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Glossary

Abbreviation	***Full term***
CA	Consortium Agreement
CO	Project Coordinator
CB	Coordination Board
GA	Grant Agreement
SH	Stakeholders
WP	Work Package
WPL	Work Package Leader
IPCC	Intergovernmental Panel on Climate Change
USA/ US	United States of America
UK	United Kingdom
NGO	Non-Governmental Organization
OECD	Organisation for Economic Co-operation and Development
NNT	Number needed to treat
SCT	Social Cognitive Theory
CLT	Construal Level Theory
EFSA	European Food Safety Authority
WWF	World Wide Fund
ATSE	Australian Academy of Technological Sciences & Engineering
COVID-19	Coronavirus Disease 2019
GBM	Gateway Belief Model
GMO	Genetically Modified Organism
FDA	Food and Drug Administration
MBA	Masters in Business Administration

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Executive Summary

This report underscores the pivotal role of effective communication of scientific uncertainties to policymakers, particularly in critical areas like climate change. The multifaceted landscape of uncertainty communication strategies is explored, with a focus on diverse aims and implications.

The analysis begins with a systematic examination of scientists' strategies in communicating uncertainties to policymakers, revealing a consensus in the literature that advocates for scientists to serve as neutral informants rather than influencers in the decision-making process. The importance of inclusive communication, highlighting uncertainties and the limitations of scientific findings, is emphasized.

To evaluate policymakers' ability to comprehend and utilize uncertainty information, the report reviews existing evidence from experimental studies on how uncertainties are perceived and managed. Considering the unique perspective of policymakers, who regularly engage with scientific research, the report contrasts their reactions to uncertainties with those of the general public, drawing insights from direct data collection.

Qualitative interviews with scientists provide valuable insights into the challenges associated with effectively communicating uncertainties to policymakers. These insights contribute to a nuanced understanding of the dynamics at play in the science-policy interface.

The report also reviews existing communication strategies proposed in the literature for conveying scientific evidence. Practical guidelines from various studies are summarized to facilitate effective communication of risks and uncertainties, addressing common misperceptions. A case study on the Intergovernmental Panel on Climate Change (IPCC) illustrates the calibrated language approach used in expert judgments, evaluation, and communication of certainty levels in assessment findings.

This report thus constitutes a comprehensive exploration of uncertainty communication strategies, offering practical insights for policymakers, scientists, and communicators involved in bridging the gap between scientific knowledge and informed decision-making.

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1 Introduction

Policymakers bear the responsibility of formulating strategies that significantly influence the trajectory of a society, exemplified by the design of crucial policies such as those addressing climate change. The decision-making environment within which policymakers operate is frequently characterized by a dearth of complete and reliable information, inherently laden with uncertainty.

This uncertainty, a pervasive element in the decision-making process, can stem from diverse sources. It may arise due to insufficient evidence quality resulting from data limitations, challenges in accurately measuring a variable of interest, or disparities in existing evidence, such as disagreements among experts or scientific models. The multitude of available models and varying expert opinions often complicates the task for policymakers, making it challenging to navigate uncertainty and arrive at well-informed decisions.

Extensive literature across various disciplines, including economics and psychology, attests to a general dislike, or aversion towards uncertainty. Individuals tend to favor certain information over uncertain ones, exhibiting a propensity to avoid being confronted with uncertainty. In this pursuit, they are susceptible to cognitive biases—predictable departures from purely rational behavior—that influence their judgments when confronted with uncertainty. Notable biases include overconfidence, leading decision-makers to underestimate relevant uncertainties, and optimism bias, wherein individuals tend to downplay potential negative impacts while overemphasizing information predicting favorable outcomes (Sharot, 2011).

Given the inherent uncertainties, effective communication becomes imperative. Clear and transparent communication serves to mitigate misinformation, foster high trust, and facilitate constructive dialogue among policymakers, enabling them to make informed decisions. The effective perception and communication of uncertainties empower policymakers to enact meaningful change.

This review delves into strategies for effectively communicating uncertainties to policymakers, with a specific focus on preventing irrational dismissals or misunderstandings of information. Conducting an extensive literature review analysis, we explore the processing and comprehension of scientific uncertainties. While the existing research on samples of policymakers is limited, our approach broadens to encompass uncertainty communication studies involving the general population.

Our objective is to extract insights that remain pertinent to the specific needs and challenges faced by policymakers. The review identifies and categorizes multiple subtopics of interest, offering a concise presentation to illuminate the subject. By amalgamating findings from diverse sources, we endeavor to provide valuable perspectives on effective strategies for communicating uncertainty to policymakers.

The report is organized as follows. In Section 2, we briefly report on the strategy employed to assess the literature relevant to the purpose of our review.

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Section 3 initiates the discussion with the question: Should scientists communicate uncertainties? Within this section, we systematically present and analyze the arguments articulated in the literature regarding the advantages and advisability of scientists transparently communicating the inherent uncertainties accompanying their scientific findings to policymakers. The discourse unfolds by categorizing the reviewed papers into three primary classifications: (1) Papers advocating for the complete exclusion of uncertainties, aiming to influence policymakers towards specific decisions, (2) Papers advocating for absolute transparency in uncertainty communication, emphasizing the imperative of providing policymakers with the utmost information, and (3) Papers endorsing a balanced approach, acknowledging scientists as informants while underscoring the importance of judiciously selecting which uncertainties to disclose and which to omit.

Section 4 presents evidence on how uncertainties are typically perceived and dealt with in experimental studies. We aim to assess the policymakers' ability to comprehend and thus use the information contained in the communicated uncertainty, and particularly to whether they might be misinformed by uncertainties, for example, if they cannot correctly use the information uncertainties present.

Section 5 focuses on the comparison between policymakers and the general public. We start by presenting and discussing the results of existing studies having directly collected data from policymakers and contrasted the results with those obtained from other samples. We then discuss personal characteristics that may affect an individual's reaction to uncertainty, thus creating potential differences between policymakers and other groups. Finally, we summarize the results of qualitative interviews with scientists exploring their perceptions of the challenges associated with effectively communicating uncertainties to policymakers. These interviews provide valuable information regarding the expectations and experiences of scientists when conveying their findings.

Section 6 summarizes and discusses the communication strategies proposed in the literature to convey scientific evidence. We start by summarizing the practical guidelines proposed in different studies for communicating risks and uncertainties in a way that promotes the audience's understanding and overcomes common misperceptions. In a case study, we present the approach followed by the Intergovernmental Panel on Climate Change (IPCC) to use a calibrated language for developing expert judgments and evaluating and communicating the degree of certainty in findings of the assessment process.

2 Approach

This report investigates how policymakers perceive, understand, and use scientific evidence, particularly the scientific uncertainty inherently associated with it. As we expected the literature to be diverse and multidisciplinary, we first conducted two consecutive Scopus searches (keywords and details are provided in the Online Appendix), which provided a general and systematic insight into the literature at hand and built the base of the literature reviewed here. We then included relevant literature cited in the papers obtained through the previous searches. The search also included papers from the Winton Centre for Risk and Evidence Communication at the University of Cambridge. Due to the high relevance of the topic at hand, we reviewed the list

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of publications on the center's website. Some specific subtopics warranted additional literature, which we obtained by non-systematic approaches.

