 17). During their 'travel', images may are not only interpreted in various ways, audiences may also copy, adjust, rework and redraw the images as they republish them. Users may adjust visualizations according to their interest, their specific audience and goals in triggering specific associations (Schneider and Nocke, 2014). For instance, a journalist may reproduce a simplified version of a scientific data visualization in order to reach a broader audience. During circulation, the ideological and conceptual framing may thus change, as actors give new meanings to the images, but the content and style may also be altered when images are reproduced (Fig. 1).

3. Materials and methods

In order to test and refine the framework, we applied it to a case study on visualizations produced by the PBL (Van Beek et al., 2019). The institute covers a wide range of environmental topics and has been experimenting with new visual methods, which allowed us to study a variety of visualizations. Based on the amount and diversity of visualizations created by PBL as well as the extent to which visualizations were expected to be relevant to a broad range of audiences, we examined visuals within two themes: energy transition and mobility (see Fig. 2). Apart from variety in themes, we selected various types of visuals (see Supplementary Material A) to ensure a diversity in type of information and intended audiences (scientific report, policy assessment, thematic website, infographic booklet, etc.). We used multiple methods to analyze

[1] In previous visual framing research, conceptual and ideological level are investigated by using the concrete and stylistic levels as proxy, by using detailed coding frameworks and multiple coders (e.g. O'Neill, 2013; Wardekker and Lorenz, 2019).

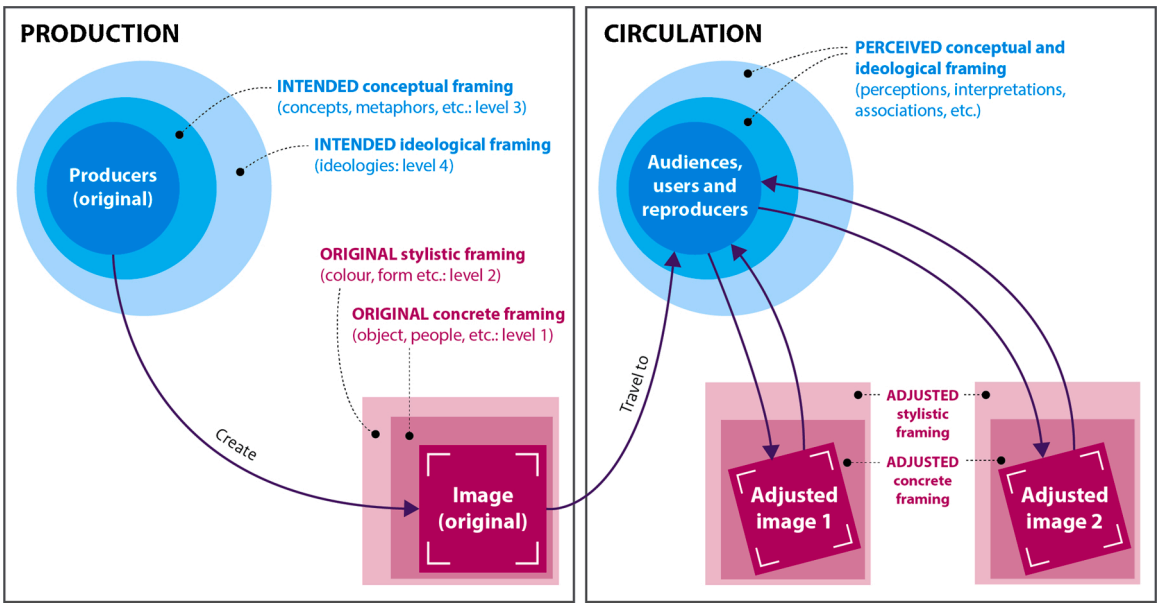


Fig. 1. Schematic representation of dynamic process of framing and reframing in various stages of the visual communication process (production, the visual image itself, interaction with audience and circulation).

