Delft University of Technology

Document Version
Final published version

Licence
CC BY

Citation (APA)
Gusheva, E., Lilliestam, J., Bock, F., Bold, F., Weko, S., Wu, F., & Pfenninger-Lee, S. (2026). Content analysis of IPCC Summaries for Policymakers 2001-2022: No shift towards policy solutions. *npj Climate Action*, 1-25. https://doi.org/10.1038/s44168-026-00391-1

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
In case the licence states “Dutch Copyright Act (Article 25fa)”, this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.

https://doi.org/10.1038/s44168-026-00391-1

Content analysis of IPCC Summaries for Policymakers 2001-2022: no shift towards policy solutions

Check for updates

E. Gusheva[1] ✉, J. Lilliestam[2], F. Bock[1], F. Bold[2], S. Weko[2], F. Wu[1] & S. Pfenninger-Lee[1]

The Intergovernmental Panel on Climate Change (IPCC) regularly publishes summaries for policymakers (SPMs) following the principle of policy-neutrality. As the urgency of climate change grows, there have been calls for IPCC assessments to be more solution-oriented, which means to assess policy instruments. Yet, there is a scholarly debate regarding whether and how it is possible to discuss policy instruments while staying policy-neutral. To inform this debate we conduct a content analysis of Working Group III SPMs on mitigation published in the last two decades. We find that the SPMs contain limited content on policy instruments with little change over time. This suggests that the SPMs have not yet become more solution-oriented while abiding by their policy-neutrality principle. On the other hand, we show that SPMs have shifted from emphasizing the cost-effectiveness of mitigation towards emphasizing projections of required emissions reductions. Thus, SPM content development is consistent with the evolution of ideas in global climate negotiations. Regardless of whether it chooses to amend its policy-neutrality principle, we recommend that the IPCC still strive to be more solution-oriented. For example, the IPCC could better support the growing ecosystem of national and local boundary organizations which can broker context-specific knowledge on policy instruments.

Human-induced climate change is accelerating with looming threats to human wellbeing[1]. This increase in urgency is met with calls for climate action to take place at record speed. Intergovernmental Panel on Climate Change (IPCC) assessments have an important role to play in accelerating climate change mitigation by providing timely scientific input to policy-making. The IPCC has a long history of providing scientific knowledge to policymakers via its assessment reports (ARs), starting from the very first assessment cycle in 1990. All ARs contain summaries for policymakers (SPMs) that emphasize high-level findings. Because of its status as a global boundary organization[2,3], fostering knowledge exchange between scientists and policymakers, IPCC assessments have unmatched legitimacy[4] impacting both science[5] and policymaking[6], especially through its SPMs.

Common to all global environmental assessments, the SPMs serve multiple audiences and can inform policymaking on international, national and local levels[7]. On an international level, statements from the SPM are quoted in international negotiations within the Conferences of the Parties (COPs)[8–10] supporting global treaties like the Paris Agreement[11]. While the SPMs are the most widely used IPCC documents to guide policy development, they are often rewritten as locally-relevant summaries instead of being cited directly, especially for local policymaking[12].

Despite its function in the science-policy interface, many scholars highlight challenges for the IPCC to be policy-relevant[13–15]. The challenge lies in the difficulty of providing useful knowledge for policymaking, in the form of discussing specific policy instruments, without crossing the line into policy-prescription. While some suggest that the IPCC ought to re-consider its policy-neutrality principle[16,17], others are strongly in favour of maintaining its policy-neutrality principle stating that it is possible to both discuss specific policy instruments and remain policy-neutral[18,19]. Thus, there is a scholarly debate regarding whether the IPCC ought to reform its policy-neutrality principle to remain policy-relevant, i.e. to discuss more specific policy instruments. Still, the ability of IPCC SPMs to discuss specific policy instruments may be limited not only because of the policy-neutrality principle, but also due to the SPMs' statement-by-statement approval process, which naturally favors the least context-specific wording.

Existing empirical research on the IPCC and its SPMs does not relate to the scholarly debate on IPCC's neutrality principle nor its intended shift to solutions. Specifically, past studies on the content of IPCC assessments focus on investigating the epistemic diversity of the ARs[20–22], finding gaps in the representation of scientific fields and disciplines. Further, a content analysis of the framing of the SPMs suggests that IPCC assessments may miss and

[1]Technology, Policy & Management faculty, Delft University of Technology, Delft, The Netherlands. [2]Sustainability Transition Policy, School of Business, Economics and Society, Friedrich Alexander University Erlangen-Nuremberg, Nuremberg, Germany. ✉e-mail: e.gusheva@tudelft.nl

underrepresent the worldviews of some of the poorest and most vulnerable people to climate change[23]. Similarly, linguistic analyses question the readability of the SPMs[24,25]. In light of this research gap, we ask "Has the content of the SPMs become more solution-oriented over time?" In line with the IPCC chair's explicit statements about wanting to move towards solutions[26], we expect that content on solutions has become more prominent in the SPMs over time. While interpretations of 'solution-oriented' may diverge, we define 'solution oriented' as knowledge on policy instruments, based on Kowarsch et al.[27] who analyzed 131 comments submitted by governments, authors and organizations in an IPCC review process following AR5. Their research found that a significant majority (80%) demanded that the IPCC be more solution-oriented with emphasis on "policies in particular (for example, regulatory measures or market-based instruments)".

Here we present a content analysis of IPCC Working Group 3 SPMs from 2001 to 2022, tasked with assessing the science on mitigating climate change. Our results map out the kinds of knowledge covered in the SPMs and how it has evolved over time. Our research has a knowledge perspective[28], building an understanding of the kinds of knowledge that can be found in global scientific assessments and an empirical understanding of the topics found in climate change mitigation assessments. Such an empirical investigation of the content of the SPMs can show whether there have been any changes in SPM content as a result of the many calls for change by the research community and the IPCC chair's explicit intent to shift to solutions.

This study makes two primary contributions. First, our results provide an empirical assessment of whether IPCC SPMs content has become more focused on policy instruments in response to calls for IPCC assessments to become more solution-oriented. Second, we demonstrate how ideas in the SPMs have co-evolved with global climate change politics, revealing how far the SPMs have tracked developments in international negotiations and the escalating urgency of climate change. Based on this, we discuss whether and how the SPMs can shift to solutions while remaining policy-neutral.

Scholarly debate on IPCC policy-neutrality

IPCC assessments are the most well-established example of scientific global environmental assessments[29]. Their task is to conduct a comprehensive assessment of policy-relevant science on climate change[30]. With reform suggestions dating back to the very first assessment cycle[31,32], the IPCC has continuously been working to improve its processes and products to, among other things, maintain and improve the policy-relevance of its work.

Policy-relevant scientific assessments provide knowledge that is useful for policymaking. The establishment of policy-relevance, however, is contextual and relational[33]. Two ways in which IPCC assessments ensure the policy-relevance of their work is via their scoping and approval processes. During both these processes, scientists conducting the assessment interact with policymakers with the intention of ensuring the policy-relevance of their work. For example, during the scoping process, the outline of the ARs is shaped both by IPCC scientists and member country government representatives[34]. Similarly, IPCC scientists and member country representatives participate in a formal statement-by-statement negotiation and approval process of the SPMs[34] where the policy-relevance of text can also be subject to negotiation. Thus, the SPMs particularly embody policy-relevant knowledge in IPCC assessments[35].

Still, scholars express concern regarding the policy-relevance of IPCC assessments, arguing that the IPCC's modus operandi is ill-suited to the knowledge needs of national and local policymakers who are spearheading climate change mitigation[13,14,36,37]. This may be because most of these national and local policymakers are not included in the above-mentioned scoping and approval processes. In light of their exclusion, there have been recent calls to transition toward a more solution-oriented assessment[16,26,27,38], i.e. an assessment that entails more content on policies like regulatory mechanisms and market-based instruments[27]. While, prior to the sixth assessment cycle, the term 'solution-oriented' was not used[15,39], the obstacles for policymakers to use knowledge provided in IPCC assessments is not new, nor is the idea that the assessments should do a better job at informing on specific policy options.

