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Analysing the influence of visualisations in global environmental governance

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ABSTRACT

Visualisations can highly contribute to the importance and authority of new ideas, concepts, and knowledge claims. Among the many visualisations, few become well-known and influential in environmental governance. Whilst these have been objects of specific research, this study questions what constitutes and underpins their influence. For this, the paper codifies influential visualisations and defines criteria for studying their visual characteristics. The criteria are applied to two case studies, the "traffic light" and the "planetary boundaries" diagrams. To increase the validity of the findings, the study also introduces two "failure cases" as a plausibility check.

1. Introduction

The perspective of the science-policy interface is particularly relevant for considering knowledge production and interactions in the environmental field (Wesselink et al., 2013). At this interface, certain propositions – whether they are ideas, concepts, or knowledge claims – spread broadly and acquire more authority and relevance than others. The explanation lays in the process of knowledge manufacturing and accreditation, but also relates to intrinsic factors like the quality of a proposition, the legibility of the information provided, the novelty in content, or advancement in knowledge. Ideas, concepts, and knowledge claims receive their credibility and recognition by a community of peers on the basis of shared interpretive frameworks (Knorr-Cetina, 1981). Latour (1987) shows that, regardless of its validity, the establishment of a concept is determined by the number and strength of connections it engenders among otherwise heterogeneous ideas. This associative power attracts experts (also from different disciplines), whom tend to form alliances and networks; through these, a concept is stabilised and enforced. Diffusion and notoriety occur within knowledge networks and actors transfering/circulating knowledge (Stone, 2001, 2013; Michaels, 2009). Another essential element for a concept or a problem to be recognised in the scientific and political sphere is good timing. Kingdon (2003) emphasises the relevance of a broad public "mood" – a bundle of interactions among elite ideas, public opinion, political events, and media attention – that defines a climate receptive to certain ideas/positions in governance affairs. This mood favours "policy windows" that are opportunities opening up when an issue captures political attention and moulds into the political debate. Differently, Heath and Heath (2007) underline how ideas stick when simple, unexpected, concrete, credible, emotional, and delivered in story form. Huber (2008) shows the applicability of these principles to writing articles, though recognising that new knowledge remains the main factor behind articles that stick. Finally, the scrutiny of huge data sets extracted from the internet is defining new affirmation patterns of ideas (Pentland, 2014).

This introductory account evidences how there are several concurrent elements in making a proposition prominent. In this study, I analyse some renowned visualisations (here called influential), produced by experts, published in the environmental literature, and associated to new concepts or scientific evidence. I argue that they can fundamentally contribute to spread concepts, and knowledge claims enabling them to gain momentum and political traction. This can happen, for example: when new ideas are formulated, when there is a greater demand for succinct knowledge, when immediacy is required for exchanging information, or when it lacks the time or background to absorb an original research (Boehme-Neßler, 2011; Wesselink et al., 2013; Michaels, 2009).

Indeed, different disciplinary perspectives consider visualisations in the production and diffusion of knowledge. Particularly, science, technology, and society (STS) studies explore the trajectories of representations – from construction to adoption in different social worlds – analysing the methods, practices, technology, actors, and networks involved (Burri and Dumit, 2008). Environmental visualisations are also examined in geography, sociology, communication, cultural, and cognitive studies. In more detail, some influential (although not named so) visualisations in environmental governance are investigated in

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relation to risk and uncertainty (Mahony and Hulme, 2012; Schneider, 2011), perception and knowledge (Grevsmühl, 2016; Cook and Balayannis, 2015), communicative and rhetorical power (Walsh, 2014, 2015), constructing ideas (Liverman, 2009; Mahony, 2015), and shared meanings in science/policy (Schneider and Nocke, 2014; Lidskog, 2014). Yet, what makes a visualisation influential in environmental governance is a little explored issue. The current study aims at closing this research gap by first defining visualisations and their role in global environmental governance (Section 2). Second, the paper proposes a framework for the analysis of influential visualisations (Section 3) applied to two cases (Section 4). These are the "traffic light", which refers to the emergence of the 2 °C target of the climate convention, and the "planetary boundaries" which is part of the current debate on earth system transformations. The framework is also tested on two failure cases as a plausibility check (Section 5). The final section summarises the findings.

2. Visualisations and influence

The term visualisation varies across knowledge domains. I define visualisation as any message presented in a format suitable for the eye, displayed on a physical support, which provides evidence or explanation to viewers. The functions of visualisations span from being purely descriptive to highly symbolic. In between, visualisations can have aesthetical, instructive, explanatory, interpretative, evaluative, and persuasive intents (Tufte, 2001; Polman and Gebre 2015; Hegarty, 2011; Gordin et al., 1996). Furthermore, visualisations can function as 'boundary object' – an entity favouring common understanding despite users' different views (Star and Griesemer, 1989), but can also work as an 'epistemic thing' – "a question-generating machine" (Rheinberger, 1997, 32).