3 Transparency: Should scientists communicate uncertainties?

At the core of the discussion on whether or not scientists should communicate uncertainties lies a conundrum of balancing the general public's need for certainty, clear guidance and instructions, and the intrinsic uncertain nature of science (Folker & Sandøe, 2008, p. 176). The authors draw attention to the following potential conflict: "While uncertainty is at the heart of science, scientific advice may seem to call for certainty, and for simple recommendations and assurances" (Folker & Sandøe, 2008, p. 177). Communication strategies of scientific uncertainties are thus thought to fall in between two extremes - an utterly transparent communication that "convey[s] all scientific uncertainty to the public" or a "paternalistic strategy," which entails withholding some information from the public to avoid confusion or panic. According to the latter, "scientific advisers should provide apparently certain, indisputable knowledge. Doubt and uncertainty should be concealed from the public. This ‘‘top-down’’ strategy is based on the supposition that it is the primary role of the scientific adviser to feed scientific conclusions to the public, and that the adviser should act as an authority that settles matters once and for all" (Folker & Sandøe, 2008, p. 183).

While Folker and Sandøe (2008) focus on communication to the general public, their arguments remain valid, at least in parts, for communication to policymakers. Yet, it should be clear that policymakers may differ from the general public in several dimensions, such as the nature of the decisions they make or their prior knowledge and familiarity with the topics at hand (see Box 1).

Box 1. What is a “policymaker”?

Policymakers is a broad term used to designate ‘people who are involved in making policies and policy decisions’ (Collins English Dictionary). They are typically (but not always) elected representatives who make collective decisions on behalf of the public. The consequences of their (policy) decisions may typically impact many people. When deciding, policymakers must consider a plurality of opinions and perspectives, and their voters' potentially contrasting needs and interests.

Policy decisions usually differ from individual-level decisions for different reasons. In a recent contribution, Brick et al. (2018) listed the following four reasons:

1. Policies can have varying effects on different segments of the population, leading to heterogenous outcomes.
2. The effects of policies are often measured on different scales, making comparisons challenging.
3. Policies often have long-term impacts that can span generations.
4. Predicting outcomes in policymaking is inherently difficult and involves significant uncertainties.

In addition, policymakers also often have to operate within various political and institutional constraints. In particular, given that their decisions typically impact a large population, they

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are often subject to deep scrutiny (before and after the decision is taken). Policymakers are thus generally held accountable by the general public. Various checks and balances (such as research, consultations, debates, and evaluations) ensure they make the most informed decisions. Whereas policymakers remain a part of the collective and are personally affected by the consequences of their policy decisions, the policy outcomes and the voters' agreement also directly affect their future as policymakers through future elections.

On average, policymakers have been shown to be more educated than the general population in the European Union (Best, 2007) and the USA (Manning, 2020). Although some policymakers may possess educational backgrounds specific to their policy domain before their appointment, they are likely to gradually develop expertise in their respective fields through experience and practical knowledge. In addition, unlike the general public, policymakers often have exclusive access to policy-relevant information through direct consultation with scientists or expert groups or through briefings by their team of (scientific) advisors. They are thus supposedly more equipped than the layperson in information, expertise, and/or experience. Moreover, as policies concern different future scenarios, policymakers are necessarily exposed to uncertainties on a regular basis.

Despite their higher educational background, policymakers may also be subject to various cognitive biases and may end up (un)consciously applying various heuristics. Heuristics are mental shortcuts used in decision-making (Kahneman et al., 1982); especially when quick decisions are needed (as is often the case with policymakers; Cairney & Kwiatkowski, 2017; Hoppe, 2018). While they aid timely action, it may also mean losing out on reviews and checks. A meta-study by Berthet (2022) finds experts in various fields susceptible to such biases, implying that policymakers - although experts in their respective fields - may not be immune against such impeding predispositions. For example, typical biases identified in different fields include overconfidence, framing, blind spot, loss aversion, herding, disposition effect availability, hindsight, anchoring, and confirmation.[1]

The reviewed literature on communication strategies of uncertainties specifically targeted to policymakers expresses divergent opinions on whether or not it is beneficial or normatively desirable for scientists who consult policymakers to provide them with the inherent uncertainties of scientific findings. Based on their position regarding this question, we classify the literature into three broad categories:

1. Papers making the case for paternalistic strategies and the complete omission of uncertainties, with the objective of coercing policymakers into specific decisions.
2. Papers arguing for the opposing strategy of encouraging transparency on the uncertainties without attempting to persuade the audience. In this case, scientists are to provide policymakers with the maximum information to enable them to make optimal decisions by themselves - without any compulsion from scientists.

[1] For example, (Bellé et al., 2018) show that policymakers were not immune to framing issues. Specifically, they show that the framing of messages (a tool which policymakers often use to inspire desired behaviors in the public) impact the decisions of policymakers across policy and management domains. This indicated that policymakers are susceptible to making systematically different decisions based on how the information is presented instead of what the information is. Moreover, public workers also deviated owing to anchoring bias (a tendency to make decisions based on the first piece of information). Next, they demonstrate that public workers dedicate more time to a project with a greater number of beneficiaries irrespective of the actual number of affected clients (the proportion dominance bias). They also prefer the status quo as the number of superior alternatives increase (status quo bias); but change decisions in the presence of a decoy (asymmetric dominance bias).

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3. Papers falling somewhere in between; while agreeing with the second strand on assigning scientists the role of informants, they highlight the necessity of selecting some uncertainties to report and omitting others.

In what follows, each strand of the literature and its arguments are discussed.

3.1 The case for omitting uncertainties

Only a few papers argue that scientists should omit the communication of uncertainties altogether and prioritize persuasive guidance over providing scientific information without an agenda. One argument is that policymakers want clear guidance and instructions on how to act and do not wish to know what is not known (Meah, 2019): "What policymakers want from climate change scientists is a confident articulation of what we know. It is a misunderstanding to believe that this is achieved through a detailed quantification of the uncertainty about specific scientific knowledge claims, i.e., more certainty about uncertainty" (p. 1619). The author further dismisses attempts to increase transparency on uncertainties, arguing "that the overemphasis given to uncertainty in the climate science discourse by scientists working in the field has been self-defeating as it has led to confusion among the intended recipients of the policy-relevant scientific knowledge and allowed room for skepticism to grow" (p. 1619). About policymakers' lack of interest in the uncertainties, Meah concludes "simply put, they did not take an active interest because they did not feel the need to" (p. 1628). Richards and Carruthers Den Hoed (2018) support this line of argument, as illustrated by the following statement: "Focusing too much on this uncertainty in an effort to be transparent, however, can be counterproductive, because policymakers have little tolerance for it" (p. 152).

Lofstedt and Bouder (2021) discuss the case of making uncertainties transparent amidst the recent rise in guidelines for risk and uncertainty communication used by organizations such as the International Panel on Climate Change (IPCC) or the European Food Safety Authority (EFSA). Specifically for the case of the EFSA, the authors evaluate the recent attempts to increase transparency critically by warning about the potentially adverse effects of greater transparency about uncertainties on public trust and some interest groups' potential misuse of uncertainties.

Bell (2006) studies the case of the Wentworth Group – a group of “concerned scientists” – which originated upon invitation of the WWF in Australia as a response to severe drought and a public debate favoring environmentally harmful “preventive” measures such as altering rivers. Many authors attribute the immediate success of the group – the Australian government implemented most of their recommendations – to the fact that they communicated solutions understandable to the general public while explicitly omitting scientific uncertainty, arguing that scientific debates should be kept out of the public. Peter Cullen, a member of the Wentworth Group, picked up on the previous conflict between uncertainties being appreciated in science but confusing to the general public:

"*Contestability is interesting in these public arenas, and this is where a strength of our science is also, in fact, our weakness. In science we are used to ideas being contested. In fact, we probably all enjoy the tussle of ideas and different interpretations of data and different models. That playing with alternative explanations is, I think, one of the great pleasures of science. But when the public hears those sorts of debates, they do not really understand the function of testing of hypotheses*

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and testing of alternative solutions that goes on within science. When they see scientists disagreeing or arguing, they tend to believe either that one of the scientists is incompetent or that he has been bought off by some particular interest. Sometimes they just might understand that scientists might be marketing an idea to try and get research funds … But the public sees many claims from scientists, and this is where I think we face a skeptical audience. As someone quips, for every PhD there is an equal and opposite PhD." (p. 565, direct quote[2]).