When discussing specific policy instruments, the IPCC has a principle against policy-prescriptiveness and for policy-neutrality, historically linked to the US government's efforts to limit the influence of the IPCC[3]. The policy-neutrality principle means that IPCC assessments should not recommend specific policy instruments for mitigation. On the other hand, the opposite concept, policy-prescription, implies that they should.

There is a scholarly debate regarding whether IPCC assessments should abandon or maintain the policy-neutrality principle. Proponents for maintaining the policy-neutrality principle[18,19,26,27,38,40,41] reason that the credibility and legitimacy established by this principle is imperative for the IPCC[41]. They suggest that IPCC assessments can and do discuss specific policies in a relative manner by mapping policy instruments to projected outcomes[18,19]. Thus, IPCC assessments ought to map out the solutions space for climate change mitigation, without influencing the decision of how to navigate that solution space as that is the responsibility of policymakers.

Proponents for abandoning the policy-neutrality principle[16,17,42–45] reason that scientific knowledge is value-laden since it it is the product of human choices and it is normative because it frames both the problem and the policy solutions discussed even when it strives for scientific objectivity[46–51]. Yet scientific knowledge is seldom reflexive of the values it embeds, making policy-neutrality an unachievable ideal. Discussing detailed policy instruments is very context-dependent and difficult to do on a global level, leaving IPCC assessments with only one choice - to focus on decontextualized mitigation strategies, such as global carbon pricing[45]. In turn, these proponents suggest that moving toward policy-prescription can help make IPCC assessments more actionable when the assessments can freely recommend detailed policy measures.

Both proponents for and against abandoning the policy-neutrality pricinple, however, tend to agree on two issues. First, they agree that IPCC assessments should be more transparent and reflexive about the values embedded (and omitted) in the knowledge they synthesize[16,19]. Second, they agree on the need for more inclusivity in terms of epistemic diversity of the literature considered in the assessments and working with stakeholders outside the organization so as to ensure many voices get heard[40,42].

Rooted in this debate, scholars present diverging outlooks for the future of IPCC assessments. For example, the pathways "Moderate path"[40] and "Diversifying viewpoints"[14], the perspective "Consensus-building"[43] and the reform agendas "Back to basics" and "Enhanced dialogue"[13] all highlight the importance of maintaining policy-neutrality. While outlooks like the perspective "Critical debate"[43], the pathways "Radical path"[40] and "Advocating for change"[14] and the reform agendas "Polycentric knowledge production" and "Action-oriented IPCC"[13] mention the need to re-consider the policy-neutrality principle.

To summarize, IPCC assessments are policy-neutral and non-prescriptive in terms of policy action, but at the same time there are intensifying calls for them to transition to solutions, which means for them to discuss more specific policy instruments to better support the transition to climate neutrality in the coming decades. The debate points to a disagreement about the extent to which it is possible to discuss specific policy instruments while upholding the policy-neutrality principle. To inform this debate, we present an empirical investigation of knowledge on policy instruments in the SPMs and how that has changed over time. It sheds light on whether, as some suggest possible, SPMs, as products of IPCC assessments, have historically become more solution-oriented while remaining policy-neutral.

Results

Practical knowledge is sparse with no change over time

SPM content reflects three types of knowledge: argumentative knowledge to *justify* policy (red in Fig. 1), strategic knowledge to *guide* policy (yellow in Fig. 1), and practical knowledge to *develop* policy (blue in Fig. 1). Let us take the example of decarbonizing electricity production to illustrate the difference between these three types of knowledge. First, the SPMs contain

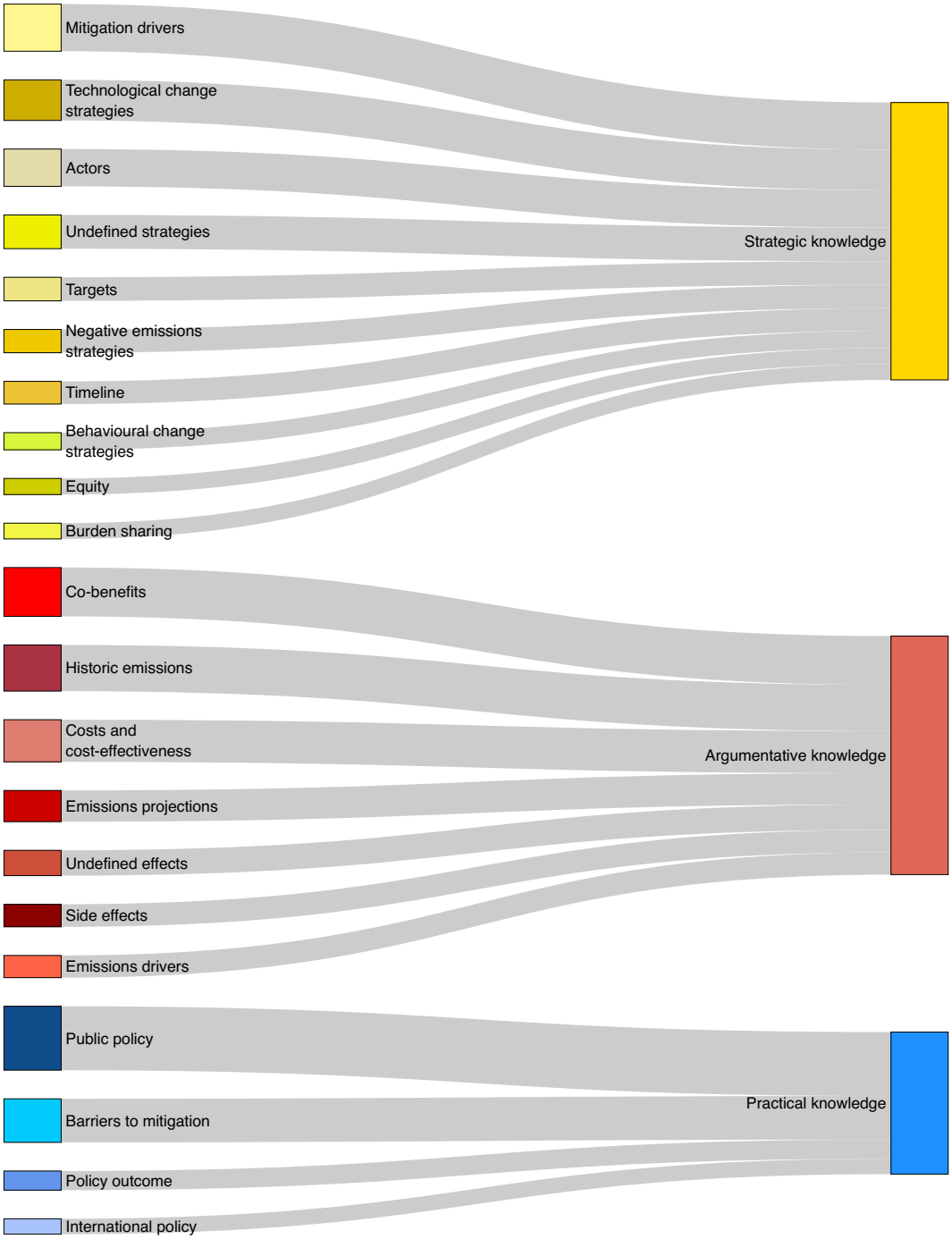


Fig. 1 | Overview of SPM content distribution. The figure shows SPM content distribution (share of statements) across topics and themes. Topics (left) are shown alongside the themes (right) they are classified in. Topics of the same theme are shown with a similar color as their parent theme. The box size corresponds to average prevalence per SPM (see Table S3 for the results in tabular format).

statements that stress the benefits of reducing air pollution when switching to electricity from renewables (coded as 'Co-benefits'). This is argumentative knowledge because it can be used to advocate for policies but does not guide their development or implementation. Next, in the SPMs, there are statements regarding the need to switch from coal-based electricity to electricity from renewable energy sources (coded as 'Technological change strategies'). This represents strategic knowledge since it informs policy makers what needs to be done for the energy transition, but not how to stimulate it. Last, the SPMs also include statements discussing policies, such as tax credits or support schemes, to incentivize investment in renewable electricity production (coded as 'Public policy'). This is practical knowledge since the information can not only be used to steer the direction but also to directly develop policy and actually trigger the changes found to be beneficial in the first to knowledge type groups.