Besides intellectual functions, visualisations fulfil practical communicative purposes while curbing an ancestral predisposition for visual objects, a sensorial and epistemological preference named visualism or ocularcentrism (Chandler and Munday, 2011). Indeed, vision is the sense with the largest bandwidth: 100 megabyte/s versus 100 byte/s of audition (Fekete et al., 2008). Visualisations accompany human history; as knowledge and technology progressed, they took the shape of graphs, diagrams, maps, illustrations, pictographs, photographs, infographics, and computer/digital images. Among these, experts visualisations are often diagrams, which are drawings intended to describe in a simplified fashion the structure or the functioning of something. Selecting and organizing the components of a representation (data, words, images, graphics, pictograms, etc.) and combining elements like size, colour, shape, diagrams entail an artificial process that ideally reconfigures knowledge in synthetic and codified terms.

Accumulation of visual tools occurs in every domain. Visualisations are highly-employed in science, allegedly since its outset. For example, Galilei's diagrams proved to be crucial for kinematic discoveries (Cheng and Simon, 1995); centuries after, the Hubble diagram changed astrophysics (Borne, 2013) and the Feynman diagrams quantum-electrodynamics (Jishi, 2013). Making data visible (Rheinberger, 1997; Ware, 2013), visualisations are inextricable to the practice of science, whether they are complementary, or fundamental to the scientific endeavour, that is when they integrate textual propositions, or when they build a system of interpretation for understanding (Griesemer, 1991). This is exemplified by the DNA double helix that trespassed the boundaries of science to become a universal topos of visuality.

In environmental governance, many visualisations are policy-relevant: they magnify environmental conditions of societal value worth of policy consideration, and are applicable to policy contexts or decision points. However, many policy-relevant visualisations are created for delimited purposes and few survive contingency. Others last in time, spread over different contexts, and are highly considered and represented, up to acquiring an iconic status, meaning that these representations act as landmarks assisting orientation in the environmental science-policy debate. Examples are: the Keeling curve, the sustainable development scheme, the Hansen projections, the traffic light diagram, the hockey stick graph, the burning embers diagram, the ozone hole images, the planetary boundaries diagram, the great acceleration charts (see the Appendix Figs. A1 – A10 in Supplementary material). All these concisely depict concepts or new evidence about global environmental change, deal with the interwoven system of human activities and natural processes, and pose governance challenges at the global and local level. The term 'influential' is chosen to define these visualisations. Influence – from Latin *influere*, flow into – is the capacity to produce perceivable effects without direct action nor coercion. The concept is wide enough to encompass elements like prestige, notoriety, impactfulness, persuasiveness, which can all co-produce or increase influence. Influential visualisations illustrate and explain a compelling environmental issue, and lay at the heart of the debate generated by that issue. They are oftentimes discussed, recalled (also verbally), and replicated in the academic literature and events. Moreover, influential visualisations are able to crosscut specialists' communities and talk to different audiences, even if made for a disciplinary community and for reaching the attention of policymaker. But what makes a visualisation an influential one?

An expert visualisation is not influential per se, but in association to an environmental concept or evidence of major societal concerns and/or high on the policy agenda. However, this is not a sufficient condition. In fact, many visualisations do not become influential even if associated to problems in the spotlight, also in relation to unprecedented evidence, cutting-edge concepts, or prominent authorship. Influence can be interpreted as a result of circulation or visibility/popularity of a visualisation. Yet, these are effects rather than causes of influence, or eventually amplifiers for further influence. As seen in the introduction, influence depends by the interplay of intrinsic and contextual factors like quality, timing, fecundity of links/alliances, or involvement of knowledge broker/networks. All these intertwine with the influence a visualisation has. Connectedly, Knaggård (2015) advances that persuasive frames depend on knowledge, values, and emotions (recalling Aristotelian logos, ethos, and pathos). Knowledge refers to what an issue is about; this needs to be connected to values in order to demonstrate what is at stake. Then, an issue is recognised as believable and important. Emotions complement these aspects linking knowledge and values with the less rational aspects of feelings. For example, collective fear can prompt a sense of urgency moving an issue up in the political agenda. Although hard to measure, emotions can be the decisive element to have a frame accepted (Knaggård, 2015). Similarly, some expert visualisations can explain a concept or knowledge claim to be recognised by visually summarising knowledge, connecting the representational elements to values, and so triggering emotions. These considerations lead to focus on how a visualisation is made, its visual characteristics, which allow it emerge and grow big.

3. The visual characteristics of influential visualisations

Although influential visualisations are studied from different angles, there are no straightforward criteria for appraising their visual characteristics. Nonetheless, scholars form different disciplines have elaborated criteria and principles to illustrate how good representations work. For instance, "effective design" studies (Tufte, 2001; Hegarty, 2011) define principles and techniques for improving the comprehension of visually-encoded information. The fields of "information visualisation", and "knowledge visualisation" (Fekete et al., 2008; Eppler, 2013) explain how representations convey knowledge and meanings. Complementarily, "perceptual studies" (Ware, 2013) show how visualisations are seen and what effects they produce. Other studies identify issues areas in different disciplinary approaches. For instance, Blackwell and Engelhardt (2002) classify four main groups in the study of diagrams: signs (i.e. graphic components), graphic-structure, meaning, and context (the interactions and cognitive implications). For

climate change images, O'Neill and Smith (2014) qualify the moment of production, consumption, and discourse, while Sheppard (2005) codifies perceptual, emotional, and cognitive attributes of effective visualisations. In the inquiry of social customs, Burri (2012), distinguishes among visual value (the simultaneous perception of visual information), visual performance (the composition of visual signs), and visual persuasiveness (the communicative and rhetorical power of images).