3.2 The case for a transparent communication of uncertainties

On the other hand, there is a strong case for transparently communicating uncertainties. One of the main arguments for this is the inherently uncertain nature of science. Some authors thus argue that policymakers must be informed about all possible outcomes (Fischhoff & Davis, 2014; Hallegatte & Mach, 2016; Smith & Stern, 2011; Ward, 2008). Smith and Stern (2011) encourage scientists to communicate not only solid findings but also uncertainties and even speculations. The authors remark: "[...] the communication of impacts with a relatively low but uncertain probability to policymakers is critical when policy-makers consider those impacts to pose unacceptable risks. Failure to speculate on the nature of plausible outcomes decreases the value of science in support of policymaking and leaves the field open to speculation based on far less understanding of the science" (p. 4826). Fischhoff and Davis (2014) write: "Taking full advantage of scientific research requires knowing how much uncertainty surrounds it. Decision-makers with too much confidence in science can face unexpected problems, not realizing how wary they should have been. Decision-makers with little confidence in science can miss opportunities while wasting time and resources gathering information with no practical value. As a result, conveying uncertainty is essential to science communication" (p. 13664). Berger et al. (2021) highlight the potential of increasing the efficiency of decision-making when the relevant uncertainties are communicated transparently to policymakers. They note: “illustrating, quantifying, and discussing the multiple sources of uncertainty may help policymakers better understand their choices’ potential impact“ (p. 6). Focusing on natural disasters, Ward (2008) notes "the effective and appropriate communication of uncertainties by scientists to other groups such as policymakers, the public and the media, is vital to allow informed decision-making about limiting the exposure and vulnerability of people and their property to natural hazards" (p. 19).

As scientific knowledge, by nature, evolves over time, rebuking previous assumptions and changing the derived policy implications, Blastland et al. (2020) suggest that scientists must communicate uncertainties to increase consistency and trust to preserve long-term credibility. These authors illustrate this point with the evolution of knowledge about COVID-19, where previous assumptions were frequently revised. In a word of caution, the authors also allude to the illusion of objectivity due to personal and subjective beliefs and values.

Recchia et al. (2022) frame the question of transparency over uncertainties as an ethical consideration. Their experiment, in which they supply subjects with uncertain information regarding the sensitivity of COVID-19 antigen tests and the related chances of false test results, demonstrates the practical importance of communicating uncertainties: "If there is substantial uncertainty around a test’s negative predictive value for individuals with symptoms, public health

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[2] (Cullen, 2003). Address to the Conference Dinner [Address by Peter W Cullen, Member of the Wentworth Group, to the “Living with Climate Change” conference held in December (2002) by the four Academies for the Australian Greenhouse Office]. ATSE Focus, (128), 2–7. https://search.informit.org/doi/10.3316/ielapa.200310837

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officials may well prefer symptomatic individuals with negative tests to exercise caution and self-isolate anyway" (p. 3).

Moreover, communicating uncertainties within scientific evidence is just accurate, and concealing uncertainties can make science vulnerable to exploitation and misuse. Stirling (2010) argues that presenting uncertainty in the form of risk is not only inaccurate but also potentially dangerous: "An overly narrow focus on risk is an inadequate response to incomplete knowledge. It leaves science advice vulnerable to the social dynamics of groups — and to manipulation by political pressures seeking legitimacy, justification, and blame management. When the intrinsically plural, conditional nature of knowledge is recognized, I believe that science advice can become more rigorous, robust and democratically accountable" (p. 1029). Pearce et al. (2015) find the public capable of dealing with complexities and uncertainties regarding the science of climate change and argue a transparent debate inclusive of uncertainties and perhaps even controversial findings is beneficial, as it increases the public's understanding and, thus, resilience towards misinformation.

3.3 The case for a selective communication of uncertainties

The third strand of the literature agrees with the previous one on intending for scientists to best inform policymakers instead of making decisions for them. Yet, it also argues for carefully selecting the uncertainties to communicate. Contrary to the first strand, this strand strives for a neutral, "value-free" communication. Frank (2017) uses the following words: "The main ethical motivation for the "value-free ideal" is that scientists should not be in the position of making value judgments for decision-makers or policymakers" (p. 82). (Spiegelhalter, 2017) underlines the role of informants in the following: "Crucially, we need to be clear about whether we are seeking to persuade, or fulfilling a duty to inform” (p.34).

Perhaps the most common argument for such a selection is that the communication of uncertainties must be adapted to the audience's ability to comprehend and use the information (Frank, 2017; Patt, 2009; Spiegelhalter, 2017). In his conclusions, Spiegelhalter (2017) includes the following in his guideline for the communication of risk and uncertainty: "For more knowledgeable audiences, consider providing quantitative epistemic uncertainty about the numbers and qualitative assessment of confidence in the analysis" (p. 53). The author therefore supports omitting some uncertain information unless the audience's ability to comprehend these expressions is not guaranteed. Patt (2007) supports the argument of an audience-specific selection of uncertainties by highlighting that not every decision-maker needs in-depth uncertainty information: "The goal of scientific assessment, when communicating uncertainty, ought not to give the right information to guide all decisions but to provide enough background understanding of the nature of the uncertainty to stimulate those decision-makers whose decisions are particularly sensitive to the uncertainty to seek further help" (p. 243). Frank (2017) supports the selection by citing Steele (2012)[3]: "If decision-makers cannot understand explicit representations of uncertainty offered by scientists, then those scientists acting as advisors will have to make value judgments in converting their scientific representations of uncertainty into a format understandable by decision-makers" (p. 91).

[3] Steele, Katie. 2012. “The Scientist qua Policy Advisor Makes Value Judgments.” Philosophy of Science 79(5): 893–904.

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Lofstedt and Bouder (2021) and Frank (2017) add that uncertainties, which may not be fully understood by the audience, can be misused by political opponents. Improper processing or understanding of uncertainties may further trigger a spike in risk aversion or induce a negativity bias (Lofstedt and Bouder, 2021). Another compelling argument is a practical consideration: as science is inherently complex, the number of uncertainties is near infinity, and thus, some selection of uncertainties is indispensable. Winsberg (2018) follows this approach, illustrated with the example of climate models, which rely on many interlinked models with thousands of assumptions from various fields. However, as all statistical analysis entails components of uncertainties, some value judgment is necessary to move forward, thus arguing the value-free ideal is unattainable. Yet, by focusing on a coarser perspective and communicating graspable and significant uncertainties, scientists can approximate an informative, asymptotically neutral communication.

The work by Folker & Sandøe (2008) links this strand of the literature to the first, as it advises scientists to balance the public's conflicting needs for guidance and knowledge by using their own "best judgment" on which uncertainties to present with the intention of a value-neutral communication.

Most of the literature presents relative consensus about assigning scientists the role of informant instead of promoting them to decision-makers. Thus, the literature urges a neutral communication of scientific findings inclusive of uncertainties and pointing out the limitations of scientific findings. What remains unclear is how to identify the uncertainties to communicate and whether research processes can ever be "value-free" - a philosophical discussion at heart.