Practical knowledge is the least prevalent of the three knowledge types in the SPMs. This is true on average across all assessment cycles and within each cycle (Fig. 2). The sensitivity analysis shows that this remains true with alternative topic classifications (details in Note S1) which indicates that our

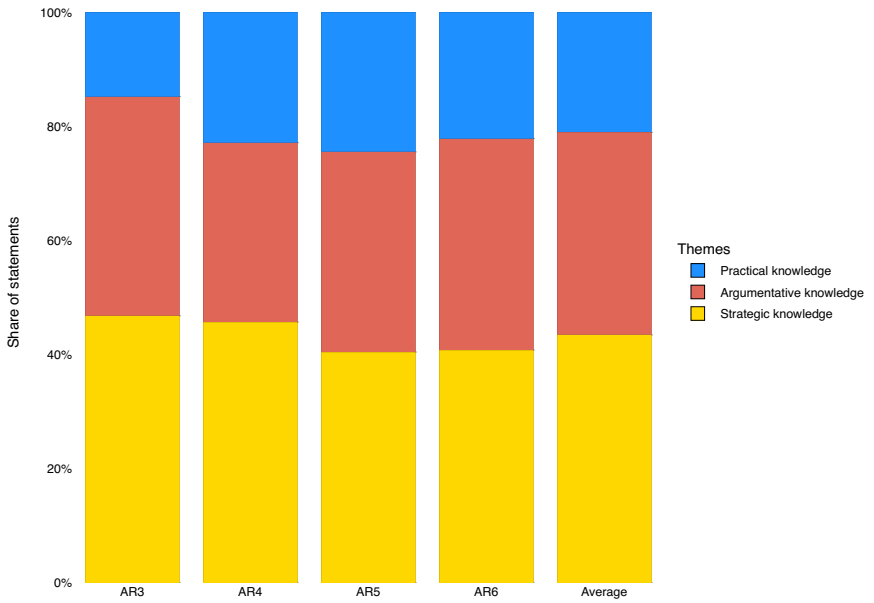


Fig. 2 | SPM content distribution across knowledgy type themes. The figure shows SPM content distribution (share of statements) across assessment cycles and per knowledge type themes: strategic knowledge (yellow), argumentative knowledge (red) and practical knowledge (blue). Argumentative knowledge covers topics that justify mitigation policy like, for example, statements on how cost-effective climate change is. Strategic knowledge covers topics that guide the direction of mitigation policy like, for example, statements that outline that shifting energy production from non-renewable to renewable energy sources enables mitigation of greenhouse gases. Practical knowledge covers topics that outline what policymakers can do for mitigation policy like, for example, statements on subsidies for renewable energy producers.

finding is robust and not sensitive to argument definitions. Thus, the majority of SPM content is of little direct practical use to develop policy-making, but rather serves as evidence to advocate for mitigation policy-making and as a general guide on its direction. While the SPMs touch upon what changes are needed to mitigate climate change, they shy away from discussing the tools needed to set those changes in motion. As an illustration, the SPMs state that certain manufacturing processes can be electrified but they do not discuss what actions managerial decision-making would need to take towards abandoning fossil-fuel manufacturing processes for carbon-neutral ones (such as electricity-based solutions).

Knowledge type distribution is strikingly consistent across assessment cycles with strategic and argumentative knowledge making up the majority of SPM content. The largest change is between AR3 and AR4 yet the relative ranking of knowledge types remains. This shows that all three knowledge types have been consistently covered in the last two decades, with strategic and argumentative knowledge being strongly dominant.

Shift from discussing cost-effectiveness to calculating past and present emissions

While the distribution of knowledge type themes is stable across assessment cycles, many specific topics exhibit large SPM-to-SPM variation. The main trend in content development is a shift from emphasis on costs and general approaches (top of Fig. 3) to calculating past emissions, future projections with and without additional mitigation (bottom of Fig. 3). These topics have the highest regression slope coefficients with a high goodness of fit (see Table S4 for specific numbers) and thus display both the clearest and the strongest changes over time.

Over time the SPMs exhibit a trend toward higher numerical precision and specificity. The top three topics with a positive change across assessment cycles are related to quantifications ('Emissions projections', 'Historic emissions', 'Targets'). Specifically, the SPMs increasingly focus on quantifying how bad climate change will get if we don't increase mitigation efforts ('Emissions projections') and calculating the amount of emissions reductions related to temperature goals ('Targets'). Not all topics concerning quantitative knowledge exhibit a positive trend (e.g. 'Cost and cost-effectiveness'), but enough do to identify a pattern. On the other hand, two of the top three topics with a negative change across assessment cycles are general and non-specific ('Undefined strategies' and 'Undefined effects'), hinting to a drop in vague statements which suggests that there is a trend toward higher specificity.

Shift from ideas associated with the Kyoto Protocol to ideas associated with the Paris Agreement

The trends of content development in the SPMs can be understood under the lens of global climate agreements. Two major international treaties took place during the period we studied (AR3-AR6): the Kyoto Protocol and the Paris Agreement. We identify topics associated with the ideas that prevailed during the time the treaties took place. The Kyoto-associated topics view mitigation as a global commons problem with tension between developing and developed countries and pays great attention to mitigation incentives. Thus, we see statements on how high-income and low-income countries differ in their capacity for carrying out mitigation ('Burden sharing') and statements on the economic costliness ('Costs and cost-effectiveness') of mitigation in the SPMs (see Fig. 4a). On the other hand, the Paris-associated topics emphasize accountability with a view toward quantifying the expected emissions without additional mitigation ('Emissions projections') and statements on a specific temperature goal ('Targets'). Note that the topic 'Targets' covers only global temperature-related targets, which are present in the Paris Agreement, and not country-specific targets, which were already a part of the Kyoto Protocol and are coded as 'Burden sharing'. To illustrate, the Kyoto-associated topics emphasize that energy efficiency measures can result in economic benefits greater than direct costs (coded as 'Costs and cost-effectiveness') while the Paris-associated topics zoom in on the estimated emissions reduction that can be achieved via energy efficiency measures (coded as 'Targets').

The evolution of ideas central to international climate change treaties is reflected in historic SPM content development (see Fig. 4b). While topics associated with both the Kyoto Protocol and Paris Agreement are present in all SPMs, we see a clear decreasing trend for the Kyoto-associated topics and an increasing trend for the Paris-associated topics, suggesting a gradual evolution of ideas over time. AR3, published after the adoption of the Kyoto Protocol, has high prevalence of Kyoto-associated topics and low prevalence of Paris-associated ideas. AR6, on the other hand, published after the adoption of the Paris Agreement, has the reverse. AR4 and AR5 are positioned in-between the two agreements and show a transitional period where ideas associated with both treaties were discussed at the same time and had similar prevalence. For example, the Copenhagen Accord, which was written in 2009, between AR4 and AR5, incorporated a global temperature target like the Paris Agreement but also, following a burden-sharing narrative like the Kyoto Protocol times, divided countries into Annex I and non-Annex I