Summarising these studies, three main dimensions emerge: 1) visual display; 2) knowledge and meaning; 3) effects to the viewers. From these, I derive three macro-criteria or attributes to apply to influential visualisations: being understandable, meaningful, and engaging.

In the three main dimensions described, graphical/aesthetical and core/substantial elements – the Aristotelian 'form and matter' categories – are combined. Therefore, the proposed criteria need to consider representational, and content-related (complementary) aspects (see Burri, 2012; Blackwell and Engelhardt, 2002). Representational aspects refer to the outward appearance and graphical/pictorial components; they explain why a representation is valuable, that means well-designed, communicative, and smooth to look at. Instead, content-related aspects pertain to: what is being depicted (i.e. the topic of a visualisation); the knowledge represented; and the effective and convincing presentation of this knowledge.

The three criteria are explained considering representational and content aspects (Fig. 1).

3.1. Understandable

Understandable means easy to grasp. The spontaneous interpretation of images occurs in a quick manner not requiring mental efforts (Boehme-Neßler, 2011).

In representational terms, understandable implies that a visualisation is displayed with clarity, immediateness, and good proportion (Tufte, 2001). A visualisation can contain few or many elements; what matters is their balance and adequate amount of information, achievable through hierarchies, few colours, and avoiding complicated constructions. Then, a representation increases visual comprehensibility and reveals relationships/patterns/dynamics (Fekete et al., 2008).

A visually-understandable visualisation makes the topic it represents explicit and comprehensible, thereby supporting thinking and "visual thinking" (Ware, 2013). Larkin and Simon (1987) prove that diagrams, clustering the information needed for inference, help task-completion and augment cognition. Compared to texts or numerical tables, visualisations simplify the cognitive workload required by understanding. Griesemer (1991) defines "propositional capacity" as the ability to bring information in comparison to sentences. Moreover, the content of a visualisation should help viewers to penetrate into what the visualisation is about while assimilating critical information. Paradoxically, even simple-looking representations can be difficult to understand because of their extreme economy and lack of information (Lowe, 1989). To assist viewers, there is in general a process called sense-making, which is the ability to understand visual information and create order from them (Baker et al., 2009). For this, multiple

Fig. 1. The three criteria.

understandings are possible (O'Neill and Smith, 2014), so as to strengthen the rapport with the viewers.

3.2. Meaningful

A visualisation is meaningful when concepts and knowledge are presented in a purposeful and convincing way so as to be appreciated and memorised.

In representational terms, this occurs when the graphical components of a visualisation are organised to make data and information expressive. For this scope, designers can use different techniques like breaking-down complexity into simple constructs, or eliminating irrelevant information making others more evident (Hegarty, 2011).

About content-related aspects, a meaningful visualisation needs to provide easily available knowledge on the topic it depicts. Since visualisations relate to specialised topics, the viewer requires some background notions to interpret them (Blackwell, 2001). However, knowledge has to be salient – i.e. highly relevant for problems in the agenda – and weighty – i.e. rich in significance and conceptualisation. In addition, a visualisation works as a "mnemonic device" to assist users recalling important elements (Am Worren et al., 2002). A meaningful visualisation stores, but also generates knowledge as viewers can interact with the displayed knowledge and enlarge/re-elaborate it. A further connotation is normativity of the content. Schneider and Nocke (2014) argue that climate change visualisations are produced for normative purposes as they are created to change what they show. Normativity derives from the relevance of a problem; however, it has to be explicit so as to intensify meaning within the contents of a visualisation.

3.3. Engaging

A visualisation is engaging when it draws attention, stimulates narratives, and encourages intellectual participation.

In representational terms, it is not easy codifying engagement because the triggers of viewer's attention/participation can be imperceptible. One factor is originality. Another factor is the vividness of images – i.e. emotionally interesting and imagery-provoking (Nisbett and Ross, 1980). The vividness effect requires designers mastering communication techniques to be applied with precision (Guadagno et al., 2011). Similarly, the "engagement effect", depends on the sensible application of design techniques like capitalising on cultural conventions (Hegarty, 2011) – e.g. applying certain colours – or using visual metaphors (Blackwell, 2001). Engagement can be generated even by very basic graphs. Visual simplicity or complexity are not relevant if there is "image agreement", the correspondence to one's mental image (Snodgrass and Vanderwart, 1980).

On content-related aspects, a visualisation is engaging when the represented issue is thought-provoking, attention-grabbing, and able to create a significant debate. Contents can be engaging once having traits of novelty, cogency, urgency, normativity, or problem-solving. These have to be linked to a relevant and lasting issue, otherwise engagement disappears. Primarily, engaging visualisations are relevant for practitioners. Goodwin (1994) argues that visualisations are essential for constructing a "professional vision" that a community of experts uses for animating the discourse of a profession. The activity of sharing – favoured by the portability of visualisations – is fundamental for allowing the dissemination of findings, stimulate debate, and through this, engage and persuade (Latour, 1987; Eppler, 2013).

3.4. The criteria, their strength, and limitations

Understandable, meaningful and engaging represent a first attempt to have straightforward criteria for appraising visual characteristics of influential visualisations. Each criterion is composed by conceptual elements which comprise a framework for analysis (Fig. 2).