4 Experimental evidence on the perception of and reaction to uncertainties

The literature presented delivers convincing arguments to support the normative desirability of transparent communication of uncertainties. As uncertainties are an essential, inseparable, and informative part of science, they must be communicated somehow. To assess the policymakers' ability to comprehend and thus use the information contained in the communicated uncertainty, we now turn to experimental evidence on how uncertainties are perceived and dealt with. Ultimately, we are interested in whether policymakers might be misinformed by uncertainties, for example, if they cannot correctly use the information uncertainties present.

4.1 Outcome variables used in the literature

In what follows, we examine a collection of papers that provide respondents with information while experimentally manipulating various aspects of uncertainty, including presentation format and levels. However, the studies differ in *what* they assess the effects of uncertainty communication. This variability is evident in the vast array of outcome variables (also known as dependent variables) employed to measure the constructs or phenomena of interest. While some papers investigate respondents' trust ratings in the provided information, others explore whether respondents utilize this information in their decision-making processes. This section proposes a systematic categorization of the multiple outcome variables, classifying them into four main categories (also see Figure 1):

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1. Attitudes or perceptions
2. Consideration of information (self-reported judgment)
3. Consistency of decision-making with the information
4. Comprehension and confidence

First, attitudes or perceptions encompass variables like trust or perceived competence, and three subcategories define the object to which the attitude or perception refers (see also Table 2.1 for a list of related papers). The first subcategory concerns attitudes or perceptions of **the information**. It evaluates the information itself, including perceived uncertainty in newspaper articles or scientific estimates used in the study to convey information. Many papers cite one or more scientists or experts whose research produced the presented information. The second subcategory relates to the attitudes or perceptions of the **communicator or scientist**. It entails variables such as the perceived competence of this provider of information. The last group concerns attitudes or perceptions of **science** in general, such as trust in science or beliefs in broader topics like climate change.

Second, consideration of information comprises self-reported variables that measure whether the information was believed and integrated into the respondents' judgments, thus indicating respondents' conviction in the message (see also Table 2.2 for a list of related papers). Belief updating is a prominent example of how respondents incorporate new information into their existing beliefs and knowledge. Other variables assess the level of agreement with the presented information.

Third, consistency of decision-making with the information is closely related to the previous category, measuring the adoption of information (see also Table 2.3 for a list of related papers). However, it evaluates the actions or decisions taken, which demonstrate respondents' incorporation of the information in their decision-making processes. This category indirectly assesses belief but does not rely on introspection. The three subcategories of individual, collective, or principle-agent decisions differentiate who is concerned by the decision or action. In the first subcategory, the decision-maker makes decisions that concern themselves only, such as receiving the payoff generated by their bet. The second category involves decisions made in a policy context or other situations where the decision-maker is only indirectly concerned with the consequences of their decision. The last subgroup of principle-agent decisions refers to a scenario where respondents are instructed to envision themselves as employees making decisions within a work environment.

Finally, the last category, **comprehension and confidence**, includes variables that assess subjective or objective understanding of the provided information (see also Table 2.4 for a list of related papers). Comprehension does not equate to believing or agreeing with the information and is, therefore, distinct from the previous category. This category also includes variables that relate to how confident a respondent felt in making an information-related decision.

Figure 1: Categorization of Outcome variables used in the literature.

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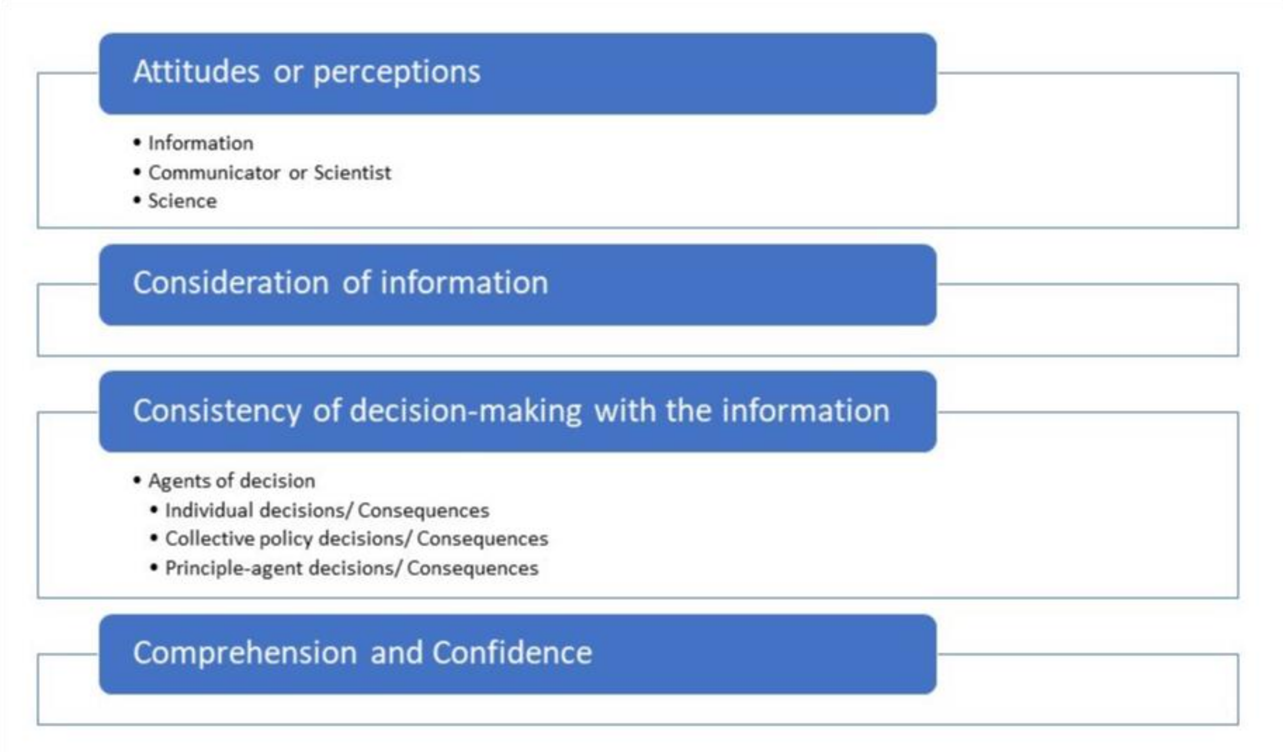

Table 2.1: Overview of variable: **Attitudes or perception towards**

Theme	Papers
1. Information	
Perceived (un)certainty of the information	Broomell & Kane, 2017; Chinn et al., 2018; Gustafson & Rice, 2019; Hendriks & Jucks, 2020; Ratcliff et al., 2023; Schneider et al., 2022; Van Der Bles et al., 2019
Perceived quality of the estimate	Cabantous et al., 2011; Recchia et al., 2021; Winter et al., 2015
Perceived difficulty in making an estimate	Cabantous et al., 2011
Trust in estimates or evidence	Brick et al., 2020; Fujimi et al., 2021; Kerr et al., 2021; Schneider et al., 2022; Van Der Bles et al., 2020
Perceived accuracy	Fujimi et al., 2021
Perceived credibility	Gustafson & Rice, 2019; Hendriks & Jucks, 2020; Ratcliff et al., 2023
Cognitive and affective reactance to the information	Kerr et al., 2022
Message engagement (liking the presentation, rating of interest for oneself and others)	Brick et al., 2020
2. Communicator or Scientist	
Perceived competence of the source	Cabantous et al., 2011