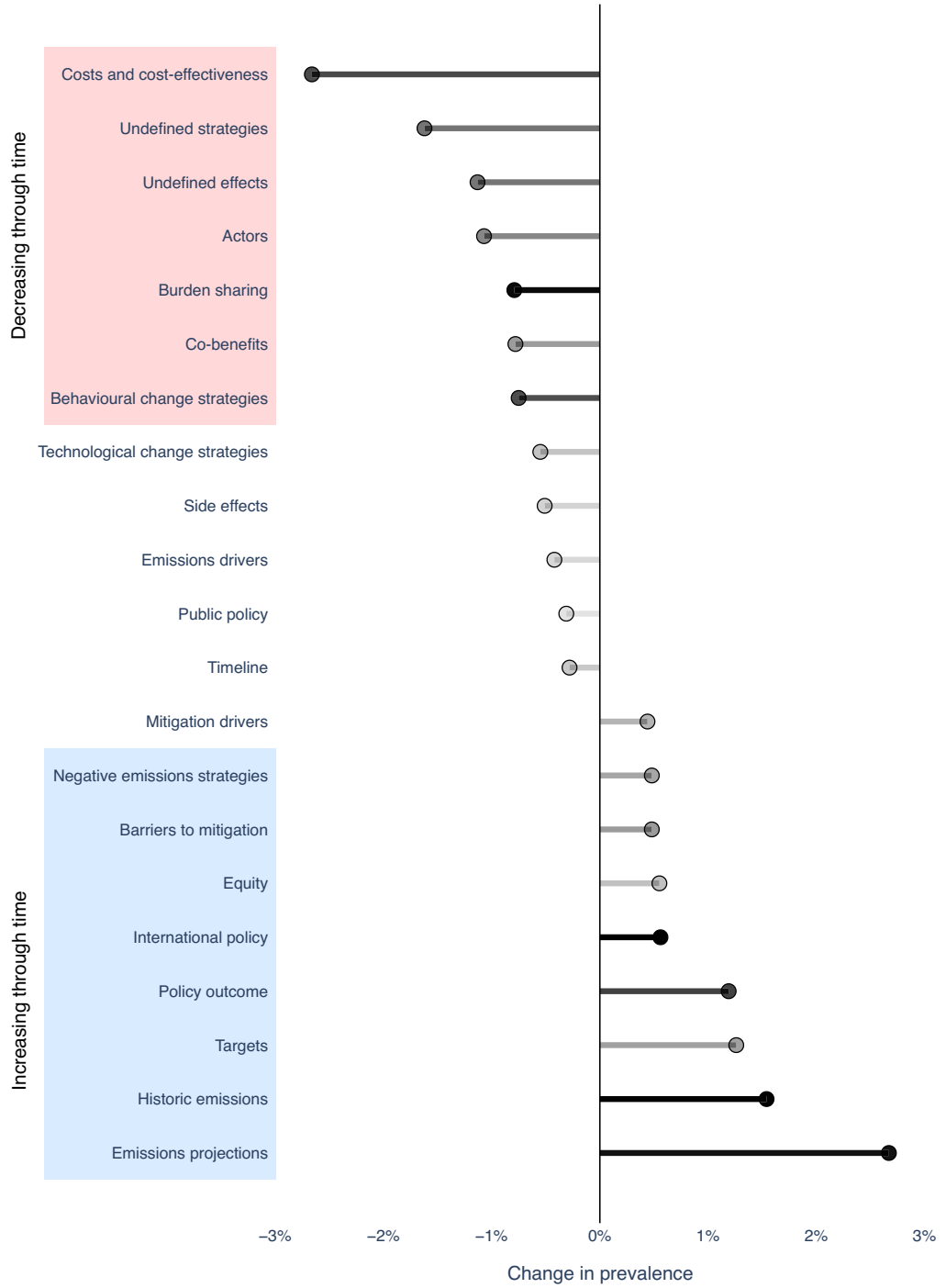


Fig. 3 | SPM content development over time. The figure shows change in topic prevalence (share of statements) across assessment cycles. The red box marks the topics with the clearest decreasing trend over time. The blue box marks the topics with the clearest increasing trend over time. Change in prevalence is calculated with a regression model as outlined in the Methods section. The transparency of the line represents the fit of the regression trendline to raw data (R^2) whereby transparent lines have a lower fit than opaque lines. See Table S4 for the results in tabular format.

countries with different legal obligations, as opposed to the Paris Agreement's universal pledge-and-review system.

Some trends associated with increasing urgency and progress in implementation

Given the passing of time, we expect SPM content to reflect progress in policy implementation over time. For example, as elaborated in the methods section, we hypothesize that there is more content on policy analysis ('Public policy'), and more content on positive examples of implemented policies ('Policy outcome'), and more content on aspects challenging the implementation of policy ('Barriers to mitigation') across assessment cycles. Similarly, given the increasing urgency of climate change as time passes, we hypothesize that SPMs cover more statements including specific deadlines ('Timeline') and the common goals associated with them ('Targets') as well

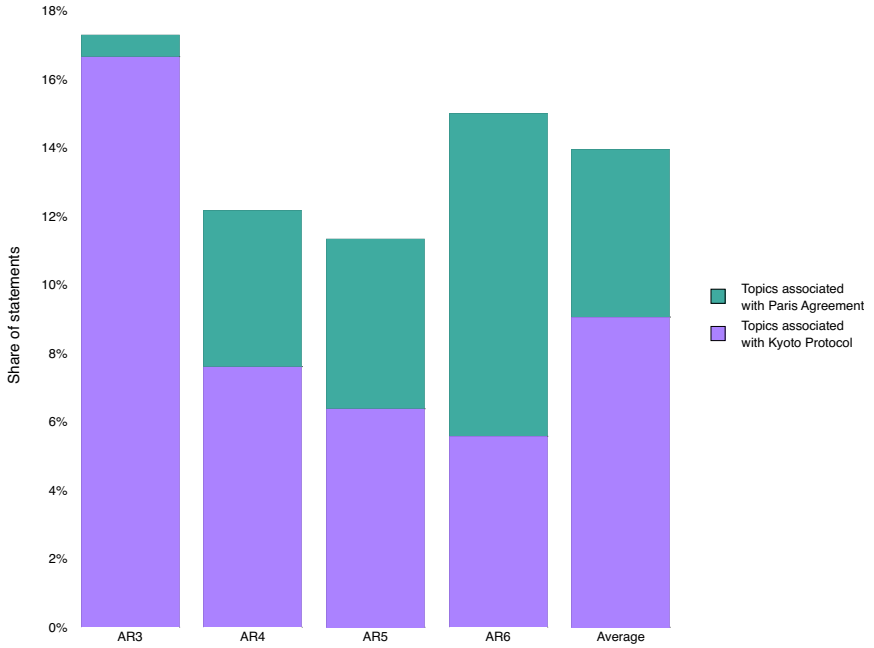


Fig. 4 | Global climate agreements as trends in SPM content development. The prevalence of topics associated with ideas in the Kyoto Protocol (purple) and Paris Agreement (turqoise) is shown per assessment cycle. The topics 'Costs and cost-effectiveness' and 'Burden sharing' are associated with the Kyoto Protocol. The topics 'Targets' and 'Emissions projections' are associated with the Paris Agreement. Read more details in the Method section.

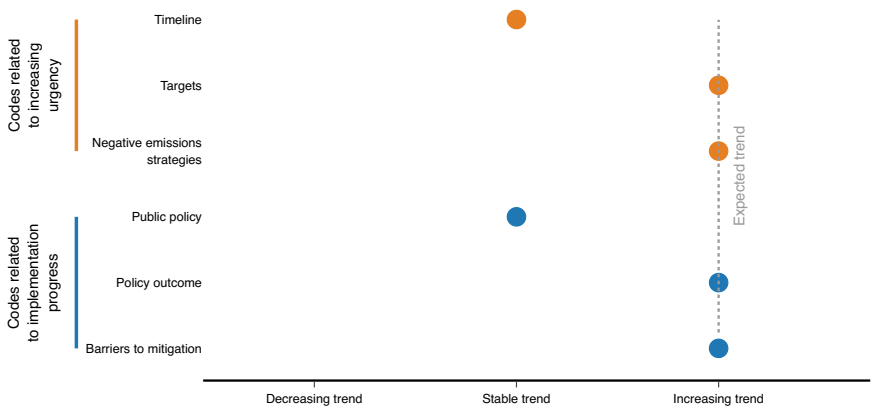


Fig. 5 | Urgency and progress in mitigation as trends in SPM content development. The figure shows differences between expected (dotted line in grey) and observed (colored dots) SPM content development across assessment cycles due to the passing of time (blue) and increasing of urgency (orange). The observed values are based on linear regression models depicting the trend in topic distribution across assessment cycles, as shown in Fig. 3. The expected values are the authors'.

as strategies to cope with failure to mitigate on time ('Negative emissions strategies') across assessment cycles.

The hypotheses relating to the topics 'Targets', 'Negative emissions strategies', 'Policy outcome' and 'Barriers to mitigation' are met, but those relating to 'Timeline' and 'Public policy' are not (see Fig. 5). This suggests that the increasing urgency and progress in implementation is somewhat consistent with SPM content development, but not as strongly as we expect. While we expected there to be more content in the SPMs covering specific public policy instruments and more content outlining a timed schedule of mitigation action, there is a slightly decreasing trend across assessment cycles for these topics.