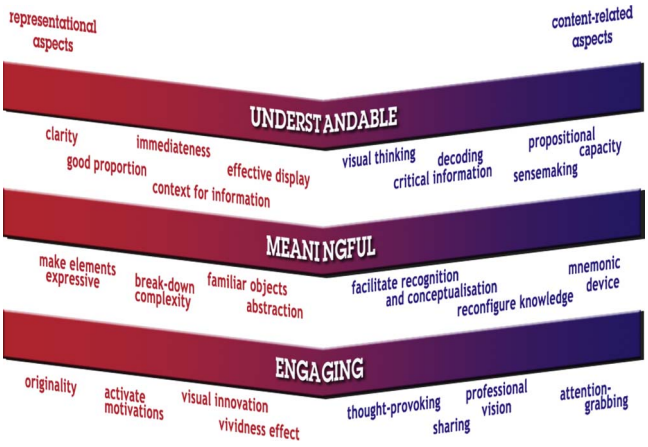

Fig. 2. Framework for analysis.

The three criteria are necessary, differential and consequential. Necessary, as they are required together; differential, as they mark-off influential visualisations from others; consequential, as one criterion enforces the others. The interconnected working-levels of the criteria – respectively informative, explanatory, and persuasive – suggest their logical sequence: understandable, meaningful, and engaging. Yet, there is no absolute dependence among the criteria since feedback loops recursively connect them into an integrated structure.

It must be underlined that the criteria alone do not explain why a visualisation becomes influential tout court. As mentioned, there are intrinsic/contextual factors (e.g. timing, innovation, accreditation) that can boost a proposition subtended in a visualisation. Nevertheless, the criteria exclusively explain why a visualisation is influential in visual terms. Yet, visualisations are all different and can perform differently in each criterion. For instance, a very simple graph can look feebler in purely representational terms than a pictorially-rich visualisation, but can acquire iconic status for the vigour of its associated meanings. Conversely, a visualisation can leverage on emotional elements, then being extremely engaging though less strong in the other criteria. Moreover, as people – as well – are all different, visual receptivity of viewing audiences can vary, according to culture, context, knowledge, sensitivity (Golec, 2013; Sheppard, 2005; Snodgrass and Vanderwart, 1980). In addition, even different communities of experts/academics/policy-makers, can be more or less exposed to specific issues, resulting variably sensible to visualisations depicting those issues. Finally, the criteria do not pretend to be all-encompassing, but aim at capturing the salient features of influential visualisations. They are thought as (easy-applicable) qualitative attributes for heuristic and evaluative purposes instead of experimental/quantitative ones.

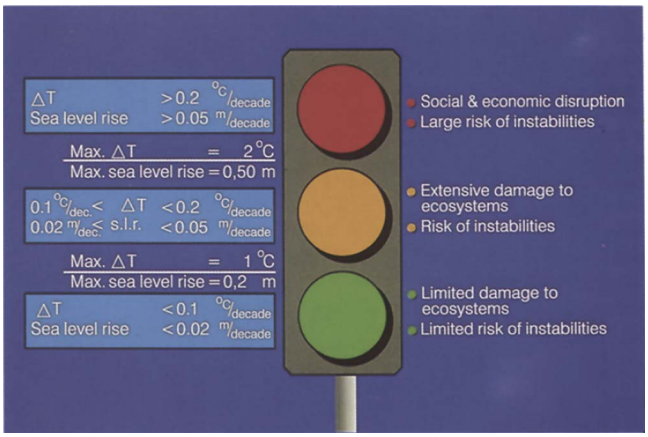

Fig. 3. The TL diagram.
Credit: Vellinga and Swart.

4. Analysis

The analytical framework is applied to the "traffic light" and "planetary boundaries" diagrams. This choice is determined by the diagrams' visual codes that make them particularly suitable for the analysis, and by their relevance in two periods of global environmental governance. The traffic light refers to the framing of responses to climate change (Morseletto et al., 2017), while the planetary boundaries diagram belongs to the current phase of countermeasures to anthropogenic changes and earth transformations. Furthermore, considering visualisations different in subject and period of development has advantages. It offers the opportunity to verify the robustness and applicability of the criteria while appreciating – beyond differences and peculiarities – the visual characteristics that make visualisations influential.[1]

4.1. The traffic light (TL) diagram

Tolerable limits of climate change were debated in the late 80 s by the Advisory Group on Greenhouse Gases (AGGG), a small advisory body of international experts (Morseletto et al., 2017). An AGGG report presents, in the executive summary by Vellinga and Gleick, a diagram (see Appendix Fig. A11 in Supplementary material) visualising the level of risk related to temperature and CO_2 limits (Rijsberman and Swart, 1990). Besides AGGG identified possible targets for climate change, it was an article by Vellinga and Swart (1991) that proposed the 2 °C as a policy target for the first time. The article presents a visualisation – became famous as the Traffic Light (TL) diagram (Fig. 3) – having elements in common with the AGGG one, but different in significance and implications. The diagram represented a key moment in the establishment of the 2C° target in the scientific and political discussions of climate change (Mahony and Hulme, 2012; Mahony, 2015) and for this is assessed according to the criteria previously defined.