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Trust in the scientist or expert who presents the information	Kahan et al., 2011; Kerr et al., 2022; Ratcliff et al., 2023; Steijaert et al., 2021; Van Der Bles et al., 2020
Credibility of the scientist or expert who presents the information	Kahan et al., 2011
Perceived bias of the communicator	Steijaert et al., 2021
3. Science or science-related	
Trust in science	Chinn et al., 2018
Trust in the scientific field from which the information is derived and trust in the assertions of scientists from this field	Hendriks & Jucks, 2020
Support for using science in public decisions, belief of scientists acting in accordance with the public interest and scientists being unbiased	Chinn et al., 2018
Belief in climate change	Budescu et al., 2012
Perceived expert agreement	Kahan et al., 2011

Table 2.2: Overview of variable: **Consideration of information**

Theme	**Papers**
Belief updating as the change between prior and posterior beliefs	Bosetti et al., 2017; Fischer et al., 2020; Gaertig & Simmons, 2023
Personal agreement with the information	Chinn et al., 2018
Concern for the topic presented	Fujimi et al., 2021
Consistency of the subjective likelihood with the estimate	Patt, 2007
Consistency with the presented attitude	Winter et al., 2015
Consistency in judgment on the reliability with presented information	Recchia et al., 2021

Table 2.3: Overview of variable: **Consistency of decision-making with the information**

Theme	Papers
1. Individual decisions/ consequences	
Incentivized bets on outcomes	Gaertig & Simmons, 2023
Certainty equivalents	Baillon et al., 2012
Choice of two urns for an incentivized bet	Berger & Bosetti, 2019
Donation intention to science	Steijaert et al., 2011
Intention to get the COVID-19 vaccine	Han et al., 2021

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Intention to change relevant behavior	Gustafson & Rice, 2019; Han et al., 2021; Ratcliff et al., 2023
Self-reported use of the information for personal decisions	Schneider et al., 2022
2. Collective policy decisions/ consequences	
Support to increase government funding	Chinn et al., 2018
Support for relying on the information for a public policy decision	Kreps & Kriner, 2020; Schneider et al., 2022
Support for immediate policy action to prevent the presented hazard	Patt, 2007
Behavior recommendations for others	Recchia et al., 2021
Treatment recommendations for others	Brick et al., 2020
3. Principle-agent decisions/ consequences	
Insurance premium	Cabantous, 2007; Cabantous et al., 2011

Table 2.4: Overview of variable: **Comprehension and confidence**

Theme	**Papers**
Objective comprehension	Brick et al., 2020; Brick & Freeman, 2021; Fischer et al., 2020
Subjective comprehension	Fischer et al., 2020; Brick et al., 2020
Ease of reaching a decision on the presented issue	Chinn et al., 2018; Kerr et al., 2021
Confidence in one's own judgment	Recchia et al., 2021
Perceived informed-ness of decision making	Brick et al., 2020

4.2 Domain-specific observations

As previously mentioned, many fields have expressed an interest in communicating uncertainties, leading to experiments having been conducted on a large variety of potential events. In what follows, we categorize the reviewed papers based on the events studied, which are then grouped into general domains. For instance, events such as rising sea levels (Patt, 2007) or the increase in global surface temperature (Bosetti et al., 2017; Fujimi et al., 2021) are grouped in the climate change domain. Table 3 provides an overview of the domains of the different events studied.

Table 3: Overview of domains considered in the reviewed experimental studies.

Domain of the studied event	**List of papers conducting research in this domain**

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Health	Brick et al., 2020; Recchia et al., 2022; Chinn et al., 2018; Folker Sandøe, 2008; Gustafson and Rice, 2019; Steijaert et al., 2021
Covid-19	Kerr et al., 2022; Kerr et al., 2021; Recchia et al., 2021; Schneider et al., 2022; Ratcliff et al., 2023; Han et al., 2021; Kreps and Kriner, 2020; Gaertig and Simmons, 2023
Diet	Chinn et al., 2018
Climate Change	Kerr et al., 2021; Van der Bles et al., 2020; Fujimi et al., 2021; Patt, 2007; Bosetti et al., 2017; Budescu et al., 2012; Fischer et al., 2020; Harris et al., 2013; Kahan et al., 2011; Richards and den Hoed, 2017
Natural disaster	Cabantous, 2007; Cabantous et al., 2011; Patt and Schrag, 2003
Weather forecasts	Patt and Schrag, 2003
Natural preservation	Kerr et al., 2022; Van der Bles et al., 2020
Nuclear Power	Kerr et al., 2022; Kahan et al., 2011
Physics	Chinn et al., 2018
National unemployment rate	Kerr et al., 2022; Van der Bles et al., 2020
Childhood development and video games	Winter et al., 2015
Handgun carrying laws	Kahan et al., 2011
Sports events	Gaertig and Simmons, 2023
Share of other respondents' interest in sports over politics	Gaertig and Simmons, 2023
Monetary losses	Baillon et al., 2012

Only a few papers experimentally investigate the impact of communication regarding more than a single event or events from different domains. Due to the limited evidence, little can be said about inter-domain differences and what domain characteristics might cause a difference in how uncertainty is perceived or dealt with. In the following, we present the arguments used to motivate the investigation of different events or different domains. Future research interested in event- or domain-dependence may expand on these arguments.

Gustafson and Rice (2019) state it is "likely that effects of uncertainty frames are issue-specific because uncertainty is more tolerable about some things than about others" (p.3). They base this argument on the work of Afifi and Weiner (2004), who developed a theory for information management in communication theory. The theory indirectly supports issue-dependency, that is, the valence[4] of an (uncertain) outcome may cause an individual to wish to resolve or maintain the uncertainty. In their experiment, Gustafson and Rice (2019) pose the following research question: "*How do individuals' responses to uncertainty frames compare across relevant issue contexts*?" (p. 686). They further hypothesize that popularization and partisan polarization of a topic influence the response and design of three issues, which vary on these two dimensions while keeping the risk

[4] The term "valence" was first used by Lewin (1951) to describe "the forces that attract individuals to desirable objects and repel them from undesirable ones" (c.f. Shuman, Sander, & Scherer, 2013, p. 1).

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target and its scientific consensus comparable[5]. However, the produced results remain inconclusive.

Relying on previous literature (including Kahan et al., 2011), Chinn et al. (2018) argue that **prior beliefs** affect perceived levels of expert consensus in politicized issues. The authors therefore avoid politicized issues in their study on the perception of different levels of scientific consensus across three bogus topics[6]. Despite significant differences in credibility across the three tested issues, no interaction with the consensus information was found, thus indicating no significant differences in the underlying mechanism between issues. Their results indicate a correlation between perceived scientific certainty and personal agreement with the findings. Instead of attributing the correlation to prior subjective beliefs on the topic, the study terms the effect as consistent with a "gateway belief" from the corresponding gateway belief model (GBM, van der Linden et al., 2015) - asserting that personal agreement is a function of perceived scientific uncertainty.

Cabantous et al. (2011) study insurance scenarios relating to three hypothetical natural disasters: (a) hurricanes and (b) floods, which are considered catastrophic by the authors, and (c) home fires, which are not considered catastrophic. Notably, the three hypothetical events do not differ in the associated risk or expected loss. Results indicate that hypothetical insurance premiums elicited from US insurance employees to differ for the same probability interval presented as originating from two experts who agree on the range (thus, an imprecise estimate) compared to disagreeing experts (wherein the interval endpoints are two different points estimates). Figure 2 contains the experimental instructions given to participants. The authors find the frame of disagreeing experts to induce smaller risk premiums for fires than the imprecise estimate. However, the effect was reversed for the events of floods and hurricanes, although the pattern did not yield statistical significance. The authors attribute the emerging differences to the catastrophic nature of floods and hurricanes, such that non-catastrophic events are judged differently. Inferring from this, domains that differ in the nature of their consequences (catastrophic or not) might also be judged differently.