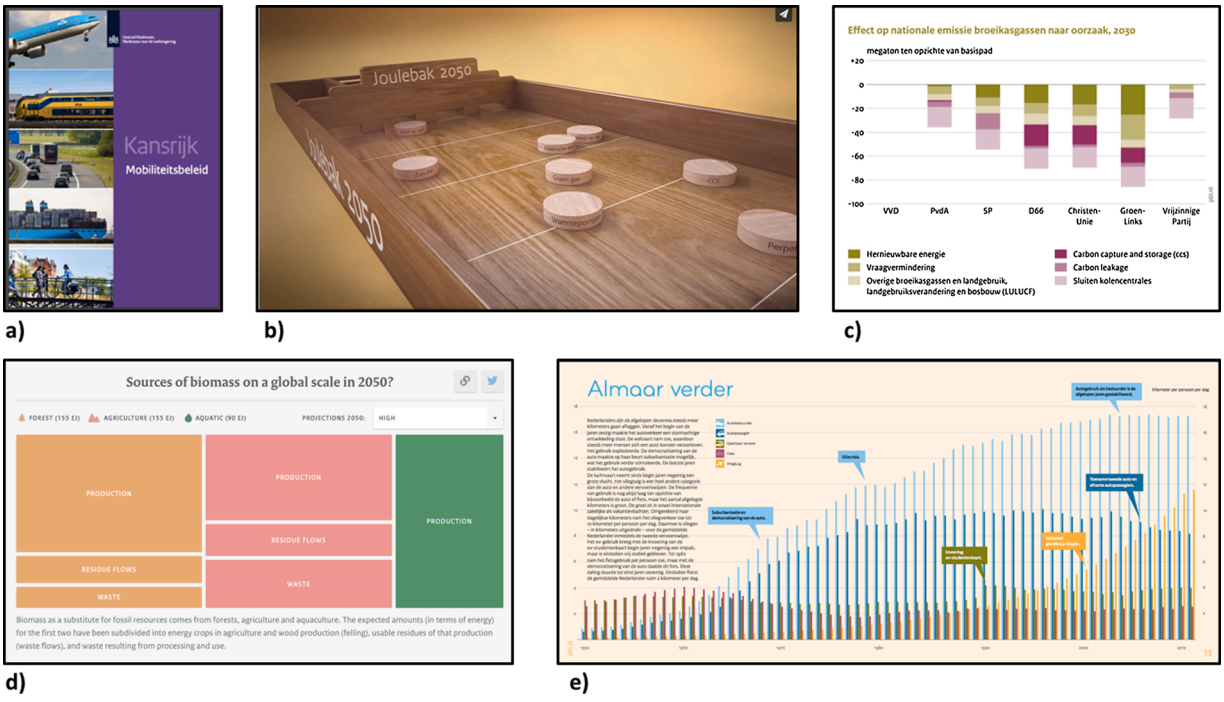


Fig. 2. Examples of analyzed visualizations. A) photographs on mobility (PBL, 2016b), B) artist impression on energy transition (PBL, 2016a), C) bar chart on energy transition (PBL, 2017), D) interactive visualization on energy transition (PBL, 2014b), E) infographic / bar chart on mobility (PBL, 2014a).

production and circulation: interviews, focus groups, and a media analysis. Producers of the selected images (researchers, visualization team, communication department) were interviewed in order to derive the role of visual framing during production and the original intended framing of images (see Supplementary Material B). The interviews provided insights in visual framing during the production of visualizations (section 4.1) and allowed for comparison between intended framing and interpretations by audiences (section 4.3). The media analysis involved a reversed Google image search to map websites where PBL images re-appeared in the original or modified form, and online search based on the content and image source, to map users of the original or modified PBL images (see Supplementary Material C). This provided insights in how the images were framed and reframed during their circulation (section 4.2). In the two focus groups, the same images were presented to relevant PBL's audiences (e.g. policy-makers, journalists, NGOs), to understand how they give meaning to the images and to gain deeper insights in the use and republishing of visualizations, reflecting on preliminary results from the media analysis (see Supplementary Material D). The focus group data provided insights in underlying reasons to use and republish visualizations (section 4.2) and audiences' perceptions and interpretations that were compared to the original intended framing (section 4.3). This mixed-method approach

allowed for testing our conceptual framework by mapping the framing and reframing of the selected images from their production to their circulation.

