The visual framing of climate change impacts & adaptation in the IPCC Assessment Reports

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Abstract

The Intergovernmental Panel on Climate Change (IPCC) is a key source on climate change information. How the IPCC presents and frames this climate information influences how policymakers and various stakeholders worldwide perceive climate change and make decisions accordingly. Visuals are powerful components in this communication. Here, we assess how the visuals (N=702) in the IPCC Working Group II Assessment Reports frame climate impacts and adaptation. We find that visuals are largely framed as distant in time and space and predominantly portray the threats of climate change rather than possible goals to be achieved. Furthermore, conceptually they are largely narrow, science-oriented instead of showing a broader multi-impact or multi-strategy evaluation of the impacts on society and necessary adaptations. They primarily depicted what the impacts and adaptations were, with minimal attention to who was impacted or needed to take adaption actions or adopt responsibility. Very few of the visuals in WG II (N=48, 6.5%) focus on adaptation and those that did often do not show a clear theme, spatial or temporal scale. Our findings suggest that IPCC visuals (still) focus primarily on showing that climate change is real and a problem, with little solution-oriented communication. We recommend that the IPCC pays explicit attention to its visual framing, and that approaches are developed to better visualise adaptation.

Keywords: Intergovernmental Panel on Climate Change, framing, visualisation, climate impacts, climate adaptation

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Author contributions:

AW and SL conceived the study, developed the analytical protocol and coding scheme, and collected, coded and analysed the data. All authors contributed to writing the paper.

Additional information:

Supplementary information is available in the online version of the paper. Correspondence and requests for material can be addressed to AW.

Competing financial interests:

The authors declare no competing financial interests.

1. Introduction

1.1. Communication processes in the IPCC

As a key boundary organisation on climate change (Guston 2001), the Intergovernmental Panel on Climate Change (IPCC) not only plays a pivotal role in summarising the scientific research on climate change, but also in the way this information is communicated and consumed among policymakers and society at large (Hulme and Mahony 2010; Vasileiadou et al. 2011). Consequently, the way the IPCC assesses and communicates climate change has been under considerable scrutiny (e.g. IAC 2010; Beck 2012; Lynn et al. 2016).

The IPCC produces different types of publications including Assessment Reports (ARs), Special Reports and Methodology Reports. Synthesis Reports of an AR, Technical Papers, Supporting Materials and Summaries for Policymakers (SPM) are also published by the IPCC, but are produced differently to the main parts of the reports. To produce IPCC reports, information from international peer-reviewed and selected non peer-reviewed publications is critically, yet objectively and transparently reviewed by a large group of international experts. Based on this review a first draft of an AR is written and reviewed by a range of experts. The second draft as well as the SPM is then reviewed again by experts as well as governments. Lastly, the revised SPM undergoes another line-by-line approval process by governments (IPCC n.d., a).

The IPCC consists of three working groups, with each of them publishing its own AR. Each Working Group is focused on different facets of climate change: i) Working Group I (WG I) 'assesses the physical scientific aspects of the climate system and climate change'; ii) Working Group II (WG II) 'assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. It also takes into consideration the inter-relationship between vulnerability, adaptation and sustainable development'; iii) Working Group III (WG III) 'assesses options for mitigating climate change through limiting or preventing greenhouse gas emissions and enhancing activities that remove them from the atmosphere' (IPCC n.d., b).

Whilst some may call for reform of the IPCC (Beck 2012), it is undoubtable that the IPCC has a discernible influence on how scientific knowledge on climate change moves into the political and decision-making sphere (Adler & Hadorn 2014), and thanks to its ARs climate change has become one of the biggest political issues of our time (Hulme 2010). Importantly though, the IPCC's goal is to communicate assessment findings and methodologies "by providing clear and balanced information", being objective and transparent, and "policy-relevant but not policy-prescriptive" (IPCC 2016). Given the status of the IPCC, the communication process has been of some research interest. Past studies have focused on the communication and interpretation of scientific uncertainties in the IPCC (Mastrandrea 2010; Budescu et al. 2014; Hollin & Pearce 2015), the representation of the IPCC in traditional and social media (Hulme 2009; Asayama & Ishii 2014; Pearce et al. 2014; O'Neill et al. 2015; Newman 2017) and the readability of the Summaries to Policymakers (Barkemeyer et al. 2015). More recent research has also started to examine the visual elements in the reports, such as the intentional and unintentional messages conveyed by specific IPCC figures (McMahon et al. 2015; McMahon et al. 2016; Schneider 2016) and the development of guidelines on improving the accessibility of IPCC visualisations (Harold et al. 2016).

Yet there is still relatively little research on how the visualisations in the IPCC reports can shape the image of climate change that is portrayed to policymakers and the wider society. Visuals can be

powerful tools in environmental communication. They have the ability to present and summarise large amounts of complex information (Wardekker et al. 2008); they can invoke emotional responses and potentially promote engagement with environmental issues (Smith & Joffe 2009), and they can help to make issues that are perceived to be far away, distant in time and 'invisible', more meaningful (Doyle 2007; Manzo 2010; O'Neill & Smith 2013) and thus influence policy preferences (Leiserowitz 2006). At the same time, visual formats are more open to broader interpretation and different audiences will have different abilities, preferences and perceptions leading to a more varied interpretation of visuals and requiring more systematic empirical testing (Spiegelhalter et al. 2011, Lorenz et al. 2015).

1.2. Framing

The process of communication, however, does not start with recipients viewing the image, but with the production of the image and the choices made within that process. These may 'frame' climate change in specific ways. Framing is the process, of presenting a particular issue in a certain way to highlight or increase the salience of specific aspects, "promoting a particular problem definition, causal interpretation, moral evaluation and/or treatment recommendation" (Entman 1993). Common public use of the term tends to focus mainly on intentional framing: highlighting something in a specific way to convince others. However, framing can (and often does) happen unintentionally/subconsciously, reflecting the way the writer or speaker perceives or appreciates the issue (Schön & Rein 1994). For complex issues, involving many aspects and ways of looking at the issue, it may be impossible to highlight all aspects simultaneously (De Boer et al., 2010). Framing, as used in this study, then simply means: what aspects of an issue are highlighted in particular?