Discussion

In this paper we investigate the content of Working Group III SPMs and show how it has changed over time. Our research has two main contributions. First, our results help empirically evaluate whether IPCC assessments have responded to calls to shift their focus towards solutions in the SPMs by providing more content on specific policy instruments. Second, we show how ideas in the SPMs have co-evolved with global climate change politics, reflecting to what extent they are keeping up with developments in global negotiations and the increasing urgency of climate change.

Our results indicate that there has not been a shift towards solutions in the SPMs, and especially not in the sixth assessment cycle. We find that practical knowledge (largely composed of analysis of policy instruments) is scarce in the SPMs and that it has not increased mentionably over time. This implies that SPMs have not shifted towards "what works" or how to actually decarbonize societies over time. Because of the IPCC chair's explicit intent and the academic community's call for a shift towards solutions[16,26,27], we expected there to have been an increase in practical knowledge over time. But, contrary to our expectation, we find that this development has not taken place in the SPMs. We find a very limited shift towards solutions even if we broaden the term 'solution-oriented' beyond analyses of policy instruments to include more general information on mitigation strategies, which is strategic ("how to mitigate") instead of practical ("what works") knowledge. Out of all topics on mitigation strategies ("Technological change strategies', 'Negative emissions strategies' and 'Behavioural change

strategies'), only 'Negative emissions strategies' exhibits a positive trend across assessment cycles. This suggests that, under the more generous definition of 'solution-oriented', there has only been a shift towards solutions related to negative emissions. Our sensitivity analysis regarding the categorization of the theme 'Practical knowledge' (see Note S1) indicates that our findings are robust across alternative plausible definitions. However, some readers may interpret the term 'solution-oriented' or the themes 'Practical knowledge', 'Strategic knowledge' and 'Argumentative knowledge' differently from the way we use them. We therefore emphasize that our results should only be understood in relation to our definitions. For example, we define 'Practical knowledge' as knowledge on mitigation policy instruments, illustrated with concrete examples of what works or what could work to mitigate climate change.

While we find that there is no shift towards solutions in the SPMs, this is not necessarily generalizable to IPCC assessments overall. There may have been a shift towards solutions in the full reports that did not make its way into the more politically contentious SPMs, but a contents analysis of the full reports was out of scope of our research. The content of the SPMs is not synthesis of the content of the reports (this is found in the technical summary). Rather, the content of the SPMs is influenced by its political approval process[52]. Studying the extent to which SPM content diverges from the content of the full report or from the technical summaries, and the extent to which the observed shifts in SPM contents is causes by a similar shift in the report contents, is an interesting future research direction. It can shed light on whether the SPM approval process limits the amount of practical knowledge on policy instruments, or whether this is a feature also present in the full reports.

Further, our content analysis is of a quantitative character, so it was not designed to track discursive or linguistic changes in how policy intruments are covered in the SPMs. For example, there may have still been a shift toward more policy-specificity without there being any relative growth in the share of policy-related topics in the SPMs. However, previous research does not support that idea. Specifically, Minx et al.[53] analyze the linguistic framing of regulatory policies, carbon tax and cap-and-trade mechanisms in SPM text in AR3, AR4, and AR5; and find little knowledge accumulation on these topics with limited policy relevance due to the very generic nature of the statements. Future research employing a content analysis of a qualitative character or a discourse analysis, possibly with automated methods that also enable analysis of the vastly longer reports, can address this issue. Since we make all our data availably openly and freely, future researchers can save time by working only with our already-coded dataset as opposed to re-coding the entire SPM text.

The key implication of our findings is that the IPCC SPMs have not become more solution-oriented while remaining policy-neutral and with the current SPM writing and approval process. Therefore the empirical evidence supports the logic that IPCC assessments may need to re-consider their policy-neutrality principle or its approval and scoping processes to enable a shift toward solutions in the SPMs. So far, this shift has not happened and maybe it could not within the existing task description of the IPCC.

The failure of SPMs to shift to solutions poses a more fundamental question regarding the utility of SPMs. Have SPMs outlived their intended utility as bridging tools between science and policy? Recent developments like the failure of governments and experts to agree on an SPM for the seventh Global Environment Outlook (GEO-7) suggest that the SPM writing and approval prorcess may be under growing strain. In the ongoing AR7 process, these negotiation dynamics are likely to intensify, driven by stronger climate policy resistance from several countries and their increasing institutional influence within the IPCC. For example, this is evidenced by a higher representation of lead authors from fossil fuel–exporting states[54] and the growing leverage of their governments in both the IPCC and UNFCCC arenas. Given our finding of the IPCC WG3 SPMs' limited content on policy instruments and the burdensome SPM writing and approval process, it is unclear whether SPMs are still an asset or rather a liability for global environmental assessments.

We find that ideas in SPMs have co-evolved with changes in global climate policy. In particular, we show a shift from Kyoto-associated topics, focused on the cost-effectiveness of mitigation and burden-sharing between countries, to Paris-associated topics, emphasizing accountability and global target-setting through calculations of past and estimated emissions. This corresponds to the shift in global climate policy, from the global commons framing of the Kyoto Protocol to the NDC-centred approach of the Paris Agreement. However, the shift has not been all-encompassing as our results show that content on costs and burden sharing is still strong in AR6. This indicates that the SPMs, like documents from other international organizations, have historically moved to more discursive diversity on climate change mitigation rather than just changing the paradigm[55]. The discursive diversity is especially visible in the SPMs of AR4 and AR5, which mark a transitional period where topics associated with both treaties were both present with similar prevalence. This is consistent with the framing of the Copenhagen Accord which contained a mix of ideas of both treaties like the temperature target from the Paris Agreement and the burden sharing efforts in the Kyoto Protocol. Future research can identify and explain causalities in the relationship between SPM content and the international climate agreements as previous research on the Special Report on 1.5 has found that IPCC assessments were shaped by political negotiations[56].

Last, we find that the SPMs are increasingly covering topics relevant to the urgency of climate change mitigation, for example emissions reductions needed to achieve the Paris Agreement temperature goal and negative emissions approaches; and topics focused on implementation, for example ex-post policy evaluations and barriers to climate action. This suggests that the SPMs are co-evolving with dominant ideas in international climate change mitigation policy, even though they are not shifting to solutions.

While we build an empirical overview of the changes in SPM topic prevalence over time, we are limited in explaining the causes for those changes. In other words, with our research we only analyze whether and how the SPMs have changed. But we do not and cannot say why they have changed because the writing process is outside of the scope of our analysis. Future research can link changes in SPM topic prevalence to changes in scientific output, geopolitical developments or IPCC authorship and procedures. Another idea is to study the SPM writing process, for example, by conducting interviews with authors or government representatives. Such interviews could target the underlying reasons for the (lack of) changes in SPM topic prevalence.

Our findings empirically demonstrate that the SPMs changed their focus, suggesting that they can do so again in the future. While we set out to empirically examine the policy-neutrality debate, we ultimately suggest that the IPCC ought to emphasize the topic of policy instruments to maintain policy-relevance for national and local policymakers, regardless of whether it is in a policy-prescriptive or policy-neutral manner. In addition, we find that there is consensus among scholars for the IPCC to be more transparent about the value-ladenness of its work[57], put more effort in promoting a more diverse evidence base[58,59] and dialogues with stakeholders outside of the assessment[19].