4.1.1. Understandable

In representational terms the diagram is tidily structured: two groups of information are organised around the correspondent traffic-light colours. These are the leading pictorial elements. Visually, blocks of information are neat and consistent. The left side alternates data on thresholds (contained in rectangles), to data on levels. Mathematical symbols give more complex, but scientific appearance, while the high density of information is unburden by the hierarchy among elements. The right side presents less information, with bullet points in traffic-light colours to keep the message visually tighten and comprehensible.

In contents terms, the TL is equally understandable. On the left, quantitative data, on the right correspondent qualitative information. The propositional capacity of the diagrams highly depends on sixteen written-sentences. These are many, but necessary to avoid misinterpretations of colours and provide the right amount of details. Information-clustering favours visual thinking and sense-making of impacts/scenarios. Moreover, the well known traffic-light colours guide the decoding of critical information. Focusing on few issues, the picture allows a quick assimilation of the indications. The use of visual elements and the breaking down of complexity result in an easily understandable display. Since the inception, the authors opted for a practical approach though being aware of the limitations of simple figures, and of the trade-off between comprehensibility and completeness, so as

[1] The case-study investigation is supplemented by document analysis and interviews with the authors of the visualisations. Document analysis focused on academic and gray literature in which the visualisations were quoted or used. Interviews–conducted repeatedly through semi-structured questions conducted vis-à-vis and by telephone and emails–were functional to understand the authors' point of views and the context of development of the diagrams.

between conciseness and accuracy.

4.1.2. Meaningful

Meaning is conveyed in a very practical way. Visually, the message is simply presented as each colour is associated to meanings from common road experience. The right-side options are the translations of the left-side information. This adds significance to concepts like temperature-variations or eco-systemic consequences. According to the authors, few scientists criticised the precise boundaries chosen, which do not exist in reality in such a discrete fashion. Yet, this choice is a necessity deriving from the provision to be visually meaningful. In representational terms, the vexed question of scientific uncertainty (Gramelsberger and Feichter, 2011) deserves careful analysis. Vellinga and Swart's article deals with climate sensitivity, an intricate notion requiring estimates of uncertainties. Optically, uncertainty is an amorphous concept therefore a visualisation to be meaningful requires visual determinism and certainty of what can be represented.

In terms of contents, the TL provides knowledge from different domains. The idea of risk relates to the impacts in the bulleted list where the word "risk" appears in each of the last associated bullets. The diagram is meaningful also because it works as a mnemonic device: it summarises salient information and key consequences. Finally, the TL is memorable in its main normative messages "high-risk above 2 °C/red light"; which reduces the climate change problem "to core visual statements and concise synopses" (Schneider and Nocke, 2014, 16) comprehensible to large audiences and decision-makers.

4.1.3. Engaging

In representational terms, the image was totally new in the scientific domain. The traffic device in the blue sky poses the observer at a road intersection. This vivid image immediately activates attention and imagination. The metaphor is very simple and for this effective: it proposes three ineluctable options while allowing unleashing narratives for each of them, but particularly for the high-risk/red one.

These aspects help to appreciate how the visualisation is engaging in terms of contents. The TL became a landmark in the definition of the 2 °C-temperature target because it represents a knowledge synthesis, but also a thought-provoking framework for discussion. The TL was presented at important venues and high-level conferences related to climate change science and negotiations at the EU and UN level where – according to the authors – it was very well received – particularly by decision-makers. The figure achieved visibility in the literature of the period, even if in that time the digital portability of images was hindered by crudeness of software and infancy of internet. However, its legacy remains considerable since the traffic-light colours became a visual meme in climate change communication. Still, the metaphor of the TL is particularly suitable for engagement because the combination red/high-temperature/high-risk corresponds to common associative-meanings of that colour (Gage, 1999). Moreover, it contains a direct normative-message: going beyond the 2 °C is as dangerous as running a red light. Such a message was criticised by some scholars for its boldness and elision of uncertainties. Nonetheless, every traffic-light model "represents an oversimplification but reflects the actual need for a judgment at the end of the appraisal and evaluation process" (Renn, 2008, 150). This exemplifies another vexed question, whether scientists should neutrally inform policy or provide an interpretation of risk. The answer remains inextricable as long as risk is involved. Renn (2008) locates it in the philosophical category of contingency. Risk deals with uncertainties, effects, valuable assets, all implying contextual judgment.

In sum, the TL diagram wholly fulfils the criteria considered. It can be seen as a lesson of pragmatism in condensing meanings, forming visual conventions and helping to understand a problem. It is difficult to measure the full impact of this influential visualisation. Yet, how problems get noticed play a fundamental role in tackling them (Pralle, 2009). Accordingly, the TL was a fundamental tool to communicate risk, connect with decision-makers, and create a memorable image which favoured the approval of the 2 °C as global target of the climate convention.