The analysis of framing of climate change information and communication has focused mainly on written and verbal material (e.g. Spence and Pidgeon 2010, Gifford & Comeau 2011, Ford & King 2015), yet it is also increasingly being adopted for the analysis of visuals (O'Neill 2013, Rebich-Hesphana & Rice 2016, Wozniak et al. 2017). How visuals highlight their contents (how and what is visualised, and what is not?) (Spence & Pidgeon 2010), and choices on scale, colour, and focal topic, promote particular ways of looking at climate change, while obscuring and marginalising others (O'Neill & Smith 2014). Importantly, it has been found that the choice of framing influences how the message is perceived and what decision is taken as a result (Reese et al. 2001, Gifford & Comeau 2011, Grabe & Bucy 2009, Spence & Pidgeon 2010). It was also shown that there are differences in how different professional groups' visual frames of climate change are represented in the mainstream media, thus potentially portraying a biased view towards one professional groups' interests and attitude (Wozniak et al. 2017). Furthermore, O'Neill et al. (2015) found that frames applied to the reporting of the IPCC's Fifth AR (AR5) not only varied by country but also by WGs. Interestingly, WG II's coverage predominantly used a 'disaster' frame, implying that the impacts of climate change will be terrible and that adaptation to them is negligible (O'Neill et al. 2015). These findings show that the way in which the IPCC findings are framed is of key importance to policymakers' and the public's interpretation of, attitudes to and engagement with climate change.

To date, studies have focused on the frames the media have employed when reporting on the IPCC (O'Neill et al. 2015) or the Conference of the Parties (Wozniak et al. 2017). However, given that the IPCC is the most established institution influencing the scientific, political and public debate on climate change (Hulme 2010), and more attention on how climate visualisations can frame this debate has

been called for (Maes 2017), it is highly relevant to learn more about how the IPCC itself frames climate change in its visuals.

1.3 Aims of this study

Given the IPCC's goal of being 'policy-relevant, but not prescriptive', visual framing may not be intentional (agenda setting). However, unintentional framing may take place, for instance as a result of the way specific scientific fields study climate change. This may also vary over time, as more or different knowledge becomes available, different author teams write the reports, or different aspects become policy relevant. Framing is important, because different science-based frames of climate change are associated with different approaches to climate policymaking (De Boer et al. 2010). Careful attention to visual framing may improve the uptake of information, e.g. by making sure that there is a diversity of visual frames, matching policy approaches in different countries, and that those aspects are highlighted that are highly policy relevant. WG II is particularly interesting, because it lies at the intersection of scientific knowledge on problems and solutions. We therefore aim to assess:

- Which aspects are highlighted in the WG II visuals over time?
- Are there any differences in this between impacts and adaptation visuals?

We hypothesised that WG II's visual framing would reflect the maturing of the scientific fields as well as the IPCC as a science-policy boundary organisation. We expected that (1) early visuals might focus on reporting and detailing the various impacts, reflecting the head start of this field compared to adaptation. In later years, with advances made in the field of adaptation, we expected to see a greater balance between impacts and adaptation visuals as well as a shift towards solution-oriented framing, in line with a move towards exploring adaptation options and assessing the progress of their implementation. This also reflects the notion that, now that climate change is becoming an unavoidable reality, knowledge on adaptation is becoming increasingly policy-relevant (Moss et al. 2013). Furthermore, we hypothesised that (2) early visuals might present a relatively narrow, scientific perspective reflecting the emerging evidence of the threat of climate change and its impacts. In later reports, we expected framing to become broader, oriented towards the societal challenges interlinked with climate change and the diverse policy audiences that the IPCC now services. Lastly (3), given the wide range of sectors and impacts categories included in WG II, we expected a spread of themes covered (e.g. coastal issues, freshwater, health, biodiversity, etc.). However, the spread may not be even, given varying data availability in different sectors and greater uncertainties around some impacts, but also given the differing levels of political and financial interests and resulting perceived policy-relevance.

To assess these hypotheses, we present a framing analysis of the visualisations in the IPCC ARs from WG II on Impacts and Adaptation (N=702). Further to the content-analysis approach, typically employed in other relevant climate-framing studies (e.g. Wozniak et al. 2017), our analysis takes a quantitative approach, evaluating the visuals from WG II on a list of criteria that cover various aspects of framing and importing such data into statistical software. This allows us to statistically examine differences between the ARs, trends over time, as well as comparisons between impacts and adaptation visuals.

2. Methods

2.1 Applying a framing analysis to scientific visualisations

The concept of frames and framing is employed widely across linguistics, social and organisational psychology, policy studies, philosophy, and communication and media studies. Qualitative and quantitative methods have been developed for the analysis of media coverage and policy debates on politically relevant issues (e.g. Matthes & Kohring 2008; Nisbet 2009; Fünfgeld & McEvoy 2011; Berkhout et al. 2014; O'Neill et al. 2015; Schäfer & O'Neill 2017). Applying a framing analysis to scientific material is novel, and consequently the approach taken in this paper is experimental. For media and policy debates, framing analysis is relatively straightforward: analysing agenda setting and contrasting policy positions based on argumentation or specific content highlighted (specific problems, solutions, etc.). For scientific visuals, this is difficult. Scientific material is supposedly 'non policy-prescriptive', although it is a matter of debate in philosophy of science on whether that can ever truly be the case, especially for policy-relevant knowledge (e.g. Pielke, 2007). The IPCC specifically also has the goal of covering all relevant topics, with many visuals (WG II: n=702) over a long timeframe (1990-2014), and its authors are heterogenous compared to a single media outlet or policy actor. However, choices are made in scientific assessments in highlighting (and therefore framing): what is considered 'policy relevant', and what issues from the text are visualised (therefore highlighted) and how exactly? Such choices have political dimensions (Schneider & Nocke 2014; Schneider 2016). The 'burning embers' diagrams for example, first published in the IPCC's Third Assessment Report, includes, aggregates and associates specific topics with white-yellow-red gradients to signify levels of danger. This involves interpretations and choices (e.g. how intensely red should the endpoint be?). Discussions and different variants of this figure reflect varying views on scientific norms in different fields, and the role of the IPCC as a science-policy intermediary (Schneider & Nocke 2014; Mahony 2015). Similarly, De Boer et al. (2010) observe that framing in science-policy discussions on climate adaptation shapes how people conceptualise climate change. Moreover, frames are also connected to different scientific methods and assessment tools to support adaptation. These studies show that framing does take place in scientific visuals. However, scientific framing seems less obvious than media and policy framing: not only related to the specific content promoted on the policy agenda, but more to inherent structures of perception (Schön & Rein 1994) and ways of conceptualising climate. This also means that we cannot rely on standard cultural frames of climate change as described in media framing studies. Rather, we will need to look at different 'framing elements' that cover various content and conceptual aspects (Matthes & Kohring 2008; Runhaar et al 2015). An advantage of this approach is that it allows for a quantitative longitudinal exploration of many aspects for many visuals.