Given the divisions in the debate on whether the IPCC should abandon its policy-neutrality or not, we stress that the IPCC need not be "all things to all people"[14]. For example, it is imaginable that the IPCC itself maintains its policy-neutrality function, while focusing more on synthesising the scientific evidence of policy instruments. In addition to this, it can let other boundary organizations in their specific international, national and local contexts expand on its assessments to offer science-based policy advice. For example, The Subsidiary Body for Scientific and Technological Advice (SBSTA) provides advice at COPs based on the IPCC assessments[2,3]. Further, in some countries there are national boundary organizations creating assessments tailored to national contexts akin to those by the IPCC[3]. The IPCC may consider taking a more proactive role acting as a network facilitator and support other boundary organizations, which can create more context-tailored information for policymakers akin to the SPMs. As an example, the IPCC could consider fostering exchange of scientific knowledge on policy instruments between national knowledge brokers like the

Table 1 | Codebook of WG3 SPMs

Topic	Definition
Actors	Statements that focus on governments, organizations or individuals as contributors to climate change mitigation
Background information	Information about the past or definitions which sets the context for nearby statements
Barriers to mitigation	Statements regarding the challenges which hinder climate change mitigation action
Behavioural change strategies	Statements that outline approaches which lower the extent of human activity as a way of mitigation climate change
Burden sharing	Statements that outline the distribution of mitigation efforts across regions because of the variance of regional mitigation costs or other drivers of mitigation potential
Co-benefits	Statements on positive (un)intended consequences of climate change mitigation
Costs and cost-effectiveness	Statements about the costs and cost-effectiveness of climate change mitigation
Emissions drivers	Statements about the factors driving greenhouse gas emissions
Emissions projections	Statements that explain how greenhouse gases emissions are likely to develop in the future based on current measures
Equity	Statements about the fairness of climate change mitigation
Historic emissions	Statements about past emissions as recorded in the greenhouse gases inventory
International policy	Statements about initiatives or policies that can be or have been implemented internationally
Introductory information	General statements which introduce the concept of climate change mitigation and call for climate change motivation
Methodological considerations	Statements which outline or discuss the way the scientific evidence was created, assessed and its limitations
Mitigation drivers	Statements about factors driving greenhouse gas emissions reduction
Negative emissions strategies	Statements that outline approaches which increase greenhouse gases capture and storage as a way of mitigation climate change
Policy outcome	Statements that describe the outcome of implemented climate change mitigation measures
Public policy	Statements about policies that can be implemented on a national or local level
Side effects	Statements on negative (un)intended consequences of climate change mitigation
Targets	Statements which focus on global and temperature-specific targets
Technological change strategies	Statements that outline technological change approaches which decarbonize energy sources and carriers or increase the efficiency of human activity
Timeline	Statements about the timeline of climate change mitigation policy
Undefined effects	Statements on both positive and negative (un)intended consequences of climate change mitigation
Undefined strategies	General statements about mitigation strategies or statements that mix multiple mitigation strategies

OECD's approach in education[60]. This could be in addition to or instead of its global-level SPMs which can miss context-dependance when discussing policy-instruments.

We conclude that the SPMs have not shifted towards discussing more solutions, but have kept up with the times by switching their focus from ideas associated with the Kyoto Protocol to ideas associated with the Paris Agreement. Our empirical findings suggest that it has not been possible for IPCC assessments to discuss more specific policy instruments in the SPMs within their current working procedures. Regardless of whether the IPCC chooses to reform, we stress that it is still important for the SPMs to strive to cover more content on specific policy instruments. Additionally, the IPCC could strive to become a central clearinghouse amongst the growing ecosystem of national and local boundary organizations. Thus, its policy-relevance to national and local policymakers will be perserved.

Methods

We conduct a quantitative content analysis of AR3-AR6 WG3 SPMs. First we code the text as topics and calculate intercoder agreement to establish the validity of the coding. Next, we analyze topic distribution and test hypotheses about its behaviour over time as a way of explaining SPM content development across assessment cycles.

Coding

Quantitative content analysis is an established method for identifying patterns in content in a reliable replicable manner[61]. We chose a quantitative approach because our primary research aim was to identify whether there is a shift a pattern in how much policy instruments are discussed and because we aimed to cover a large corpus of SPM text spanning two decades.

We coded all statements by hand, applying a one-statement-one-topic rule. This allowed us to cover the meaning of each statement, which would not be possible with automated methods like a keyword-driven analysis from a topic modelling algorithm. In the words of the AR5 SPM, "mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases"[62]. Yet, for such an important issue, the concept of climate change mitigation lacks a widely agreed upon theoretical underpinning[63]. Hence, it was necessary to build a codebook from scratch.

Using an inductive coding process, we developed a codebook that captures the topics of the SPMs in what Braun and Clarke refer to as "domain summaries"[64]. We created the codebook working solely with the AR5 SPM because it was the latest published and longest SPM at the time of designing the research. Basing the codebook on a subset of the analyzed text or on theoretical concepts is common practice in quantitative content analysis[61]. While specific niche topics that appear pre- or post-AR5 can be missed with this appraoch, the broader groups of topics that they are a part of exhibit fluctuations to account for this. The two criteria we followed when creating the codebook were that it should be large enough to capture the full spectrum of SPM content and specific enough to allow for mutually exclusive coding, i.e. that the boundaries between topic definitions are unambiguous. We iterated the codebook development four times with feedback from two independent coders who practiced applying the codebook on five pages of the AR5 SPM. The resulting codebook features 24 topics (Table 1, see Table S1 for full codebook including examples, inclusion and exclusion criteria). The code definitions are at a high level of abstraction, which was necessary to keep the codebook at a manageable size and to accommodate the inherent vagueness of SPM statements resulting from their political approval process.

As an example, statements which describe mitigation strategies related to energy, transport and buildings are coded as 'Technological change strategies' unless they include knowledge specific about policy (coded as 'Public policy') or relate to behaviour change that would lower energy

consumption (coded as 'Behavioural change strategies'). Similarly, statements that cover finance are coded as 'Mitigation drivers' according to our codebook.

At least two coders (the codebook developer and an independent coder, five coders in total) coded each text to ensure the reliability of the coding. The independent coders were first trained on a small sample of SPM statements to practice applying the codebook (four independent coders for four SPMs). We then tasked the independent coders to code all the statements in one SPM on their own. Afterward, we compared our coding and resolved intercoder disagreements by engaging in a discussion until reaching consensus. Thus, our analysis is based on the coding performed by and agreed upon by both the codebook developer and the independent coders. Last, three topics ('Background information', 'Introductory information' and 'Methodological considerations' in Table 2) refer to contextual information, so we omitted them from the analysis (see distribution of ommitted topics in Table S2).

Evaluation

We analyse the codes in three ways: first, a frequency analysis, including of topics grouped into larger themes; second, a linear regression to examine changes through time; and finally, an assessment of whether topic distribution over time is consistent with two descriptive trend patterns.

For the first analysis we counted the frequency of topic occurrence within each SPM separately, and on average by giving equal weight to the distribution in each SPM. In addition, we induced overarching themes and analyzed their patterns of change over time. The overarching themes arise from the logic that not all scientific knowledge is directly actionable for policy. Rather, some knowledge only has conceptual impact[65], whereby it provokes debate on policy but does not driectly inform its development. Thus we distinguish between three knowledge type themes: argumentative knowledge (that justifies the case for mitigation policy), strategic knowledge (that broadly guides on the direction of mitigation policy) and practical knowledge (that directly informs the development of mitigation policy). We classified all topics in knowledge type themes by analyzing the raw data, i.e. the underlying SPM text. To test the sensitivity of our findings to our classification, we experimented with four alternative classifications. We found that our theme distribution remains the same despite the perturbations, providing proof that our results do not hinge on a single strict arrangement of topics into themes (see Note S1 for full description of sensitivity analysis results).

As a second analysis, to identify broad trends in the data that are concealed by SPM-to-SPM variation, we fit linear regression models to four topic distribution values across four SPMs. We calculate trendlines, their slope coefficients and the goodness of fit (R^2) for linear regression models of topic distributions. The topics whose regression models had the largest slope coefficients and highest goodness of fit are those with the clearest and strongest change over time.

Last, we examine whether two descriptive trend narratives are consistent with the temporal patterns in SPM content development as identified with the regression models. The first narrative considers alignment between SPM content and developments in global climate policy. The second considers alignment between SPM content and the passage of time, reflecting increasing climate urgency and progress in mitigation implementation.

For the first trend narrative, we look at global climate treaties as milestones of international climate policy with a specific focus on the Kyoto Protocol and the Paris Agreement[11]. Different principles govern these treaties, pointing to a progression in central intellectual ideas regarding mitigation[55].