4. Results

4.1. Visual framing during the production of visualizations

Based on interviews with researchers, communication advisors and editors at PBL, we identified two key processes involved in visual framing during production of visualizations: (1) dilemmas in what to visualize, to whom and how and (2) awareness of framing in visualizations.

4.1.1. Trade-offs in complexity/clarity and contrasting perspectives on intended audiences

During the production of visualizations, several dilemmas determined visual framing in decisions in what to visualize, how and to whom. Given the high amount of information and complexity, producers of visualizations at PBL need to balance between completeness of information and comprehensibility and thereby intentionally or unintentionally engage in framing. For example: *"The largest problem is the disclosure of all information we hold. Sometimes there is just not one figure that captures the message"* (interview 1). Producers of visualizations are thus making a trade-off between complex figures that are difficult to comprehend and concise figures with high levels of simplification. This involves not only decisions about what to visualize, but already starts during the selection of indicators; *"The choice for indicators is challenging. The right indicator is often difficult to understand because it involves many aspects, whereas a more easily understandable indicator only partially represents reality."* (interview 3). Furthermore, producers sometimes had contrasting views on their intended audiences, affecting decisions in what to visualize, how and to whom: *"Within PBL there are different perspectives on the importance to convey information to a broad audience as opposed to policy makers specifically."* (interview 1).

4.1.2. Awareness of visual framing

Producers of visualizations were more aware of framing in text and numbers compared to visualizations: *"I'm not particularly worried about the impact of figures […]. However, the numbers produced by PBL are often brought up for discussion. […] Numbers that are intended to be illustrative can sometimes go beyond their original intention when they circulate."* (interview 2). Another interviewee highlighted the importance of framing in titles of visualizations: *"The titles of the infographics are in fact one-liners that convey the main message. The figures are merely illustrations of these one-liners* (interview 4). During the selection of figures from reports to present on website news items, textual rather than visual elements are considered: *"Deciding which visualizations from the report to publish in news items or social media is based on the main messages of the report and to what extent it matches the text"* (interview 1), *"Sometimes the researcher has a preference for which images it should contain, but this choice is often considered relatively unimportant"* (interview 4). Visualizations were thus perceived as illustrative of textual arguments, rather than conveying a distinct argument in themselves.

4.2. Visual framing and reframing during circulation

As argued earlier, circulation involves the interpretation by audiences (4.2.1) as well as how these audiences use and republish visualizations (4.2.2). These two processes appeared to involve visual framing and reframing in distinct ways.