2.2 Rationale for selecting the 'framing elements'

A wide range of potential and expressed frames exist for complex issues such as climate change, and framing analysis is hampered by the sheer flexibility and context dependency of frames. A 'framing elements' approach makes this more manageable, and suitable for quantitative analysis by looking specifically at different aspects on which they might vary. For example, visual framing might relate to the content (who/what is visualised), conceptualisation (ways of conceiving climate change, ideas), stylistic aspects (techniques, colours, shapes), and ideological aspects (morals, ideals) (Hansen & Machin 2015; Powell et al. 2015). Within those overall types, a diversity of framing elements can still be designed. Very limited research exists on framing elements, and these are media studies focusing

particularly on content (Matthes & Kohring 2008; Runhaar et al 2015). As discussed above, we expect that scientific framing, particularly for the IPCC, will particularly influence the conceptual aspects of visualisations. Designing framing elements for scientific visuals is therefore inherently experimental and partially subjective. A useful selection of framing elements depends on the questions and material studied, and a first qualitative analysis of the research material is helpful. Furthermore, existing qualitative framing research can guide the design of framing elements. Given the experimental nature of this method, we conducted a pilot project on visuals in national climate assessments, to determine the potential for applying and analysing framing elements for scientific visuals. The final selection of framing elements includes: i) ***conceptualisation***: conceptual focus (climate as distant or nearby issue); goal-orientation (threats or vulnerabilities visualised or options and opportunities portrayed); temporal focus; and spatial scale; ii) ***content***: the theme/topic of the visual; iii) ***stylistic aspects***: visualisation type; and iv) ***ideologic aspects***: we used a proxy - whether the visual focused on who (suggesting responsibility) or what (primarily factual) was affected.

2.2.1 Framing of impacts & adaptation (what versus who)

This framing element examines whether visuals showed more a diagnosis of problems in terms of what the problem physically is (impacts – what); defines the problem in terms of who it affects (impacts – who), suggests a solution/remedy (adaptation – what), or indicates who is/should be creating these solutions (adaptation – who). These aspects relate to responsibility (Dirikx & Gelder, 2010) and public accountability and governance (Nisbet 2009): who is causing problems for whom and who can or is doing something about it? Hence, this is also a matter of morality and ethics (Entman 1993; Nisbet 2009; Dirikx & Gelder 2010; O'Neill et al. 2015). Such an indirect metric (and thus indirect coding approach) of moral framing is necessary, because explicit moral framing is highly unlikely in scientific visualisations such as those in the IPCC reports, bearing in mind the nature of the data and preference of the IPCC for a neutral, non-prescriptive tone (IPCC 2016). Whether scientific material contains moral evaluations is a point of discussion in philosophy of science. We'd caution that who-framing doesn't mean the visual is (intentionally/unintentionally) taking a moral stance necessarily. Analysing that would require in-depth study of the design process of the visuals. Rather, this framing element resembles the presence of information relevant to moral discussions.

2.2.2 Highlighted theme or aspect of climate change

This category examines which 'theme' (Runhaar et al. 2015) or 'topics' (Matthes & Kohring 2008) of climate change impacts and adaptations are highlighted more strongly than others. Climate change is a multifaceted issue, but different facets may receive more visual attention than others. This category relates to several content-related cultural and media frames found and used in the climate change communication literature, including economic development, human/public health, security, and disasters (e.g. Nisbet 2009; O'Neill et al. 2015). We included a wide range of topics for both human and natural systems, based on traditional frames (as mentioned above) but expanded to include all topics covered by the IPCC ARs. As a number of visuals also showed the direct and indirect causes of climate change and its impacts as well as broader climatic variables, we also included codes for the themes of energy, greenhouse gasses, and physical climate variables.

2.2.3 Temporal focus

Whether visuals frame climate change as something in the here and now, near future or past, versus the distant future or past (de Boer et al. 2010) also affects people's perspectives of their personal efficacy, the extent to which current versus future generations will be affected, and the level of urgency for action. Similarly, Vink et al. (2013) observe that the selection of the timeframe marks important differences in the framing of concrete adaptation proposals. Furthermore, O'Neill (2013) indicates that the media utilises 'distancing' (that is the portrayal of climate change as an issue removed in time from the here and now) as a key framing element in the portrayal of climate change.

2.2.4 Spatial scale

Linked to the 'distancing frame', considering whether visuals frame climate change as something that happens locally/ nearby (from the viewpoint of the reader) or far away at the continental or global scale, can be related to the salience that a visual may have to specific audiences (O'Neill 2013). Similarly, Spence & Pidgeon (2010) note that presenting climate change as distant versus local has implications for readers' risk perception.

2.2.5 Goal orientation and focus

De Boer et al. (2010) observe that one key strategic contrast in the conceptual framing of climate change relates to the goal orientation: whether the issue is presented primarily from the perspective of prevention (focus on the threat) or promotion (focus on the goals to be achieved). A promotion-oriented framing of impacts and adaptation makes people sensitive to positive outcomes and achievements, gains, aspirations, accomplishments and ideals. This can be linked to media or cultural frames such as social progress, middle-way framing, economic development, and opportunity (Nisbet 2009, O'Neill 2015). A prevention-oriented framing, in contrast, makes the reader sensitive to negative outcomes, losses, threats and errors that need to be avoided. This can be linked to frames such as morality and ethics, Pandora's box, scientific uncertainty, public accountability, risk, and disaster (Nisbet 2009, O'Neill 2015). This is linked to psychological literature on goal-directed behaviour (Higgins 2000), attitudes to nature (De Boer et al. 2010), and positive versus negative risk communication (Wardekker 2004; Spence & Pidgeon 2010; Moser & Dilling 2011).

2.2.6 Conceptual focus

We related the conceptual focus to the perception of the policymakers and other societal actors that form the audience of the ARs: narrow, more science-oriented visualisations will have a different appeal and salience to various audiences than a broader assessment of the societal implications of climate change. The conceptual focus represents whether the visual frames climate change impacts and adaptation from a narrow, scientific point of view or from a broader, multi-impact or multi-strategy evaluation of the impacts on society, and adaptations in various human and natural systems. Framing can thus be close to the observer (proximal) or far away from the observer (distal) (de Boer et al. 2010). This links with psychological literature on different levels of thinking and observing (e.g. broad, global, general or narrow, local, specific) (e.g. Warslak & Trope 2009). De Boer et al. (2010) use this contrast to condense several aspects, such as: abstract versus contextualised, general versus specific features, long-term versus short-term, and broad versus narrow. For instance, a morality/ethics frame is more conceptual and broad, while economic development is much more context-related and narrow (cf. Nisbet 2009). In our study, we split this into three aspects: temporal focus (e.g. long or short-term)

(see above), spatial focus (e.g. specific location or more global) (see above), and conceptual focus (broad or narrow).