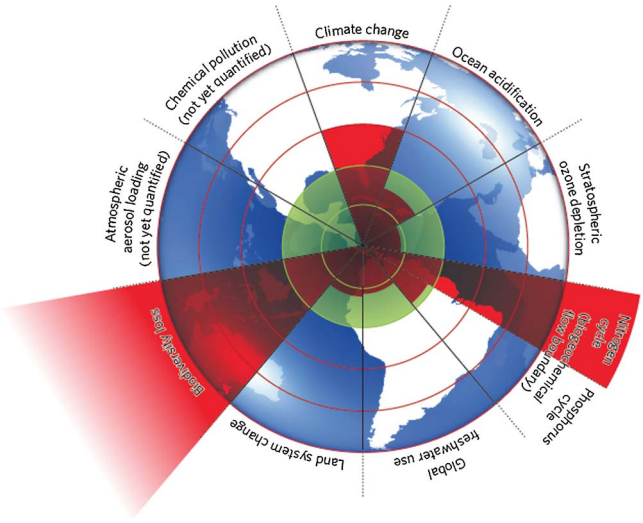

Fig. 4. The PB diagram.
Credit: Nature Publishing Group.

4.2. The planetary boundaries (PB) diagram

In 2009, twenty-nine scientists presented a conceptual framework based on nine interrelated limits of Earth's biogeophysical processes (m et al., 2009a,b; m et al., 2009a,b). Together, these boundaries define a safe operating space for humanity, while crossing them would have severe repercussions for human wellbeing. The planetary boundaries (PB) concept immediately received widespread attention by academics and policymakers, and it generated a – still ongoing – broad debate (Galaz et al., 2016). According to one author of the PB, the involved scholars felt the necessity of a visual translation to be very part of the concept. The result, published in an extended article (Rockström et al., 2009a), was a radar/spider representation (see Appendix Fig. A12 in Supplementary material).

A shorter article was published in Nature (Rockström et al., 2009b). The journal decided to develop another diagram internally (Fig. 4). The work was done by Wesley Fernandes, Nature's art director.

This diagram – commonly identifying the PB concept – is analysed according to the criteria defined in the framework section.

4.2.1. Understandable

In representational terms, the work done by Fernandes was noticeable compared to the previous diagram. First, he introduced the image of the Earth, as the PB are all about it. With sensible use of colours, overlays, and opacity/transparency, he balanced the planet into a clear, unitary whole. The radar was re-plotted into a segmented circle to fit over the globe making evident that some boundaries cross its contour. The black dots and connecting lines, indicating the boundaries' trajectory in time in the previous diagram, were eliminated as unnecessary visual clutter. All these elements created a figure that was understandable on the spot while the journal had a visual entry-point for the article.

Contents are characterised by conciseness and comprehensibility. Visual thinking is triggered by the image of the Earth (to which all we belong) and by the boundaries written on the planet's edge. Some boundaries manifestly overshoot the green "safe" zone, whereas two boundaries are not quantified. The propositional capacity of the picture is therefore slightly limited, since the details on each boundary are in the article. However, these aspects are not evident because the diagram conveys relevant information and provides an all-at-once overview of

the concept. A last point is that the interrelations among boundaries are (visually) missing; nonetheless, due to the complexity of this issue, it would be difficult representing them adequately even through a series of diagrams.

4.2.2. Meaningful

In relation to the representational aspects, the globe makes the picture real and tangible. It condenses the PB concept even further since "the image of Earth […] is a universal common property with shared meaning" (Jasanoff, 2004, 49). In the diagram, the foreground continents are in plain white, the others are faded in the background. Consequently, the Earth is more inclusive and idealised compared to a photograph. The slight distortion of the Americas' shape allowed the author to sensibly place the geometrical centre where two oceans touch each other, thus aligning the pictorial elements to the observer's perspective. All these purifications indirectly introduce a strong political/transnational visual-message that is intensified by the red beams of the figure. Similarly to the TL, the PB diagram presents the problem of uncertainty depiction. Here, the usage of overlays and opacity/transparency for boundaries strongly mitigates this predicament and the absence of numerical data minimises possible disagreements on the scale and position of the boundaries. The diagram is presented as a metaphor without pretention of absolute precision, but with an expressive function: the "small" Earth (nonetheless immense in people's mind), neutralises any claim of exactness.

On meaningfulness of contents, knowledge is provided by the spatial relation among the Earth, the inner safe zone, and the boundaries. The viewer is acknowledged and alerted about the dangerous state of the planet. Another mechanism enforces meaning: the two-dimensional radar frame represents an extra dimension to the three-dimensional Earth. The optical juxtaposition of these planes suggests the idea of societal steering of humanity. Moreover, attention is intensified by the interplay of radiuses and cycle, which allows acquiring significant knowledge. For the multiplicity of contained meanings, the diagram works as a mnemonic device: like a map describing the condition of the planet, and like an action-priority dashboard. In a snapshot, the figure provides recognition and conceptualisation of the planetary issues. More strongly, it is the visual synonym of PB, a sort of ideogram, a graphic holophrasis for the concept.

4.2.3. Engaging

In representational terms, the diagram offers a vivid image of the planet framed/monitored by a radar. This is an instrument providing standard information and alert signals, here expressed in red and green – parenthetically – the main traffic-light colours. Additionally, the overhanging boundaries form a shape that recalls the radioactive symbol. This enforces even further the idea of the Earth in peril. There is another element of involvement: the observer is like an astronaut, but – continuing the narrative – an astronaut who has to return back. All these indications make the diagram engaging and a memorable synthesis for discussion in the scientific and political domains.