[5] One topic is both popularized and object to partisan divide. The second one is just popularized, but not affected by partisanship, while the last is neither popularized, nor affected by partisanship. The topics investigated all concern impacts on agriculture and workers in this sector. The specific topics are related to climate change, GMO labelling or the medical hazards of vibrating machinery, which threatens the musculoskeletal health of operators.

[6] The three made-up topics discuss whether the gravitational pull of the moon causes stronger earthquakes, whether repeated motions lead to bone damage, or whether artificial sweeteners affect the composition of gut microbiota.

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Figure 2: The sources of uncertainty in the experiment run by Cabantous et al., 2011 (table 2 of the appendix, p. 32).

Table 2. Scenarios: The Three Sources of Uncertainty

Source of Uncertainty	Implementation
Risk The probability of the risk is well established. There is a consensus on a precise probability.	You have asked two modeling firms with whom you usually work to evaluate the annual probability of a flood severely damaging a home in the area. Both modeling firms estimate that there is **1 in 100 chance** that a flood will severely damage homes in this area this year (i.e., the annual probability is 1%). They both are confident in their estimate.
Imprecise ambiguity There is uncertainty about the probability of the risk but there is no controversy.	You have asked two modeling firms with whom you usually work to evaluate the annual probability of a hurricane severely damaging a home in the area. Both modeling firms recognize it is difficult to provide you with a precise probability estimate. The two modeling firms however agree that the probability that a hurricane will severely damage homes in this area this year ranges somewhere between **1 in 200 chance and 1 in 50 chance** (i.e., they have converged to the same 0.5% to 2% probability range).
Conflict ambiguity There is controversy about the probability of the risk.	You have asked two modeling firms with whom you usually work to evaluate the annual probability of a fire severely damaging a home in the area. There is a strong disagreement between the two modeling firms. One modeling firm confidently estimates that there is **1 in 200 chance** that a fire will severely damage homes in this area this year (i.e., the annual probability is 0.5%). The other modeling firm confidently estimates that the chance that a fire will severely damage homes in this area this year is much higher: **1 in 50 chance** (i.e., the annual probability is 2%).

Other reviewed studies which study more than one topic or domain include Kerr et al. (2021), who investigate if observed patterns following uncertainty manipulations hold for topics more **psychologically distant** but do not expand on the potential underlying mechanisms relating to said psychological distance. The study was conducted with a British sample and included the national unemployment rate, the predicted rise in global surface temperature, and the number of tigers roaming free in India. Their results indicate significant similarities across topics and thus confirm the previous findings of Van der Bles et al. (2020), who tested the same three topics and found no differences.

At odds with the hypothesized domain dependency as indicated by previous studies, Steijaert et al. (2021) argue that comparing three different topics increases generalizability and thus seem to assume no reason for the link between the trustworthiness of a scientific finding and uncertainties of that finding to vary depending on the domain of the studied event. The three bogus topics they investigate span the domains of health, particulate matter, and diet. No differences in the trustworthiness of the scientist, intention to donate to the scientist or the perceived persuasiveness between the three topics are revealed.

In summary, various arguments for differences in treating uncertainties of topics from different domains have been proposed in the literature. These include the impact of topic popularization, partisan politicization or prior beliefs, the catastrophic nature of the events assessed, or the psychological distance subjects perceive. As none of the hypothesized mechanisms have been cross-validated, the evidence presented here is preliminary.

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4.3 Varying uncertainty

4.3.1 Varying uncertainty qualitatively

Uncertainty in scientific findings emerges from many different factors. Spiegelhalter and Riesch (2011) propose a five-level list of objects of uncertainty in modelling, which includes uncertainties arising for *aleatory* reasons, such as events that may only occur in the future, and for *epistemic* reasons, such as a lack of available data to evaluate a specific claim or having only preliminary models at hand. See Box 2 below for an illustration of their proposition.

Box 2 Spiegelhalter and Riesch (2011): A five-level list of uncertainties in modelling.

1. Events and their essential unpredictability,
2. The parameters (not) included in the model and therefore, the limitation of information,
3. The range of models to choose from and, with that, the limits of formalized knowledge,
4. Model inadequacy due to epistemic uncertainty over missing parameters or due to methodological shortcomings and
5. Somewhat aleatory uncertainty, which expresses that there are unspecified doubts, either due to an unwillingness to name all other factors that might reduce the reliance on a model or the general inability to provide an exhaustive list of omitted factors.

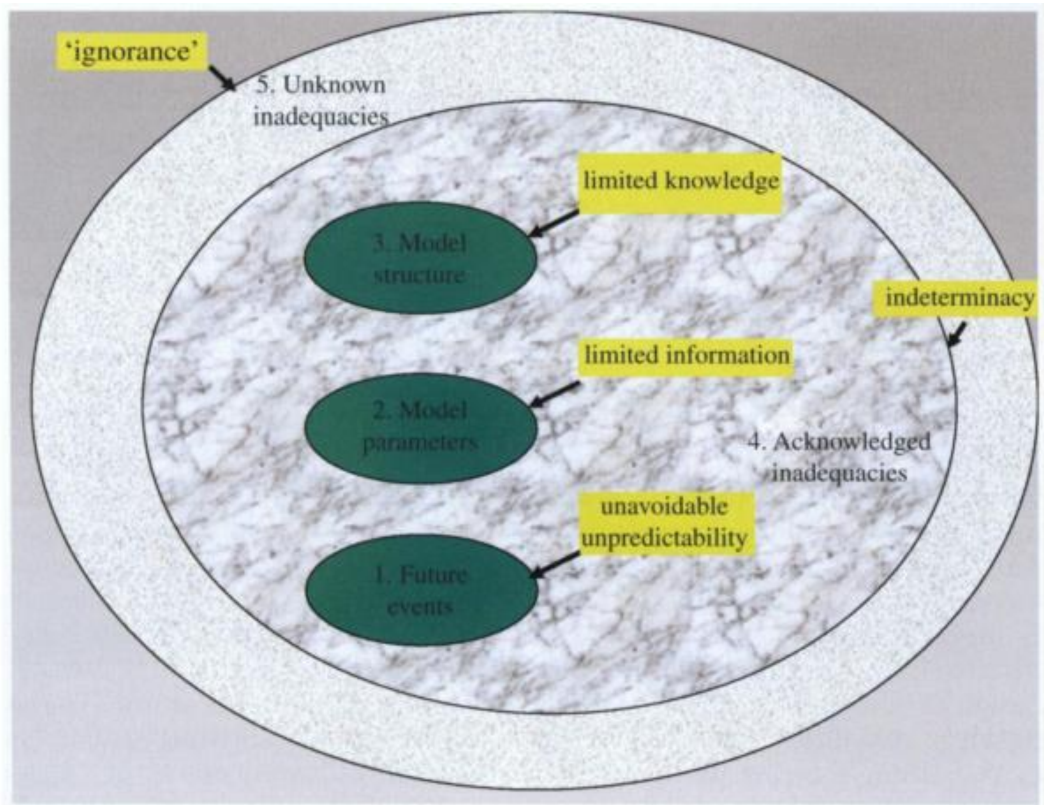

Figure 1. Five levels of uncertainty. While the first three form a natural hierarchy, levels 4 and 5 apply to the entire modelling process and may exist even if there is little uncertainty expressed within the modelling framework.

In the context of climate, Smith and Stern (2011) define five areas of relevance for climate policies where uncertainty prevails, such that large uncertainties of various nature exist around them,

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ranging from societal to technological and physical uncertainties. A more detailed description of the five areas is presented in Table 4.