2.2.7 Type of visualisation

This category briefly explores stylistic aspects. We were particularly interested in differences in classic scientific figures such as charts (bar, pie), line graphs, box & scatter plots, diagrams, and maps, versus explanatory visuals such as infographics, and illustrations such as photographs. Different visualisation types can impact comprehension and perception of how 'scientific' a visualisation seems (McMahon et al. 2016).

Table 1. Framing elements and coding categories used in the analysis.

Framing elements	Brief description and associated codes	Link to literature
General data *(Type: metadata)*	Report year, visual name, visual number	
Framing of impacts & adaptation (what versus who) *(Type: ideologic)*	Specific portrayal of impacts or adaptation Diagnosing problem in terms of what the problem physically is (impacts - what), Defining the problem in terms of who it affects (impacts - who), Problem solving/remedy suggestion (adaptation - what OR adaptation - who)	Entman 1993, Nisbet 2009, Dirikx & Gelder 2010, O'Neill et al. 2015
Highlighted theme or aspect of climate change *(Type: content)*	Specific topic or sector that is represented Cryosphere, water (rivers, lakes, floods, droughts), coasts (erosion, sea level), ecosystems (marine, terrestrial, food production (managed, extractive), wildfires, agriculture (non-food) and forestry, livelihoods and economics, health, energy, infrastructure, climate, GHG and carbon management, other	Matthes & Kohring 2008, Nisbet, 2009, O'Neill et al. 2015, Runhaar et al. 2015
Temporal focus *(Type: conceptual)*	Specific timeframe portrayed Present, Near future: (near term till 2030; mid-term - 2050s; long term – 2100), Distant future (beyond 2100), Near past (up to industrial revolution), Distant past (millennia, paleo), Multiple timescales	De Boer et al. 2010, O'Neill 2013, Vink et al. 2013
Spatial scale *(Type: conceptual)*	Specific scale captured Geographical scale (if possible) or non-geographic: Geographic (global, regional, national, local), non-geographic (sectoral, topical)	De Boer 2010, Spence & Pidgeon 2010, O'Neill 2013,
Conceptual focus *(Type: conceptual)*	Conceptual width of analysis narrow (specific, well-defined), broad (wide reach, multi-topic, abstract)	Nisbet 2009, Warslak & Trope 2009, De Boer et al. 2010,
Goal orientation *(Type: conceptual)*	Specific goal visual is oriented towards prevention (visualises threats or vulnerabilities), promotion (visualises options or opportunities)	Wardekker 2004, Nisbet 2009, de Boer 2010, Higgins 2010, Spence & Pidgeon 2010, Moser & Dilling 2011, O'Neill 2015
Type of visualisation *(Type: stylistic)*	Type of visual used graph (line), chart (bar, pie); plot (scatter, box), map, diagram (narrative, analytical), photograph, infographic, other	

2.3. Analytical scheme

Based on the 'framing elements', we developed a scheme for analysing the visualisations. In social science, this is referred to as 'coding': applying a structured analytical classification/labelling scheme, assigning one or more labels to specific sections of text or visualisations (Saldana 2015). A 'code' then reflects as set of these labels (numbers or letters). (See Online Supplementary 3 for an example of coding of an adaptation and an impacts visual). The 'codebook' (coding scheme plus instructions on what label to assign when) for this study was developed using an iterative approach, which facilitated an explorative code scheme development, tailoring it to the specific challenges of analysing the framing within visualisations in the IPCC reports. First, a round of inductive, bottom-up coding was performed on the visuals in TAR WG II and TAR Synthesis Report and resultant first impressions of framing and potential coding categories applicable to visualisations were compared to approaches in the literature on framing of climate change and other environmental issues (Matthes & Kohring 2008; De Boer et al. 2010; Runhaar et al. 2015). A draft set of coding categories with codes was then tested in a pilot study conducted on national science reports on climate change impacts and adaptation. Based on the pilot study we developed a draft coding scheme for the IPCC analysis. Subsequently, the authors tested the draft scheme on a random sample of 15 visuals from the IPCC WG II ARs. Coding differences were discussed and resolved, and the codebook was validated and further refined using intercoder reliability tests on a random sample of visuals from the IPCC WG II ARs (N=70; 10% of the total number of visuals) (See Supplementary Material 1 for the complete codebook). In the analytical scheme (see Table 1) we employed coding categories for the framing elements detailed in Section 2.2 (conceptual, stylistic, ideologic, content as well as metadata). The Cohen's κ scores show 'substantial' agreement for type of visualisation (%=0.73, κ=0.69), spatial scale (%=0.79, κ=0.71), goal orientation (%=0.86, κ=0.72), conceptual focus (%=0.89, κ=0.74), framing impacts-adaptation (%=0.84, κ=0.75) and 'almost perfect agreement' for temporal focus (%=0.87, κ=0.83) and highlighted theme/aspect of climate change (%=0.94, κ=0.93). The scores were above accepted standards for intercoder reliability (Landis & Koch 1977).

2.4. Data collection

We assess all visuals, across all five ARs from WG II (and III in the case of FAR). This covered all sections, including front pages, SPMs, Technical Summaries, cross-chapter boxes or case studies, and main texts. The focus on the ARs, rather than all reports, was chosen because the ARs deal with the full breadth of the IPCC work, are widely disseminated and oriented towards the policymaking process.

Reports included are: First AR (FAR) WG II and WG III (N=72) (FAR has a different WG-structure compared to later Reports) (1990), Second AR (SAR) WG II (N=127) (1995), Third AR (TAR) WG II (N=121) (2001), AR4 WG II (N=138) (2007), AR5 WG II (part A & B) (N=244) (2014) (IPCC 1990, 1991, 1995, 2001, 2007, 2014a, b). Given that after FAR reporting on impacts and adaptation has become the clear domain of WG II – we will refer to the reports and visuals listed above simply as WG II reports and visuals. All visuals from the pdf files of the ARs were registered in an Excel database and copied (including captions to ensure comprehensibility) to Word documents. We included all figures, plus front-page photos and other elements containing graphics that communicated a substantial part of the information. This included several tables with embedded graphics, such as bar charts and infographics. It excluded non-content graphics such as logos, signatures, dedication photos, design-related graphics, and elements with graphics that only served to highlight (e.g. with colour codes) the textual information already provided in that element. This resulted in a total of 702 visuals: 25.9% maps, 21.1% line graphs, 10.0% bar charts, 9.3% narrative diagrams, 6.8% analytical diagrams, 6.3%

infographics, 4.3% scatter plots, 1.9% box plots, 1.4% pie charts, 1.3% photographs, and 11.8% 'other' visuals.