4.2.1. Perceptions and interpretations of visualizations by audiences

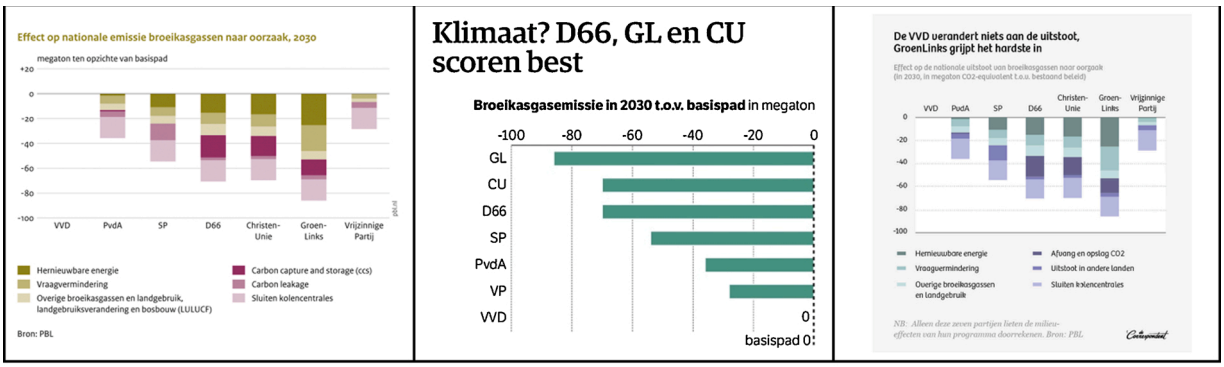
Our analysis of focus group participants' responses (see Supplementary Material D), revealed that perception and interpretation of visualizations by audiences largely depends on the level of knowledge, values, personal preferences and beliefs about the environmental issue depicted. For example, Fig. 2d was interpreted by one focus group participant as: *"if you have high expectations, there is a large potential of biomass, whereas if your expectations are low, biomass will play a minor role"*. This contrasted the interpretation of another participant: *"if we are expecting a low potential, our efforts towards biomass will be small whereas if we have high expectations we'll respond to that by an attempt to expand our biomass supply efforts"*. Another example is Fig. 2e, which shows the number of kilometers travelled per person per modality over time. Some focus group participants perceived the image as 'neutrally' showing trends in shares of modalities, whereas other attendees interpreted this as 'alarming' because of their associations with environmental impacts. This implies that reframing occurs on conceptual and ideological levels when audiences make sense to visualizations and make associations to their own context, background or political ideologies.

4.2.2. Reframing by users of visualizations by reworking, editing and adjusting visualizations

The media analysis revealed a number of users that republished and adjusted PBL visualizations and the focus group provided insights in the underlying reasons for these adjustments. When data visualizations were reproduced during their circulation, it often represented the same data, although their framing was adjusted on different levels. For example, as illustrated in Fig. 3, the original figure produced by PBL was edited and modified by one user in terms of colors, direction and form, which involves stylistic reframing (e.g. green and purple may have different cultural meanings). Moreover, images were reframed on the concrete level: for instance whereas the original emphasis was on the sources of emission reduction (Fig. 3a), in Fig. 3b this distinction disappears, emphasizing the differences between political parties. Although the users of this particular visualization were not attending the focus group, journalists from newspapers explained that the reasons to adjust figures are multiple: space available in the article, format requirements, intended audience and the intended message (derived from statements of focus group participants). The second user kept the distinction between emission reduction sources, but adjusted the colors as well (stylistic level). Also, emphasis was put on differences in strategies between the liberal ("VVD") and the green party ("GroenLinks") in the figure titles (Fig. 3c).

Another example is illustrated in Fig. 4. The original visualization (Fig. 4a) was reframed at the stylistic level (form, color, direction) when reproduced by an online news medium (Fig. 4b). For example, car drivers are represented in a light blue color in the original image, whereas the user presented this in a bright red color. The image was not visually reframed on the concrete level: the same data, scales and categories were used. In the focus group on mobility, the reproducer of this visualization explained that one of the reasons to rotate the visualization was to better fit smartphone size.

The media analysis pointed to a difference between types of visualizations during their circulation: when creative images and photographs circulated, they were more often used and republished by unexpected audiences compared to data visualizations. The classic data visualizations on mobility and energy were only used by 'expected' audiences such as knowledge platforms (e.g. 'FluxEnergie', 'EFM Energy'), newspapers or news platforms (e.g. 'NRC', 'De Correspondent') and specialist journals (e.g. 'De Ingenieur'), whereas creative images were also used by 'unexpected' audiences, such as on the Facebook page of a realtor company. When republished, creative images seemed also more strongly reframed and more disconnected from its original policy context. For example, the original image of PBL (Fig. 5a) was presented on a report on national mobility strategies. This image was reused by a local news website ('NU Maassluis') in an article on the cost-effectiveness of one specific road tunnel (Fig. 5b) and in a booklet on parking in one specific city, published by a knowledge platform on parking management ('Vexpan').