For example, the costs of mitigation and burden sharing between countries was especially politically relevant in the 1990s[66,67]. The Kyoto Protocol emphasized cost-effectiveness by prioritizing emissions reductions where it is cheapest and it distinguished between the responsibilities of developed and developing countries[68,69]. However, over time, the framing of mitigation has progressed from a 'zero-sum game', as evidenced in publications by international organizations[53], to one where the cost-effectiveness of mitigation is established. Further, over time, it has become more politically relevant to emphasize global targets like the temperature goals in the Paris Agreement. That is not to say that the Kyoto Protocol did not include targets, but they were country-specific rather than global[69]. Because of the Paris Agreement's bottom-up approach with a ratchet mechanism[70], continuous accounting of necessary emissions reductions is important. This drove the production of quantitative emissions projections to operationalize the shift from vague stabilization goals to specific temperature outcomes[71]. Given these developments, we conceptualize the topics 'Costs and cost-effectiveness' and 'Burden sharing' as related to ideas in the Kyoto Protocol, and the topics 'Targets'(focused only to global and temperature-specific targets) and 'Emissions projections' as related to ideas in the Paris Agreement. We assess the development of the Kyoto-associated and Paris-associated topics across the SPMs and evaluate how much content development is captured by these topics by calculating the share of content they represent. Further, we examine whether the topic distribution over time is consistent with international climate policy timelines by checking whether the topic distribution over time aligns with the timeline of international climate treaties. Specifically, we hypothesize that the prevalence of the Kyoto-associated topics decreases over time while the prevalence of the Paris-associated topics increases.

For the second narrative trend, we examine how the progression of time is reflected in SPM content development across assessment cycles given the increased urgency of climate change and progress achieved in implementing mitigation policy. Specifically, we form hypotheses about how topic prevalence ought to have developed over time and then test whether the analysis supports or rejects the hypotheses. Because of the increased urgency of climate change, we hypothesize that there is increased prevalence of 'Negative emissions strategies' and 'Timeline' as negative emissions strategies become more necessary to deal with delayed action[72], and increased prevalence of 'Targets' since more an more countries have set targets[73]. Because of progress in implementation, we hypothesize that there is increased prevalence of 'Public policy' as more policy instruments are considered[74], and an increased prevalence of 'Policy outcome 'as more ex-post policy analyses are conducted[75], and an increased prevalence of 'Barriers to mitigation' as more challenges are encountered while implementing policies in the real world[76].

Data availability

The datasets generated and analysed during the current study are publicly available in the 4TU repository, doi: 10.4121/25e15a4e-bebe-4a76-8b4d-b9121f7dbecf.

Code availability

The code used to create regression models from the coding data is publicly available in the 4TU repository, https://doi.org/10.4121/25e15a4e-bebe-4a76-8b4d-b9121f7dbecf.

Received: 9 September 2025; Accepted: 27 May 2026;
Published online: 26 June 2026

References

1. Lamb, W. F. & Steinberger, J. K. Human well-being and climate change mitigation. *WIREs Clim. Change* **8**, e485 (2017).
2. Beck, S. & Mahony, M. The IPCC and the new map of science and politics. *WIREs Clim. Change* **9**, e547 (2018).
3. Hoppe, R., Wesselink, A. & Cairns, R. Lost in the problem: the role of boundary organisations in the governance of climate change. *WIREs Clim. Change* **4**, 283–300 (2013).
4. Hughes, H. Bourdieu and the IPCC's Symbolic Power. *Glob. Environ. Politics* **15**, 85–104 (2015).
5. Vasileiadou, E., Heimeriks, G. & Petersen, A. C. Exploring the impact of the IPCC Assessment Reports on science. *Environ. Sci. Policy* **14**, 1052–1061 (2011).

6. Lidskog, R. & Sundqvist, G. Political Context. in *A Critical Assessment of the Intergovernmental Panel on Climate Change* (eds De Pryck, K. & Hulme, M) 209–216 (Cambridge University Press, Cambridge, 2022). https://doi.org/10.1017/9781009082099.028.
7. Lee, H. et al. Reforming the products and processes of the IPCC to enhance its relevance. *npj Clim. Action* **4**, 1–5 (2025).
8. Broome, J. A philosopher at the IPCC. *The Philosophers' Magazine* 11–16 (2014) https://doi.org/10.5840/tpm20146673.
9. Broome, J. Philosophy in the IPCC. in *A Guide to Field Philosophy* (eds Brister, E. & Frodeman, R.) 95–110 (Routledge, New York, USA, 2020).
10. Rietig, K. Neutral' experts? How input of scientific expertise matters in international environmental negotiations. *Policy Sci.* **47**, 141–160 (2014).
11. Gupta, J. A history of international climate change policy. *WIREs Clim. Change* **1**, 636–653 (2010).
12. Howarth, C. & Painter, J. Exploring the science–policy interface on climate change: The role of the IPCC in informing local decision-making in the UK. *Palgrave Commun.* **2**, 1–12 (2016).
13. Hermansen, E. A. T., Boasson, E. L. & Peters, G. P. Climate action post-Paris: how can the IPCC stay relevant? *npj*. *Clim. Action* **2**, 1–8 (2023).
14. Asayama, S. et al. Three institutional pathways to envision the future of the IPCC. *Nat. Clim. Chang.* **13**, 877–880 (2023).
15. Carraro, C. et al. The IPCC at a crossroads: Opportunities for reform. *Science* **350**, 34–35 (2015).
16. Beck, S., Forsyth, T. & Mahony, M. Urgent need to move toward solution-orientated environmental assessments. *One Earth* **5**, 586–588 (2022).
17. Pedersen, J. T. S. et al. Science-policy: UNFCCC policymakers' perspective of scientific scenarios and their policy relevance. *npj Clim. Action* **4**, 52 (2025).
18. Edenhofer, O. & Kowarsch, M. Cartography of pathways: A new model for environmental policy assessments. *Environ. Sci. Policy* **51**, 56–64 (2015).
19. Maas, T. Y. et al. Effectively empowering: A different look at bolstering the effectiveness of global environmental assessments. *Environ. Sci. Policy* **123**, 210–219 (2021).
20. Callaghan, M. W., Minx, J. C. & Forster, P. M. A topography of climate change research. *Nat. Clim. Chang.* **10**, 118–123 (2020).
21. Bjurström, A. & Polk, M. Physical and economic bias in climate change research: a scientometric study of IPCC Third Assessment Report. *Climatic Change* **108**, 1–22 (2011).
22. Gusheva, E., Pfenninger, S. & Lilliestam, J. Past peak prominence: The changing role of Integrated Assessment Modelling in the IPCC. *iScience* **27**, 111213 (2024).
23. Fløttum, K., Gasper, D. & St. Clair, A. L. Synthesizing a policy-relevant perspective from the three IPCC "Worlds"—A comparison of topics and frames in the SPMs of the Fifth Assessment Report. *Glob. Environ. Change* **38**, 118–129 (2016).
24. Mach, K. J., Freeman, P. T., Mastrandrea, M. D. & Field, C. B. A multistage crucible of revision and approval shapes IPCC policymaker summaries. *Sci. Adv.* **2**, e1600421 (2016).
25. Barkemeyer, R., Dessai, S., Monge-Sanz, B., Renzi, B. G. & Napolitano, G. Linguistic analysis of IPCC summaries for policymakers and associated coverage. *Nat. Clim. Change* **6**, 311–316 (2016).
26. Lee, H. Turning the focus to solutions. *Science* **350**, 1007–1007 (2015).
27. Kowarsch, M. et al. A road map for global environmental assessments. *Nat. Clim. Change* **7**, 379–382 (2017).
28. Radaelli, C. M. The role of knowledge in the policy process. *J. Eur. Public Policy* **2**, 159–183 (1995).
29. Castree, N. Global environmental assessment. in *International Encyclopedia of Geography* 1–13 (John Wiley & Sons, Ltd, 2020). https://doi.org/10.1002/9781118786352.wbieg2036.
30. IPCC. Procedures for the preparation, review, acceptance, adoption, approval and publication of IPCC reports. (2013).
31. Boehmer-Christiansen, S. Global climate protection policy: the limits of scientific advice: Part 1. *Glob. Environ. Change* **4**, 140–159 (1994).
32. Boehmer-Christiansen, S. Global climate protection policy: the limits of scientific advice: Part 2. *Glob. Environ. Change* **4**, 185–200 (1994).
33. Hermansen, E. A. T., Lahn, B., Sundqvist, G. & Øye, E. Post-Paris policy relevance: lessons from the IPCC SR15 process. *Climatic Change* **169**, 7 (2021).
34. De Pryck, K. Governmental Approval. in *A Critical Assessment of the Intergovernmental Panel on Climate Change* (eds De Pryck, K. & Hulme, M.) 187–196 (Cambridge University Press, Cambridge, 2022). https://doi.org/10.1017/9781009082099.025.
35. Livingston, J. E. & Rummukainen, M. Making policy-relevant knowledge in the IPCC Special Report on 1.5 degrees: An analysis of reviewer comments. *Environ. Sci. Policy* **147**, 305–314 (2023).
36. Pereira, L. et al. Grounding global environmental assessments through bottom-up futures based on local practices and perspectives. *Sustain Sci.* **16**, 1907–1922 (2021).
37. Pereira, L. et al. Advancing a toolkit of diverse futures approaches for global environmental assessments. *Ecosyst. People* **17**, 191–204 (2021).
38. Jabbour, J. & Flachsland, C. 40 years of global environmental assessments: A retrospective analysis. *Environ. Sci. Policy* **77**, 193–202 (2017).
39. Petersen, A., Blackstock, J. & Morisetti, N. New leadership for a user-friendly IPCC. *Nat. Clim. Change* **5**, 909–911 (2015).
40. Berg, M. & Lidskog, R. Pathways to deliberative capacity: the role of the IPCC. *Climatic Change* **148**, 11–24 (2018).
41. Schenuit, F. Staging science: Dramaturgical politics of the IPCC's Special Report on 1.5 °. *C. Environ. Sci. Policy* **139**, 166–176 (2023).
42. Turnhout, E. The Politics of Environmental Knowledge. *Conserv. Soc.* **16**, 363 (2018).
43. Pepermans, Y. & Maeseele, P. The politicization of climate change: problem or solution? *WIREs Clim. Change* **7**, 478–485 (2016).
44. Beck, S. et al. Towards a Reflexive Turn in the Governance of Global Environmental Expertise. The Cases of the IPCC and the IPBES. *GAIA - Ecol. Perspect. Sci. Soc.* **23**, 80–87 (2014).
45. Pollitt, H., Mercure, J.-F., Barker, T., Salas, P. & Scrieciu, S. The role of the IPCC in assessing actionable evidence for climate policymaking. *npj. Clim. Action* **3**, 1–9 (2024).
46. Pearce, W., Mahony, M. & Raman, S. Science advice for global challenges: Learning from trade-offs in the IPCC. *Environ. Sci. Policy* **80**, 125–131 (2018).
47. Gluckman, P. D., Bardsley, A. & Kaiser, M. Brokerage at the science–policy interface: from conceptual framework to practical guidance. *Humanit Soc. Sci. Commun.* **8**, 1–10 (2021).
48. Daviter, F. The political use of knowledge in the policy process. *Policy Sci.* **48**, 491–505 (2015).
49. Hukkinen, J. I. Knowing when knowledge performs its power in ecological economics. *Ecol. Econ.* **169**, 106565 (2020).
50. Carrier, M. What Does Good Science-Based Advice to Politics Look Like? *J. Gen. Philos. Sci.* **53**, 5–21 (2022).
51. Capano, G. & Malandrino, A. Mapping the use of knowledge in policymaking: barriers and facilitators from a subjectivist perspective (1990–2020). *Policy Sci.* **55**, 399–428 (2022).
52. Wojick, D. E. T. heU. N. IPCC'S Artful Bias: Summary of Findings: Glaring Omissions, False Confidence and Misleading Statistics in the Summary for Policymakers: (The science summary – Working Group 1 of the Third Assessment Report). *Energy Environ.* **13**, 311–328 (2002).
53. Minx, J. C., Callaghan, M., Lamb, W. F., Garard, J. & Edenhofer, O. Learning about climate change solutions in the IPCC and beyond. *Environ. Sci. Policy* **77**, 252–259 (2017).
54. IPCC. IPCC Authors. https://apps.ipcc.ch/report/authors/ (2026).
55. Meckling, J. & Allan, B. B. The evolution of ideas in global climate policy. *Nat. Clim. Chang.* **10**, 434–438 (2020).