The coding of the 702 visuals was performed manually by the two authors in the Excel database, each coding half of each report's visuals. In cases of indecision, both coders examined the visual to arrive at a code. Visuals were cross-checked for repetitions (e.g. main report text and SPM) to ensure consistency. Partial repetitions (e.g. partially reused or compound visuals) were coded separately. The data was imported into SPSS for statistical analysis. Descriptive statistics were generated and non-parametric tests to assess differences across years and between impacts and adaptation visuals were performed (See Supplementary Material 2 for details on the descriptive statistics).

3. Results

3.1 Contents of the visuals

The IPCC WG II visuals (N=702) portrayed a range of themes of climate change. Most of them (72.8%) focused on one specific theme. Visuals showing physical climate data (e.g. temperature) were most common (12.5%), followed by freshwater issues (8.4%), terrestrial ecosystems (8.3%), greenhouse gases (7.4%), energy (6.4%) and coastal issues (6.3%). Little attention was devoted explicitly to non-food agriculture and forestry, wildfires, extractive food production, and infrastructure (see Figure 1a). Many WG II visuals focused on natural systems (44.6%); fewer on human systems (20.8%)[i]. Visualisations of climate change impacts (N=438), covered 13 themes; amongst these the predominant themes were: climate (18.3%), freshwater issues (rivers/lakes/floods/droughts) (10.5%), and terrestrial ecosystems (9.8%). 76.1% of adaptation visuals (N=46) did not focus on a clear theme or aspect of climate change (such visuals for example covered potential theoretical decision-pathways or processes, risk management frameworks or adaptation trade-offs and synergies). Those adaptation visuals that had a clear theme only covered six themes (infrastructure; human health; livelihoods and economics; coastal erosion and sea level effects; and rivers, lakes, floods and droughts) (see Figure 1a).

Given the WG II's remit (impacts, vulnerability and adaptation), we were surprised to find that in fact much more weight was placed on problem reporting impacts visualisations (N=438, 62.4%) compared to solution focused, adaptation visuals (N=46, 6.5%). Interestingly, 31.1% of WG II visuals (N=218) did not clearly depict either one or the other but explained e.g. general concepts such as sub-regional classifications or stakeholder participation, but also detailing climate indices or physical climate science findings. Changes over the years in terms of whether they clearly depicted impacts, adaptation or something in this 'other' category were significant (χ^2 (8, N=702) =145.76, p<0.001, ϕ_c=.322), with increasingly more visuals depicting either impacts or adaptation. In 1990, visuals were 0.0% adaptation, 43.1% impacts. In 2014, they were 11.9% adaptation and 70.9% impacts. Whilst we see a rise in adaptation visuals across the years, impacts visuals clearly dominate (see Figure 1b). Given this imbalance between visuals on impacts and adaptation, we will analyse the differences between these two categories in more detail when we look at the conceptual focus, the goal orientation as well as the spatial and temporal scale.

[i] Assuming: Natural: Glaciers, snow, ice permafrost; Rivers, lakes, floods and droughts; coastal erosion, sea level effects; marine and terrestrial ecosystems; climate. Human: managed and extractive food production; livelihoods and economics; human health; energy; infrastructure. Not applicable: GHGs, carbon management and 'none of the above'.

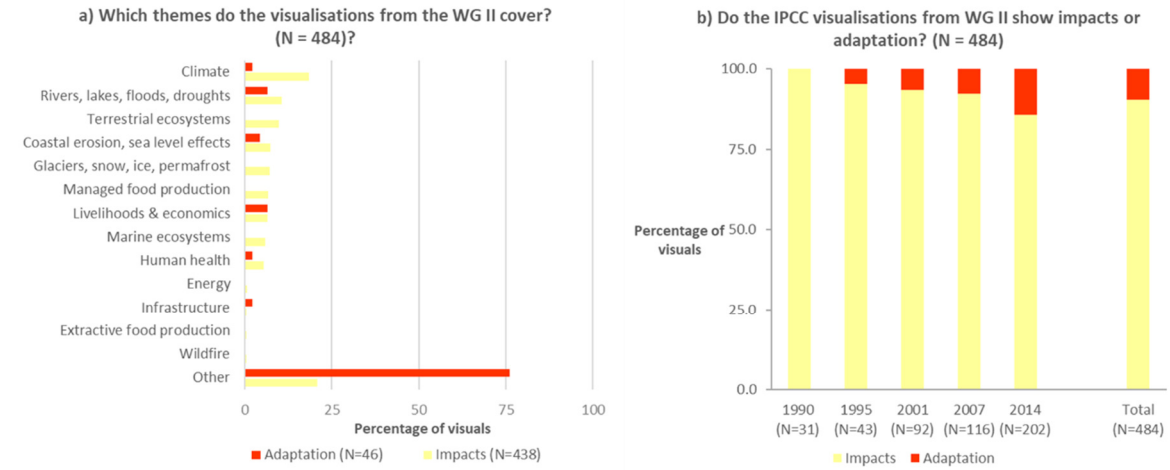

Figure 1. Framing and themes of IPCC visuals and themes covered: panel a) Themes covered by IPCC WG II impacts and adaptation visuals. The figure shows the percentage coverage (relative to the total number of visuals within each the impacts and adaptation groupings) of each theme. The distribution clearly shows that adaptation visuals cover less themes than impacts visuals. Panel b) Do IPCC WG II visuals show impacts or adaptation? Of the 484 visuals that portray either impacts or adaptation, the vast majority of images focuses on impacts. Note: 218 visuals (31.1% of the total 702 visuals) did not portray either impacts or adaptation and are thus not included in this figure.

3.2 Conceptualising impacts and adaptation visuals

We assessed how climate change was conceptualised using four variables: conceptual focus, goal orientation, spatial scale, and temporal focus (see Figure 2).

Most visuals from WG II (N=702) had a narrow (71.8%), rather than broad (28.2%) conceptual focus. Impacts visuals (N=438) showed very similar percentages: 71.0% broad, 29.0% narrow. In contrast, adaptation visuals (N=46) were mostly broad (80.4%) instead of narrow (19.6%). We found a significant association between conceptual focus and report years ($\chi^2(4, N=702) = 59.79$, $p<0.001$, $\phi_c=.292$). Most visuals were narrow across all years (1990: 88.9%, 1995: 92.1%, 2001: 73.6%, 2007: 65.9%, 2014: 58.6%). However, broad visualisations increased from 11.1% in 1990 to 41.6% in 2014. In part, this could be due to an increase in compound figures and figures showing multiple themes of climate impacts in one figure, which have become more common since AR4.

Furthermore, IPCC WG II visuals (N=702) show a predominantly prevention-oriented framing (62.8%), with minimal focus (4.4%) on promotion and many visuals not showing either (32.8%). Among those figures with a clear goal orientation (N=472), prevention-framing prevailed (1990: 100%, 1995: 79.7%, 2001: 96.1%, 2007: 98.2% , 2014: 92.5%) (see Figure 2).