a) Original: *"Effect on national greenhouse gas emissions according to cause, 2030"*

x: political parties
y: emission reduction in megaton compared to baseline

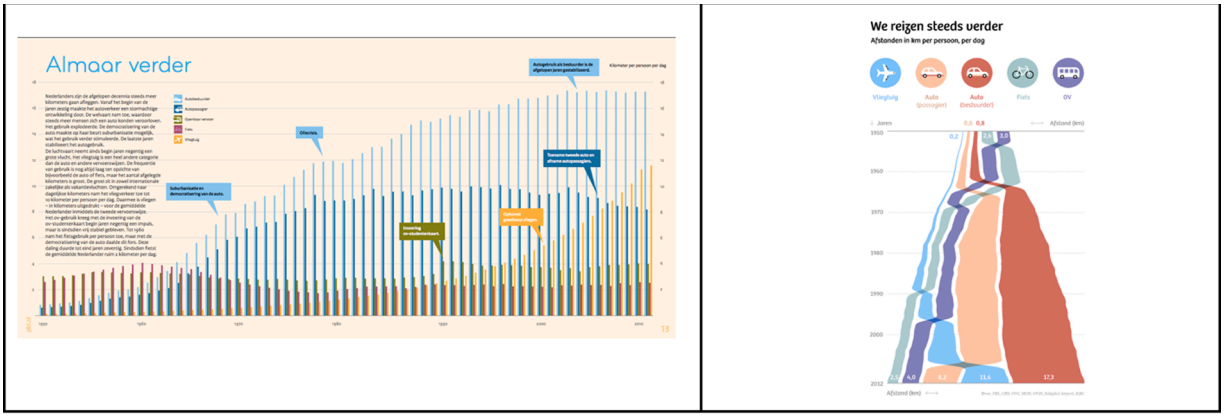
b) (Re)framing 1: *"Climate? D66, GL and CU highest scores"*

x: emission reduction in megaton compared to baseline
y: political parties

c) (Re)framing 2: *"VVD not reducing any emissions, GroenLInks takes strongest action"*

x: political parties
y: emission reduction in megaton compared to baseline

Fig. 3. *a)* Original image (PBL, 2017), b) reframing by Dutch newspaper (NRC 2017), *c)* reframing by news website (De Correspondent, 2017).



a) Original: *"Increasingly further"*

x: time (1950-2012)
y: kilometers per person per day

b) Re(framing) 1: *"We travel increasingly further"*

x: kilometers per person per day
y: time (1950-2012)

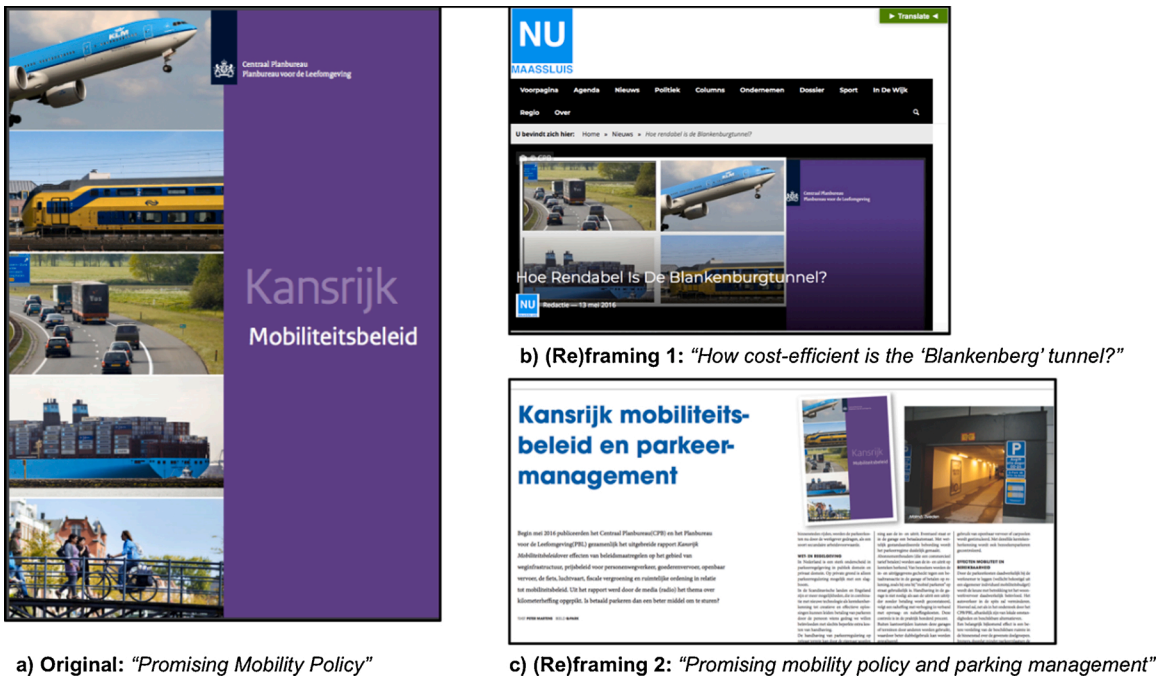
Fig. 4. a) Original image (PBL, 2014b) and b) Reframing by news website (De Correspondent, 2018).