Table 4: Areas relevant to climate change and policies and their respective uncertainties from Smith and Stern (2011, p 4825). *Note*: The authors use the term "Links" as they refer to each area as a link in the "causal climate chain"
Link 1: emissions occur, our quantitative understanding of which is hindered by societal and technological uncertainties.
Link 2: atmospheric concentrations change, our quantitative understanding of which is hindered by biological, chemical and physical uncertainties.
Link 3: weather changes, defining a new global climate, the details of which are obscured by societal, biological, chemical and physical uncertainties.
Link 4: systems[7] alter both political and ecological subsystems, the detailed evolution of which is obscured by environmental and societal uncertainties. It is unclear exactly which initial changes will occur, when those that do occur will happen and how feedback effects owing to these changes propagate, in turn, through the Earth system.
Link 5: risks to individuals change, the desirability or undesirability (the 'value') of which is obscured by uncertainty (valid diversity) in preferences and values, by uncertainties in vulnerability and by uncertainties related to new technologies

In science, uncertainties about a study's result may be attributed to several, often interlinked sources[8]. The primary interest in this section is to investigate if attributing uncertainty to a specific source alters perception and reaction to the given uncertainty compared to stating uncertainty without mentioning its cause. Studies investigating the attribution to a single source will be presented and the different sources investigated will be discussed. A secondary interest is determining if specific sources increase the perception of uncertainty about a finding compared to other sources. This might indicate different tolerance levels for uncertainties arising from one source over the other. The title of this section - Qualitative Variations of Uncertainties - expresses an interest in a different *quality* of uncertainties.

Ratcliff et al. (2023) provide participants with scientific information about whether or not Pfizer's COVID-19 vaccine is effective in recipients who do not experience any side effects. As part of their experimental manipulation, they disclose the study's preprint status and describe it as preliminary. None of the four variables of interest – the presented claim's perceived uncertainty and trustworthiness, the trustworthiness of the scientists involved, or a respondent's intention to get vaccinated - was found to be significantly impacted by this manipulation. Another manipulation, which includes hedging through speculative language and underlining the deficiency of knowledge, was found to negatively influence all tested outcome variables. Personal characteristics such as an expressed preference to be informed about uncertainties and epistemic beliefs, which "capture whether individuals view medical science as an ongoing and fallible process" (p. 6), mediated the found effects. This study suggests the attribution of uncertainty to the preliminary, preprint status of the provided evidence not to be influential for beliefs or behavior. However, the study was conducted with a US sample in April 2021 - four months after the FDA approved the first vaccine

[7] Changes in physical systems (i.e., biological, chemical, and physical uncertainties) further impact political and ecological subsystems.
[8] A lack of available data is likely to restrict the reliability of a model built upon the data and diverging interpretations of the uncertainties within a data set might trigger some experts to disagree.

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against COVID-19- when less than half the population had received a first shot. As the authors note, preprints and preliminary findings were commonly reported by the media and were welcomed due to the urgency and threat to the public health situation. These circumstances might contribute to the results and present an unusual context.

Hendriks and Jucks (2020) presented participants with a newspaper article on climate change and ocean acidification to elicit participants' assessment of the claim, the perceived credibility of the article as a whole, trust in the arguments brought forth by the scientists involved with the presented finding, trust in the general climate science, and the self-reported ease participants experienced when making related, climate-friendly, and personal decisions. In their experiment, the authors provided participants with information on the methods employed in empirical research on climate change. The authors justified their manipulation using previous findings, which indicated that more scientifically knowledgeable individuals reacted less negatively to the presentation of scientific uncertainties. This argument was indeed also considered by Ratcliff et al. (2023), who tested it and found an association with participants' epistemic beliefs. Hendriks and Jucks (2020) argue "*that if, along with a text discussing the scientific uncertainties of a particular issue, participants were also given information about the direct source of the uncertainty— namely, the associated scientific research methods— this might make them more trustful and allow them to more easily make decisions*" (p. 403). However, neither of their two studies found a significant effect on the information provision. In a second study, the authors highlighted the contribution to uncertainties by either to the research methodology as in their first study, or by a lack of expert consensus. Notably, the manipulation did not explicitly state that uncertainty arises only or due to either of these sources. Additionally, the authors designed experimental conditions with either normalized uncertainty in science to *"test[...] whether the framing of scientific uncertainty—either as something inherent to science or as something that fundamentally challenges making reliable conclusions from evidence— affected participants' ratings of the article's credibility, ratings about trust, and their decision-making surrounding the issue*" (p. 406). The results again revealed no significant effects of any experimental condition. However, the collected data provided preliminary evidence that "*intellective epistemic style—an appreciation for dealing with complex issues and engaging in problem-solving*" (p.408) positively impacts trust in the message, in climate science and ease of decision making.

Schneider et al. (2022) attribute uncertainty to either expert (dis)agreement or data (un)availability by statements on the quality of the underlying evidence: "The quality of the evidence underlying the reported case fatality rate is uncertain, because there is disagreement between experts" (p. 855) or "[...] because there is a lack of data" (p. 856). Participants are provided estimates about the current COVID-19 fatality rate: "Out of every 100 people in the UK who test positive for COVID-19, it is estimated that eight will die. This is known as the COVID-19 case fatality rate" (p.855). In subsequent studies, the authors vary the evidence quality from high, which renders the estimate "fairly certain" (p. 862) to ambiguous without attribution to a specific source ("The quality of the evidence underlying the reported case fatality rate is uncertain. The quality of the evidence could be high or could be low", online supplementary materials p. 46). Control conditions do not mention the evidence quality or sources of uncertainty. Three outcome variables were recorded and tested: the perceived (un)certainty of the estimate, trustworthiness thereof, and the self-reported use of the given information in decision-making - both on the individual level and as a normative expectation for government decisions ("To what extent do you think the government should base its decisions and recommendations on how to handle the pandemic on the mentioned COVID-19

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case fatality rate?", p. 867. The two items formed an index and were not analyzed individually). No significant difference was found between the two sources of uncertainty in any of the levels.

In a related study, Patt (2007) tests an expert vs model consensus frame on predicting sea-level rise above a certain threshold in Boston (USA). The employed 2x2 experimental design varies the likelihood between 20% and 80%, together with the estimate obtained by either models or experts (see Figure 3 for the exact wording of all four conditions). After the intervention, participants indicated their subjective probabilistic belief of the event and their preference for the city to take immediate, protective action instead of delaying a decision over potential measures until further information becomes available. Subjective beliefs significantly differ between the model- and expert frame for the unlikely event of 20%, such that the beliefs are closer to the given estimate for subjects exposed to the model frame. A trend towards a similar inclination to adjust personal beliefs more closely to the provided estimate in the model frame is indicated but remains statistically insignificant. The demand for immediate action is congruent with the elicited subjective belief: the share of participants demanding immediate action in the model frame is significantly below the share in the expert frame in the unlikely condition. However, unlike subjective beliefs, the trend for the action demand is less clear for the more likely condition, such that no increased demand can be observed. Statistically, the estimates are not significantly different from one another. The experiment was run in three waves, with the second occurring shortly after two devastating hurricanes. The results of this wave show no difference between the framing conditions. The first and third waves deliver similar results, which are presented here.

Figure 3: Experimental treatment conditions of the 2x2 between-subject design taken from Patt (2007) (p. 43).