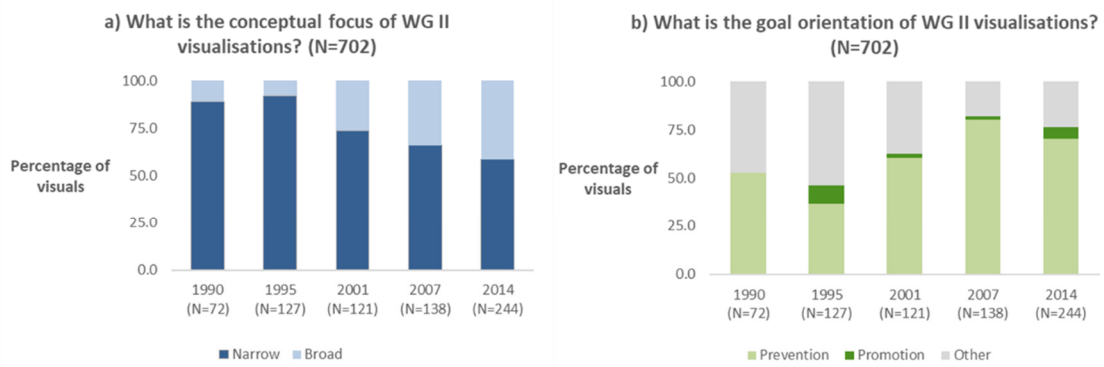

Figure 2. Changes in conceptual framing in the IPCC visuals. For each report year, the panels show: (a) conceptual focus (narrow or broad), and (b) goal orientation (prevention or promotion).

Impacts visuals (N=438) were also mainly prevention-oriented (86.5%), none were promotion-oriented, and 13.5% did not have a clear goal orientation (see Figure 3). For adaptation visuals (N=46), the goal orientation was more promotion-oriented (37.0%) than prevention (28.3%) with 34.8% showing no clear goal. We found a significant association between the framing of visuals as impacts or adaptation and conceptual focus (χ^2(1, n=484) =46.90, p<0.001, ϕ_c=.319) and goal orientation (χ^2(2, N=484) =191.52, p<0.001, ϕ_c=.629).

To understand better how IPCC visuals frame impacts and adaptation we also need to understand whether they are portrayed as a problem or solution in the here and now, or in faraway places and distant futures (spatial and temporal scales). For both the total set of WG II visuals (N=702) and the subset of impact visuals (N=438) the spatial scale was often global (WG II = 26.5%, impacts visuals = 27.4%) or regional (WG II = 22.2%; impacts visuals = 29.5%) (see Figure 3). National and local scales received less attention. The temporal scales of focus were relatively evenly spread, particularly for impact visuals. The largest proportion of impacts visuals (20.3%) focused on the long term (up to 2100). Looking at trends across all WG II visuals, we note that visuals with multiple timescales increased strongly in AR5 to 21.3%. Few visuals focused on the distant past (millennia), distant future (past 2100), and near term (2030). Adaptation visuals (N=46) often lacked both a clear spatial (predominantly topical 71.7%) and temporal scale (predominantly no scale 78.3%, e.g. showing analytical processes) (see Figure 3). Both the temporal (χ^2(8, n=484) =59.28, p<0.001, ϕ_c=.350) and spatial (χ^2(5, n=484) =53.50, p<0.001, ϕ_c=.332) scale were significantly associated with the impacts/ adaptation framing.

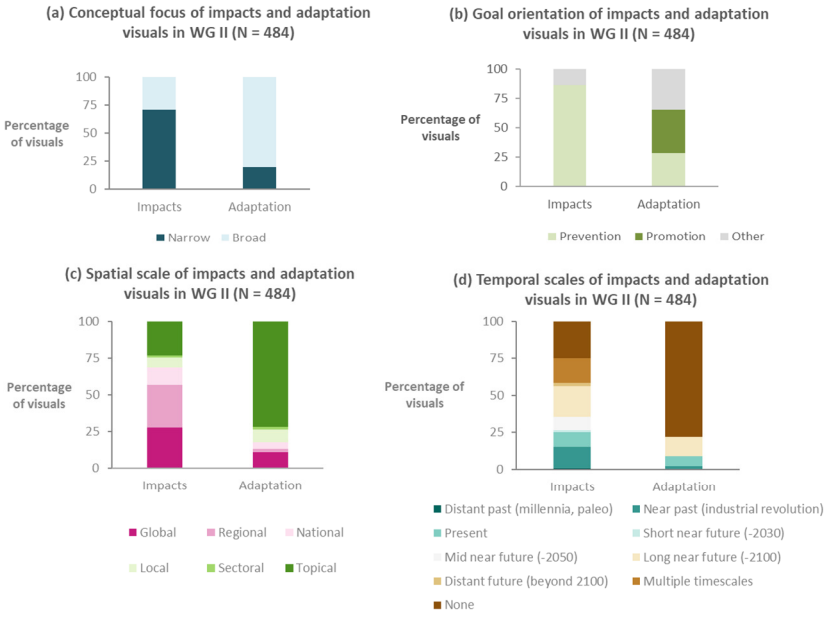

Figure 3. Impacts vs. adaptation framing in the IPCC WG II visuals. The panels show the differences in visual framing between impacts visuals and adaptation visuals, with regard to the: (a) conceptual focus, (b) goal orientation, (c) spatial scale, and (d) temporal scale that is used in the visuals.

Given the above finding that the physical climate science theme is the most common one covered by WG II visuals, it is unsurprising that the timescale at which we expect to see a clearer climate signal is the most common one. Yet, both the spatial and temporal framing of the visuals is noteworthy, as the scales less well-covered (national and local, and near term) would be highly relevant for policymakers. Whilst the lack of a focus on local and national spatial scales may be unsurprising given the international focus of the IPCC, it is yet noteworthy, as the definition of specific actions and

responsibilities is likely to be more challenging at a global scale and many policy-makers are likely to have a more spatially defined focus.

3.3 Moral framing

IPCC WG II visuals focused predominantly on portraying the type of impact and possible actions (impacts/ adaptation – what). Of the impacts visuals, 83.8% were looking at the type of impact ('what') and 16.2% on who was going to be affected ('who'). Similarly, of the adaptation visuals, 71.2% were detailing possible actions ('what') and only 28.8% portrayed who needed to act and/or adopt responsibility ('who'). We did not find a significant association between moral framing and report years ($\chi^2(12, N=484) = 17.62$, $p=.128$, $\phi_c=.110$). Yet, the weighting in favour of detailing the physicality of the impacts and the possible actions instead of focusing more on those affected or needing to act is a consistent observation over the years (see Figure 4). Considering the IPCC's mission and position in its communication strategy (IPCC 2016), avoiding moral framing is not unexpected. However, providing more detail on who is affected and should be taking action, could be relevant in helping decision-makers identify those most vulnerable, helping to draw attention to questions of accountability as well as assigning responsibilities more clearly.