Regarding contents, the PB visualisation is attention-grabbing and imagery-provoking. The implications are both persuasive and normative: "some boundaries overshoot the safe level, something should be done!" Furthermore, the interpretative flexibility of the Earth's image favours fascination and appropriation, together with sense of finiteness, fragility and human dependence (Jasanoff, 2001). Finally, the PB diagram appeared in a full array of contexts like presentations, seminars, news coverage, scientific articles, websites, high-level policy briefs or main UN conferences like Rio + 20. The countless appearances testify the relevance of the concept within the debate on global change. It emerges that once the PB concept is mentioned, the diagram appears. This tendency deserves a specific inquiry. The diagram is a reification of the PB concept and sometimes is a visual complement to be conveniently attached to a document or presentation. Occasionally, the figure might work as a logo. This falls outside the scope of this paper. However, in the study of brands, factors like identity, association, resonance, affinity, reputation, might be good proxies to explain how the PB diagram works as a milieu for recognition and culturally-shared meanings. This hypothesis is congruent with the several re-elaborations of the PB diagrams,[2] which are anyhow an expression of engagement.

In sum, the PB visualisation wholly fulfils the criteria considered. It communicates the complexity of the PB concept in an intuitive and intelligible way. The diagram proposes a bundled-knowledge that stimulates a holistic reasoning in environmental governance. This can be considered a major achievement. As previously for the TL diagram, it is difficult to access the full impact of the PB diagram, but in being an element that recalls the whole picture combined with the essentiality of ecosystem services for humanity, it executes its influence at best.

5. Plausibility check

In order to check the relevance of the analytical framework, this section considers two representations that display new knowledge, and relate to relevant environmental issues similar to those of the PB and TL. The purpose is not judging their value, but quickly verify their performance against the understandable, meaningful and engaging criteria.

The first is the Arctic sea ice volume designed by Andy Lee Robinson (Fig. 5), as part of a main project by the Polar Science Center.

This representation is a spider-chart, highly employed in metric-measurements; therefore it is not novel, besides its visual neatness in providing a large amount of multivariate data. The diagram is apparently simple, but it is slightly complex to be understood in its content and visual structure. Thereby, its alarming message – ice is melting at a record pace – is not straightforward unless having familiarity with those charts. This little immediateness makes the message difficult to grasp for a broad audience. For the same reasons, the representation is less proficient in capturing attention and stimulate narratives than, for instance, the TL or the PB diagrams. The name given by the author "the Arctic Death Spiral" is quite effective and attracting; nonetheless, Arctic ice-melting has many environmental and societal implications which are not evoked (e.g. the planetary heat-absorption, sea-level increase, methane released from permafrost). The diagram therefore remains an outstanding visual account for those interested in the topic, but is less likely to engage a wider community.

The second visualisation is from a ground-breaking article by Hans Joachim Schellnhuber (1999) published in the journal Nature. Perils and opportunities of different approaches of sustainable development are represented by a figure, called "A Theatre World" (Fig. 6).

This diagram has some conceptual elements in common with the TL and many with the PB diagram. However, it is much less understandable both in visual and contents terms while it is mandatory to carefully read the caption of the figure. Also in terms of meaning, it is not easy to grasp the knowledge it contains. For instance, the blob-morphic shape in the centre needs reflection to be appreciated, so as the (beyond-Earth boundaries) Martian and Venusian regimes respectively ultra-cold (green?) and hot (pink?). Clearly, the figure is intentionally provocative and extreme. As the article, it contains refined knowledge about the complex state of the planet combined with reflections on scientific and philosophical matters. The absolute originality of the figure might make it notable, but difficult to engage with.

To summarise, the two cases presented are extremely interesting, well-conceptualised, and relevant for knowledge content. Nonetheless, they do not fulfil entirely the three criteria.

[2] I catalogued 28 different versions from the internet.

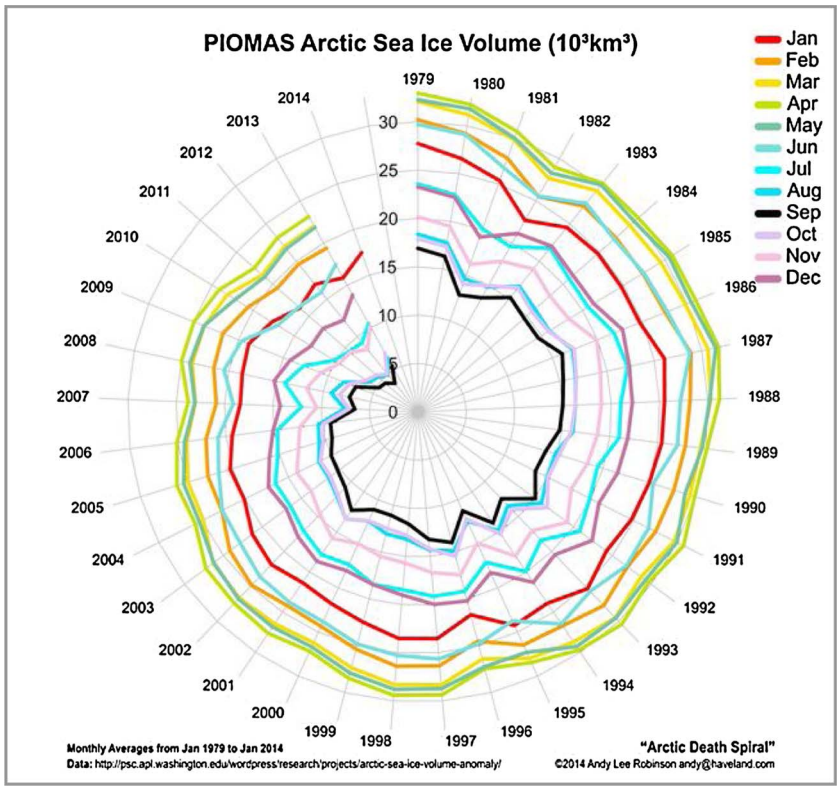

Fig. 5. Arctic -sea ice volume.
Credit: Andy Lee Robinson.