4.3. Visual framing and reframing from production to circulation

Combining insights from interviews, media analysis and focus groups, the visual framing process from production to circulation was mapped in relation to the conceptual framework. More specifically, this entailed the intended framing of original PBL images (interviews), and how and why audiences interpreted, used and re-published the images in certain ways (media analysis and focus groups). Fig. 6 illustrates an example of applying our conceptual framework to investigate framing and reframing from production to circulation. The intended framing by the producers was to show the full scope of transport modalities in one cover picture in order to provide a politically neutral view on mobility (interview 4). This intended framing involves the conceptual and ideological levels of framing during the production process. During the focus group on mobility, on participant stated that: *"The image shows only standard mobility options. It makes me expect the report will not discuss innovative strategies"*. Although this is just one example of an interpretation, it illustrates that the intended and perceived framing can differ strongly. During the circulation of images, images are thus reframed on conceptual and ideological levels as audiences make sense and interpret visualizations. Moreover, the figure itself was also reframed on the concrete level when republished by users, such as by adjusting data, color and form, as described in section 4.2 (Fig. 5).

5. Discussion

We conducted a dynamic visual framing analysis and found that framing occurs throughout the entire process from production of visualizations to their circulation. Producers of visualizations at PBL continuously made trade-offs between comprehensiveness and clarity and had contrasting perspectives on intended audiences. This underlay their choices in what to visualize, to whom and how. These choices, either deliberately or not, involve framing. A key insight is that producers of visualizations were more aware of framing in numbers and text compared to visualizations. Visualizations were viewed as merely illustrative of textual arguments, whereas our findings clearly points out that images are powerful framing devices in themselves. Furthermore, although producers were often aware of concrete levels of framing (data or objects depicted), they were less aware of how their visualizations may be framed or reframed by audiences on other levels. In contrast, our results indicate that visualizations are in fact reframed on all four levels of visual framing during their circulation as they reach various audiences. Audiences' interpretations often mismatched the intended conceptual and ideological framing in visualizations, depending on their personal experiences, knowledge and beliefs, which is in line with previous research (e.g. Morseletto, 2017; McMahon et al., 2016; Hullman and Diakopoulos, 2011). Moreover, visualizations were reframed on concrete and stylistic levels when used, reworked and republished by



a) **Original:** *"Promising Mobility Policy"*

b) **(Re)framing 1:** *"How cost-efficient is the 'Blankenberg' tunnel?"*

c) **(Re)framing 2:** *"Promising mobility policy and parking management"*

Fig. 5. a) original image (PBL, 2016a), b) Reframing by local news website (NU Maassluis, 2016) and c) a booklet on parking management (Vexpan, 2016).