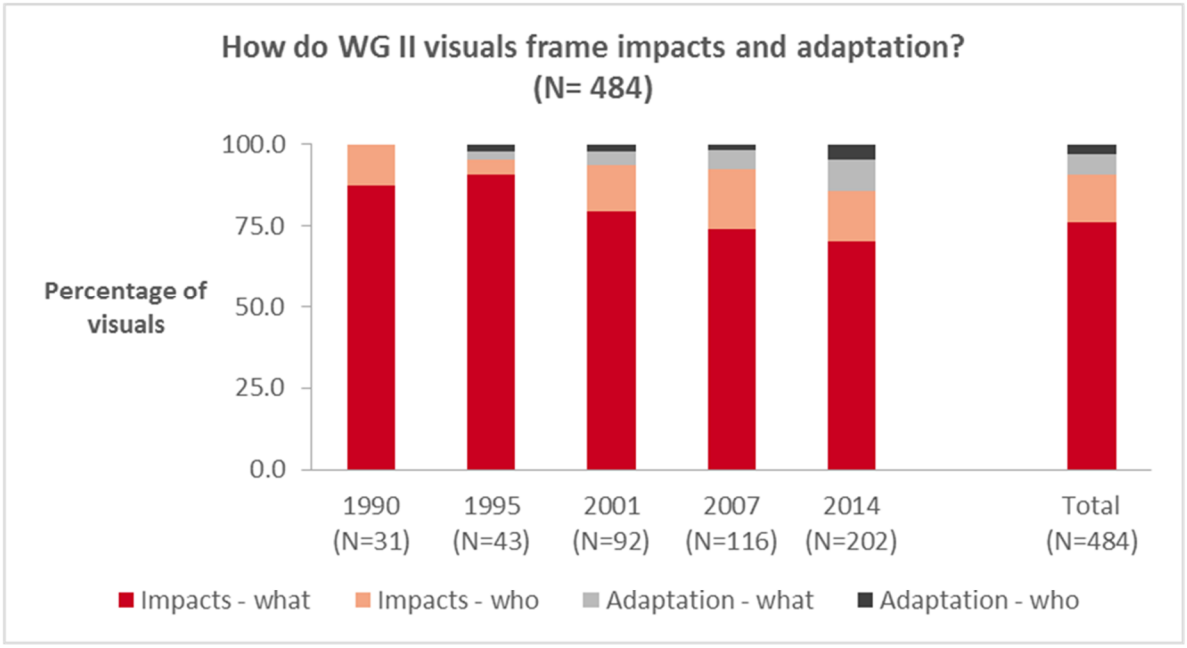

Figure 4. Do visuals from the IPCC WG II address questions of morality and responsibility? For each report year individually and for all WG II visuals overall, an imbalance is highlighted, showing that within both groupings of impacts visuals and adaptation visuals, the larger percentage of visuals focus on the physicality/ type of impact and possible actions (impacts/ adaptation – what), instead on those affected or possible actors (impacts/adaptation – who).

3.4 Framing of the visuals in the SPMs

Given the much wider audience of the SPMs compared to the ARs, we have also included a brief discussion of the SPM visuals. Only very few visuals are included in the SPMs over the years, with AR5 marking a distinct increase to previous report years (FAR: N=2; SAR: N=6, TAR: N=3; AR4: N=2; AR5: N=11). For an overview of the framing elements in the SPMs see Supplementary Material 4. As SPMs

are the sections of the reports that are most widely read and used by decision- and policymakers, it ought to be noted that we can see very similar trends as those observed for the complete reports highlighted in the sections above. Impacts visuals and those that focus on the 'what' rather than the 'who' dominate. We also find that most visuals show a narrow, prevention focused framing, with little attention given to present or short-term decision-making timescales. AR5-SPM however has many broad visuals. As the limited number of visuals included in the SPMs would suggest a higher degree of inclusion selectivity, it would seem as if this distant-in-time, narrow and prevention focused image of impacts and adaptation is not just the one communicated to the scientific audience that may read the entire reports, but also the one communicated to the more policy-facing audience.

4. Implications

We presented a quantitative framing analysis of the visualisations in the IPCC ARs that focus on impacts & adaptation (generally WG II). Framing is often subconscious, but is an important uncertainty in research, science communication, and climate policymaking (Matthes & Kohring 2008; De Boer et al. 2010; Runhaar et al. 2015). Our study is the first to assess this framing in a quantitative way for the entire body of visuals in the WG II ARs, exploring general features and trends over time, rather than earlier studies that analysed specific figures in a qualitative way (O'Neill 2013, Rebich-Hesphana & Rice 2016, Wozniak et al. 2017). Our results have important implications for climate change communication and visualisation in the IPCC and in general.

First, IPCC visuals framed climate change predominantly from a prevention-oriented (rather than promotion-oriented) perspective, with a narrow conceptual focus. They emphasised the global and regional scales, and the near past, present and long term (up to 2100), rather than more localised (national, local) and near-term perspectives. However, a trend was observed away from the single issue, narrow framing towards a broader framing of climate change, such as visuals that present multiple types of impacts utilising increasingly compound visuals.

Second, very few IPCC visuals focused on adaptation: only 6.5%. Moreover, unlike impacts visuals, adaptation visuals were broader and often had an unclear theme, spatial and temporal scale. They thus appear much 'fuzzier' than impacts visuals. Many visuals also focused on causal information, such as basic climate information – leading to and indirectly indicating impacts. IPCC visuals framed climate change primarily in terms of what the impacts and adaptations are, rather than who is impacted and is (or should be) adapting.

Consequently, IPCC visuals focused –and still focus– predominantly on presenting the message that climate change is really happening, is a threat, and will have various specific impacts. A slight shift was observed from framing climate change with a narrow focus (single topic; science emphasis) towards a broader focus (multiple topics in a single visual; relating to societal implications). Contrary to our expectations, there was only a small shift from problem-oriented towards solution-oriented framing: adaptation visuals did increase, but to only 12% in AR5, and promotion-oriented visuals varied between 0-9% for all ARs with no discernible trend. Consequently, adaptation and promotion-oriented visuals remained a stark minority compared to impacts visuals (62.4%) and prevention-oriented visuals (62.8%). Furthermore, there was no shift from 'what' (are the impacts/adaptations) to 'who' (is impacted, should adapt). Even in 2014 in AR5, 84% of impact visuals and 67% of adaptation visuals

remained what-framed, shying away from clearly communicating who is affected and who needs to act.