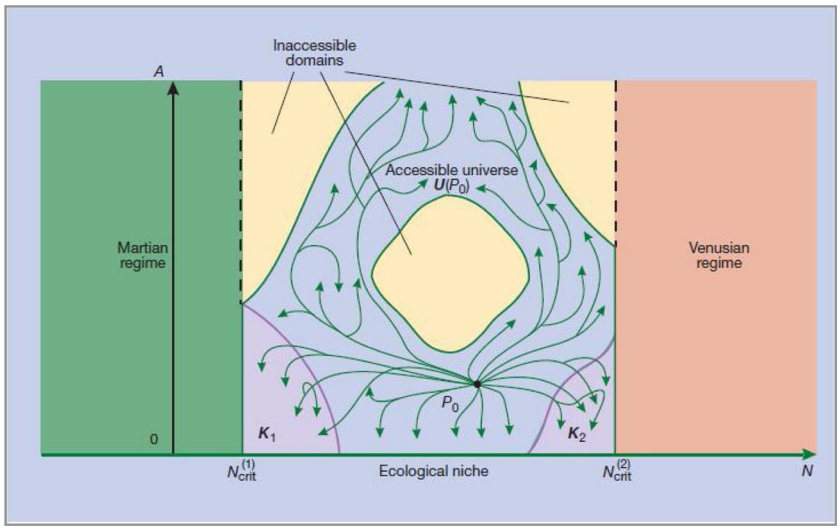

Fig. 6. A Theatre World.
Credit: Nature Publishing Group.

6. Conclusions

The TL and the PB demonstrate some important aspects of influential visualisations. Both diagrams proved to be nodes in the exchange of knowledge and practical objects that condense concepts, and frame discussions in the context of global environmental governance. In this, and in the fulfilment of the understandable, meaningful and engaging criteria, the diagrams contains instructive insights for designers, scientists, and experts using and making visualisations. In fact, in the almost two decades dividing them, radical changes occurred in the advancement of graphic technology, scientific knowledge, access to information, and attention to environmental themes. Besides these historical differences, the diagrams showed to be powerful epistemic tools. With distinctive pictorial codes, both diagrams introduced an innovative visual lexicon that made them immediately recognisable, while providing an unambiguous and stimulating message. The diagrams confirm Jasanoff's words: "images may transcend cultural lines in ways that words cannot, thereby helping to create communities of meaning and shared responses or demands that cut across ordinary linguistic and governmental divides" (Jasanoff, 2001, 311). Nonetheless, if images are the *lingua franca* in the world of visible, influential visualisations need further mechanisms to communicate persuasively and permeate a debate. In the TL and PB cases, this mechanism is trigged by the communication of an imminent risk and induced warnings. Explicitly, both diagrams use visual metaphors depicting electronic devices (the traffic light and the sonar/radar), significantly two well-know equipments for providing information at a glance. Metaphors are important in environmental matters as they "simplify a complex reality by situating facts in a web of cultural meaning" (Larson, 2011, 129). The traffic light and the radar are familiar but alerting

devices. The vis-à-vis position of the devices exalts normativity; the two diagrams communicate a main normative statement: "we are facing danger, we must do something". This is a negative and positive message at once, then significant and rhetorical. As showed by Walsh (2015), rhetoric is fundamentally integrated in any scientific graphics, and no visualisation is perfectly objective. However, in influential visualisations rhetorical elements magnify consciousness and convince of the relevance of the problem presented.

One last and related consideration is that the examined influential visualisations help to reconfigure thoughts and ease the comprehension of major environmental problems. This is their main addition to global environmental governance. Being meaningful, understandable and engaging, the TL offers a framework for tolerable temperature limits, while the PB diagram provides a visual summary for the limits of the Earth. Both help keeping in mind an issue, favouring debate among experts, and promoting a dialogue with policy-makers. Nonetheless, these fundamental contributions remain difficult to quantify with exactness since influential visualisations operate in the territory of debates, which changes shape as discussions ensue. Future research could investigate further influential visualisations, for instance defining metrics for the criteria (those here proposed or any other ones) and conducting experimental assessments; instead, for new influential visualisations, it would be advisable to study their emergence and track their progression throught debates.

Finally, the TL and PB diagrams being understandable, meaningful and engaging result being object of multiple exchanges by different actors, in different arenas, and at different time while their manifestation occurred in physical supports, verbal communications, or mental images. The fact that their full impacts are unmeasurable could be a reason for analytical concern, but it can also mean that influential visualisation never stop being inspiring and producing effects.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2017.08.021.

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