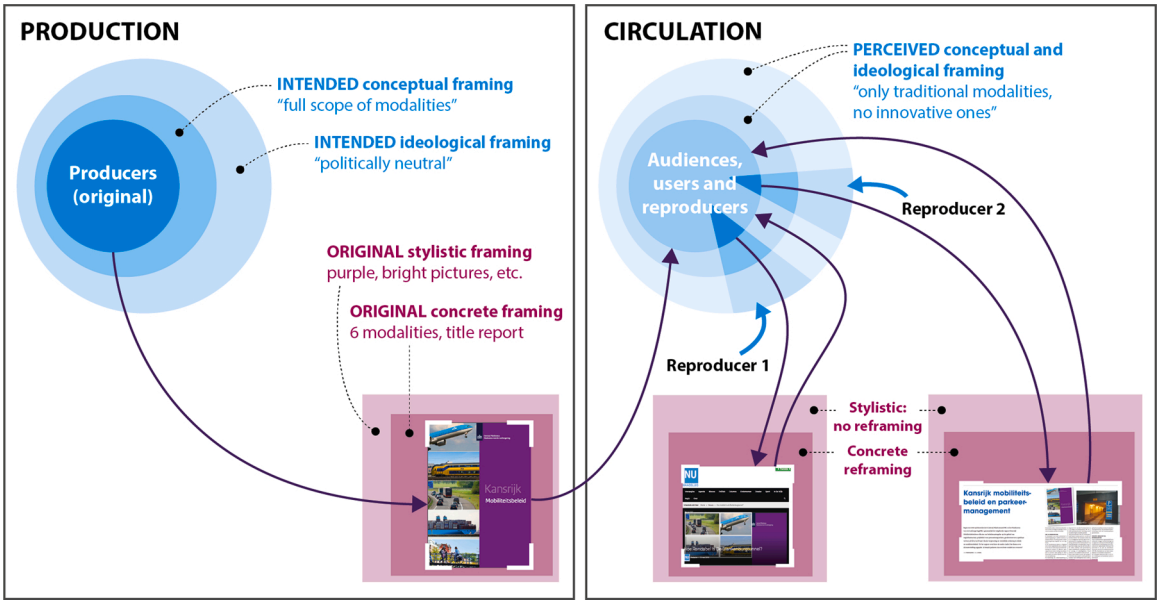


Fig. 6. Illustrative example of application of the conceptual framework for understanding the full process of framing and reframing of visualizations from production to circulation.

means of data aggregation, modifying color and form and by using titles with different meanings. The way in which visualizations circulate differed between image type: when data visualizations circulated, they were republished by expected audiences such as NGOs and journalists, whereas when creative images were reproduced, they were used by unexpected audiences and were linked to deviating policy contexts. The observation that images may become detached from their original framing when they travel (cf. Schneider and Nocke, 2014), might thus apply more strongly to photographs compared to data visualizations. This has implications for science communication: scientists should be aware that the selection of photographs is crucial in conveying their message as it may largely influence the interpretation of scientific information and which audiences they might reach.

Rather than approaching visualizations from the perspective of 'static' images, we explored the application of a framework to better understand how visual framing occurs 'dynamically' from production to circulation. This framework combined earlier work by Rose, 2006; 2016 on visual analysis with Rodriguez and Dimitrova, 2011 framework for visual framing analysis. Importantly, images were reframed during their circulation on multiple levels and sometimes in contrasting ways. The present research has some limitations, most notably only a small number of visualizations was analyzed. In addition, our media analysis only involved online sources and media outlets (e.g. knowledge platforms, newspapers, websites, specialist journals), neglecting other relevant sources and actors in the interaction between science, policy and society. The focus groups involved a wider set of actors including

policy-makers, however may still not represent the full range of audiences. Our work should thus be considered exploratory and the usefulness of this framework needs to be further established in future research, involving larger sets of visualizations covering more diverse environmental issues. Moreover, the more traditional content analyses of the (static) visualization itself could be combined with analysis of the (dynamic) process stages using methods such as those we employed or expand this with surveys and observations.