Applying framing analysis to scientific material and visualisations is new, and the method experimental. One limitation of the current application, is that it is a remote study, conducted at the level of the visual. This is necessary to conduct a large-scale quantitative analysis (many visuals, years, and framing elements). However, it means that the information on the design and production (in climate science and IPCC processes) and the reception (perception/impact among e.g. policymakers) of the visuals is not studied (cf. O'Neill & Smith 2014). For instance, for the production phase, the method shows the patterns of framing, but not the reasons behind them. Observed framing could be due to the way in which the IPCC teams perceive or want to highlight policy-relevant aspects of their topic, but they might also reflect patterns in the scientific evidence base that is assessed (e.g. lack of visuals in scientific research on adaptation), strategic choices and emphasis in the scope of the WG II reports (e.g. early stage decisions on the outline as negotiated with governments), or difficulties in visualising adaptation information (e.g. many social processes and governance aspects might be easier to describe textually, or adaptation visuals might be too locally oriented for the IPCC, or it might be difficult to make concrete). For the reception stage, little research exists on how such visuals and the framing elements in this study shape perception and might impact decision-making. A different selection of framing elements could impact the results, and more information on what elements are key in shaping the reception of visuals would facilitate a better selection. For the conceptual framing elements that took prominence in this study, there is some psychological basis showing that the elements included are important in adaptation decision-making (De Boer et al. 2010). For many content, moral, and stylistic elements this is less evident. The framing elements and their codes may also be sensitive to how they are aggregated. For example, we decided to split De Boer (2010)'s proximal/distal conceptual element into several framing elements (time scale, spatial scale, focus), because early analysis during the pilot project suggested that the visuals might score very differently on these and because they might have different relevance to policymakers in the context of the IPCC. Similarly, 'theme' includes various small (e.g. wildfire) or larger aggregated (e.g. rivers, lakes, floods, droughts) topics; different aggregation might impact the results. In applying these methods, ideally the selection of framing elements should be based on theory and applicability to the research material and questions. 'Codability' can also differ per application. In our pilot project, for example, we included '(perceptual) distance'; whether visuals were close to the life-reality of policymakers reading it. This was well-codable for national climate assessments, but poorly for IPCC reports with their diverse audiences. Similarly, coding stylistic elements was difficult for the IPCC. A qualitative spin-off study on environmental assessments, however suggested that stylistic elements can be important for the reception of visuals (Van Beek et al 2019). Further 'ground-truthing' of these aspects and experimentation with different framing elements would be highly valuable to further develop science framing methods.

More careful attention to visual framing is not merely a luxury. Framing has large implications for societal decision-making on climate change: it impacts the interpretation, perceived relevance, and uptake of climate knowledge by different societal groups, and the way climate policy and governance is shaped (Nisbet 2009; De Boer et al. 2010). For instance, there is a wealth of literature on positive versus negative framing (e.g. Wardekker 2004; De Boer et al. 2010; Spence & Pidgeon 2010; Moser & Dilling 2011). Negative framing (e.g. due to heavy overall focus on impacts and/or prevention-orientation) grabs attention and may be useful for relatively simple risks. However, it can reduce the

perceived credibility of the source, and can easily lead to paralysis, apathy and denial when people cannot see straightforward ways to reduce risks. Positive framing is more motivating and stimulates action in more complex situations. For the climate research community in general, this is relevant for reasons of science communication, but also for improving societal relevance in the co-production of climate knowledge (e.g. Bremer & Meisch 2017) and tailored climate information and climate services (e.g. Vaughan & Dessai 2014). For the IPCC specifically, given the strongly prevention-oriented framing in its visuals, this suggests a risk of locking policy debate in continuously agreeing that climate change is a problem, while failing to motivate and inspire solutions.

The IPCC process is far from straightforward (IAC 2010; Stocker & Plattner 2016), takes place in a highly politicised arena and with numerous demands on what should be included in the texts and how this should be done, with individual authors having limited influence on the final publication. This does not stimulate deliberate and careful visual framing. However, there are many opportunities for this. Firstly, the IPCC's writing teams could benefit from increased interaction with psychologists and visualisation and communication specialists (cf. Harold et al. 2016). Secondly, the AR structure does not preclude a more even visual attention to impacts and adaptation. The chapters on global and sectoral aspects might naturally want to highlight how climate change impacts specific topics but could also visualise examples of adaptation options. The regional chapters offer even more opportunity, visually highlighting local adaptation examples and progress made with adaptation (cf. Ford et al. 2015). Thirdly, the summaries, particularly the SPMs, offer ample opportunity to pay explicit attention to visual framing. Like the 'Headline Statements' (Stocker & Plattner 2016), SPM visuals should be carefully designed (involving the core writing team, psychological and visual experts), in a well-planned process, in the early draft stage of the text. Finally, our pilot study on national climate assessments suggested substantial differences in visual framing between national agencies. Compared to the IPCC reports, some national assessment agencies use much more promotion-oriented visuals. Thus, the IPCC might draw inspiration from examining visualisations by national assessment agencies.

The problem-oriented visual framing could be due to the IPCC's scientific focus and desire to refrain from prescriptive communication, or to a perceived need to communicate that climate change is a real problem. More research is required to investigate the reasons. Nonetheless, we suggest that careful attention to visual framing, including a better balance between highlighting problems and solutions, in the IPCC process and the climate knowledge community would be beneficial. A challenge also remains to find better ways to visualise adaptation. IPCC materials are often used by national scientific advisors, the media and others, who may currently lack good solution-oriented visualisations. A better balance between impacts and adaptation (and prevention and promotion framing in) visuals is important, also in view of developing the IPCC AR6, due 2021. Promotion-oriented framing provides a more engaging, motivating narrative than prevention-oriented framing. Adaptation is also becoming increasingly important in UNFCCC discussions and efforts to track adaptation progress globally are underway (e.g. Ford et al 2015). However, adaptation is also 'messy', involving both locally specific and conceptual aspects. The outline for AR6 WG II (IPCC 2017) highlights topics such as: significance and limits to adaptation, enabling conditions, interactions with sustainability, and 'climate resilient' development pathways. These are challenging, somewhat vague concepts. A directed visual strategy, with attention to framing, can help make those complex issues both imaginable and engaging.

Online Supplementary material

Supplementary Material 1: Codebook

Supplementary Material 2: Descriptive statistics

Supplementary Material 3: Coding example

Supplementary Material 4: Analysis of SPM visuals only

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