56. Livingston, J. E. & Rummukainen, M. Taking science by surprise: The knowledge politics of the IPCC Special Report on 1.5 degrees. *Environ. Sci. Policy* **112**, 10–16 (2020).
57. Turnhout, E., Dewulf, A. & Hulme, M. What does policy-relevant global environmental knowledge do? The cases of climate and biodiversity. *Curr. Opin. Environ. Sustain.* **18**, 65–72 (2016).
58. Ford, J. D. et al. Including indigenous knowledge and experience in IPCC assessment reports. *Nat. Clim. Change* **6**, 349–353 (2016).
59. Viner, D. & Howarth, C. Practitioners' work and evidence in IPCC reports. *Nat. Clim. Change* **4**, 848–850 (2014).
60. Seitzer, H., Baek, C. & Steiner-Khamsi, G. Instruments of lesson-drawing: comparing the knowledge brokerage of the OECD and the World Bank. *Policy Stud.* **45**, 839–859 (2024).
61. Krippendorff, K. *Sage Research Methods - Content Analysis: An Introduction to Its Methodology*.
62. *Climate Change 2014: Mitigation of Climate Change*. (Cambridge University Press, 2015).
63. Moore, B. et al. Transformations for climate change mitigation: A systematic review of terminology, concepts, and characteristics. *WIREs Clim. Change* **12**, e738 (2021).
64. Byrne, D. A worked example of Braun and Clarke's approach to reflexive thematic analysis. *Qual. Quant.* **56**, 1391–1412 (2022).
65. Edler, J., Karaulova, M. & Barker, K. Understanding Conceptual Impact of Scientific Knowledge on Policy: The Role of Policymaking Conditions. *Minerva* **60**, 209–233 (2022).
66. Leimbach, M. & Giannousakis, A. Burden sharing of climate change mitigation: global and regional challenges under shared socio-economic pathways. *Climatic Change* **155**, 273–291 (2019).
67. Ringius, L., Torvanger, A. & Underdal, A. Burden Sharing and Fairness Principles in International Climate Policy. *Int. Environ. Agreements: Politics, Law Econ.* **2**, 1–22 (2002).
68. Bernauer, T. Climate Change Politics. *Annu. Rev. Political Sci.* **16**, 421–448 (2013).
69. Chan, G., Stavins, R. & Ji, Z. International Climate Change Policy. *Annu. Rev. Resour. Econ.* **10**, 335–360 (2018).
70. Falkner, R. The Paris Agreement and the new logic of international climate politics. *Int. Aff.* **92**, 1107–1125 (2016).
71. McLaren, D. & Markusson, N. The co-evolution of technological promises, modelling, policies and climate change targets. *Nat. Clim. Chang.* **10**, 392–397 (2020).
72. Vaughan, N. E., Lenton, T. M. & Shepherd, J. G. Climate change mitigation: trade-offs between delay and strength of action required. *Climatic Change* **96**, 29–43 (2009).
73. Iacobuta, G., Dubash, N. K., Upadhyaya, P., Deribe, M. & Höhne, N. National climate change mitigation legislation, strategy and targets: a global update. *Clim. Policy* **18**, 1114–1132 (2018).
74. Wang, D., Dong, L. & Mei, J. An advanced review of climate change mitigation policies in Germany, France, and the Netherlands. *Environ. Res. Lett.* **18**, 103001 (2023).
75. Lilliestam, J., Patt, A. & Bersalli, G. The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical ex-post evidence. *WIREs Clim. Change* **12**, e681 (2021).
76. Steg, L. et al. A method to identify barriers to and enablers of implementing climate change mitigation options. *One Earth* **5**, 1216–1227 (2022).

Acknowledgements

This research is a part of the lead author's doctoral dissertation, which was funded by the European Commission as part of the European Climate and Energy Modeling Forum. Grant agreement ID: 101022622.

Author contributions

E.G.: Conceptualization, Methodology, Investigation, Writing—Original Draft, Visualization. J.E.: Conceptualization, Writing—Review & Editing. F. Bock: Investigation, Validation, Writing—review & editing. F. Bold: Investigation, Validation, Writing—review & editing. S.W.: Investigation, Validation, Writing—review & editing. F.W.: Investigation, Validation, Writing—review & editing. S.P.: Conceptualization, Writing—Review & Editing.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44168-026-00391-1.

Correspondence and requests for materials should be addressed to E. Gusheva.

Reprints and permissions information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

© The Author(s) 2026