Visualizations are increasingly prominent in the interaction between environmental science and policy (Morseletto, 2017). Our study implies that visual framing and reframing by various actors in this interaction is therefore of critical importance. This particularly applies to boundary organizations, who use 'portable representations' such as models, diagrams, indexes and maps which allow for coordination and interaction between actors, despite divergent perceptions and interpretations (Lidskog, 2014). Our research points out that when visualizations travel through different actors and contexts, they not only adopt different meanings, but the properties of images themselves are adjusted by actors as well, in line with Schneider and Nocke (2014). Whereas Lidskog (2014) argued that portable representations need to provide a certain level of shared meaning, we found that during their circulation, images were framed in sometimes contrasting ways. This is a crucial finding for boundary organizations such as the PBL, the IPCC and IPBES, which are internationally active and authoritative in the interaction between science, policy and society. Their visualizations reach a broad range of actors worldwide, through their own communication and that of other actors. Their images might therefore be susceptible to reframing as they circulate. By demonstrating the central role of visualizations in framing environmental issues, we highlight the need for acknowledgement of not just framing in text, but also visual framing, especially considering the growing relevance of visual communication. Although taking all potential interpretations into consideration may be impossible, our findings imply that involving relevant stakeholders in producing visualizations may increase awareness of multiple levels of visual framing. This would bring the process of production and circulation of visualizations closer. Participants from different cultural and epistemic backgrounds also seemed sensitive to different levels and stages of framing. Therefore, active frame-reflection when visualizations are created involving a diverse set of potential audiences would be valuable. Moreover, embracing the actor-network in which visuals obtain their interpretive power, may enable boundary organizations to enhance the impact of their work. In other words, rather than viewing the framing and reframing of visualizations by various actors as a threat, engaging with users of visualizations could serve as an opportunity to reach a more diverse set of audiences. Furthermore, visualizations could be deployed earlier in the research process, for instance by supporting research-by-design approaches in which visualizations are iteratively discussed and altered throughout the research process (e.g. Roggema, 2017). Apart from boundary organizations, these lessons are relevant to any producer of environmental visualizations, such as academics who increasingly communicate their findings visually on different media outlets where visualizations easily circulate.

6. Conclusions

The current research explored framing and reframing of environmental visualizations during their production and circulation to various audiences. A key insight is that although visualizations were viewed by producers as merely illustrative to textual knowledge, they are powerful framing devices in their own right. Producers of visualizations face trade-offs in their choices in what to visualize, to whom and how, which inherently involves framing. Visualizations are interpreted, used, modified, and republished by audiences in various ways as they circulate. Audiences frame or reframe visualizations to fit their assumptions, motivations, intended audiences and knowledge. Although producers of visualizations were aware of possible framing in the objects or data presented in visualizations (content/denotative framing), awareness of other levels of framing (stylistic, ideological, conceptual framing) was limited and most often unintentional. Our results reveal that the distinction between producer and user of visualizations becomes a blurred line in reality, as users become producers as visualizations migrate freely and are continuously modified and reframed by various actors. This implies that boundary organizations should devote more attention and time to their visualizations and the dynamics of framing and reframing by others, as this may increase the visibility of their work and the usability of their visuals by a wider audience. Our study highlights that visual framing involving only so-called 'found' images may neglect the crucial process of continuous framing and reframing as visualizations by various actors. Visualizations are thus powerful tools in the dynamic interactions between science, policy, and society.

CRediT authorship contribution statement

Lisette van Beek: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Tamara Metze:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration. **Eva Kunseler:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Funding acquisition. **Hiddo Huitzing:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Funding acquisition. **Filip de Blois:** Writing - original draft, Writing - review & editing, Visualization. **Arjan Wardekker:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2020.09.011.

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