Table 1
Four experimental treatment groups

	Unlikely	Likely
Model-based	Models indicate that there is a 20% chance it will occur	Models indicate that there is an 80% chance it will occur
Conflict-based	Two of ten experts say it will occur	Eight of ten experts say it will occur

In brief, the heterogeneous methodology employed makes comparisons across the presented studies complex such that differences exist: not only in the nature of the outcome variable, but also in measurement thereof; in the manipulation itself (merely stating it is attributed to source X with few words or providing lengthy information texts); the studied events and their nature (domain differences between health and climate change mainly, but more); and more. While Hendriks and Jucks (2020) and Schneider et al. (2022) find their manipulations on expert consensus not to matter, the results of Patt (2007) indicate a difference between model and expert consensus. While other studies investigate the mediating effect of beliefs related to science and epistemic knowledge (see section Comparing Policymakers to Lay People - Mediating Variables), the evidence on the provision of preprint status (Ratcliff et al., 2023) or research methodology (Hendriks and Jucks, 2020) revealed no significant effect.

Imprecision vs. expert disagreement

The reviewed literature includes three studies that distinguish between uncertainty arising from imprecise estimates and diverging estimates with the same boundary values. The range is either

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framed as a single imprecise estimate upon which two experts agree or as two distinct estimates from the two experts.

Cabantous (2007) tests for differences in a hypothetical insurance premium as elicited in a sample of French actuaries. Two scenarios are presented to participants: "insuring a factory against property damage caused by an earthquake" or "insuring a plant that uses toxic chemicals during the production process" (p. 223). The earthquake scenario is less severe in the expected loss (likelihood of 0.002 with a potential loss of €1.5 million; expected loss being 0.002x €1.5 million = €3000) than the pollution scenario (likelihood of 0.02, loss of €7.5 million; expected loss being 0.02x €7.5 million = €150'000). Three experimental conditions were presented to each participant:

1. A simple risk, where both experts agreed on the estimates of 0.002 and 0.02 respectively;
2. An imprecision, where the described range of 0.001 to 0.003 and 0.01 to 0.03 respectively, upon which the two experts agree was used; and
3. A conflict, where the two individual expert estimates of 0.001 (0.01) and 0.003 (0.03) were used.

Respondents indicated if they would grant the demand for insurance and if so, which minimum premium they would ask for. For the analysis, the risk premium was normalized by the expected value. No main effect was found for the scenarios; thus, the data for both earthquake and pollution scenarios was merged. Risk premiums were significantly lower in the simple risk scenario in the pooled sample and the two scenarios, indicating persistent *ambiguity aversion* (i.e., a preference for the risk condition over imprecision or conflict). In the pooled sample of both scenarios, risk premia were significantly higher when presented with conflict rather than imprecision or simple risk. The effect did not reach statistical significance in the sub-group analysis of both scenarios.

In a subsequent paper, Cabantous et al. (2011) conducted a similar experiment with US insurers. They elicited insurance premiums for home insurance against three hazards (hurricane, flood or housefires), all with the same potential loss of $100 000 and an expected loss of $1000 with a likelihood of 0.01 in the simple risk and 0.005 and 0.02 for imprecision and conflict, respectively. Unlike previously, the range did not equate the simple risk by an arithmetic mean, but by a geometric mean. No statistically significant difference from all three scenarios could be detected in the pooled sample. In a sub-group analysis, the risk premium was found statistically lower for conflict rather than imprecision home fires - a finding opposing the previous pattern of higher insurance premiums for conflict over imprecision. The hurricane and flood scenarios revealed the opposite pattern - in line with the previous finding - such that risk premiums were higher for conflict than imprecise ambiguity, however the difference did not reach statistical significance (the paper states no p-value of the analysis). The authors categorize hurricanes and floods as catastrophic and home fires as not catastrophic, and the reason that this nature of events might cause a difference in the premia elicited. Hurricanes occurred relatively frequently during the time in which the experiment was conducted, thus the damage might be more salient to participants. Additionally, the data available for home fires is generally more extensive and more consistent, whereas many insurance firms just reviewed their policies relating to climate risk to account for the increased likelihood due to climate change. The authors also elicited whether the given risk estimates were perceived as usual. For the home fire scenario, the estimates were judged mostly as usual or standard for the risk treatment, but less for imprecise and less for conflict ambiguity. The same tendency was observed for floods and hurricanes, albeit statistical significance was not met.

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Baillon et al. (2012) designed a choice experiment using lotteries with potential losses. As before, three conditions are investigated: simple risk, imprecision, and conflict. The authors elicit the certainty equivalents[9] (CEs) of all three scenarios along (mean) probabilities ranging from 0.1 to 0.9. Figure 4 shows the choices participants made in the first experiment. The elicited CEs average €102 for conflict, €146 for simple risk, and €221 for imprecision and are statistically different. This indicates that participants preferred conflict over both risk and imprecision. Ambiguity aversion is only found for imprecision, but no aversion or seeking was detected for conflict. The authors also elicit subjective beliefs over the loss probability in a second experiment. While replicating the pattern from the first experiment, the authors find the subjective beliefs significantly removed from the average midpoint in the conflict condition, but not in the imprecision one. Thus, the authors derive a source preference for the more optimistic expert who indicated a lower likelihood of the loss appearing, such that the more favorable information is trusted and taken more into account than the one indicating a loss more probable. No such source preference exists in the imprecision condition.

Figure 4: Choices of the experiment conducted by Baillon et al. (2012) (taken from p. 48).

#	Rank	Source	p	x	y	#	Rank	Source	p	x	y
A1	13	Risk	0.1	−1000	0	A11	2	I	0.1	−1000	0
A2	3	Risk	0.3	−1000	0	A12	17	I	0.3	−1000	0
A3	8	Risk	0.5	−1000	0	A13	6	I	0.5	−1000	0
A4	5	Risk	0.7	−1000	0	A14	10	I	0.7	−1000	0
A5	9	Risk	0.9	−1000	0	A15	11	I	0.9	−1000	0
A6	7	Risk	0.5	−500	0	A16	15	C	0.1	−1000	0
A7	18	Risk	0.5	−500	−250	A17	16	C	0.3	−1000	0
A8	20	Risk	0.5	−750	−500	A18	19	C	0.5	−1000	0
A9	14	Risk	0.5	−1000	−500	A19	12	C	0.7	−1000	0
A10	4	Risk	0.5	−1000	−750	A20	1	C	0.9	−1000	0

TABLE 1. $x_p y$ (risk), or $x_{[p\text{-}0.1,p+0.1]}y$ (I), or $x_{\{p\text{-}0.1,p+0.1\}}y$ (C}

Taken together, the three studies evaluating imprecision vs. conflict do not deliver converging findings: While Cabantous (2007) finds participants to dislike conflicting expert advice more than imprecise but consensual advice, a subsequent study from Cabantous et al. (2011) finds the opposite pattern for non-catastrophic events, such that conflicting expert advice is preferred over imprecision. Baillon et al. (2012) deliver results wherein conflicting expert advice is preferred even over simple risk with a lower degree of objective uncertainty. The three studies differ in some dimensions: All investigate different events from industry to home insurance and artificial lotteries,

[9] Certainty equivalents elicit a certain outcome, which makes the decision maker indifferent with the proposed gamble. As the setting discussed here concerns losses, a certainty equivalent can be though of as the price a decision maker is willing to pay to avoid the gamble.

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and the losses at stake also vary between the studies. While Cabantous (2007) and Cabantous et al. (2011) ask participants to act as employees of a (hypothetical) insurance company and, thus, to make decisions without direct and immediate consequences for themselves, choices in the study by Baillon et al. (2012) concern the participants personal (hypothetical) losses. Further research is warranted to provide explanations for the found differences.

4.3.2 Varying uncertainty quantitatively

Studies in the previous section compare treatment conditions that explicitly mention or highlight uncertainties to a control group without explicit statements on uncertainty. However, this literature does not answer whether presenting agents with different *quantitative* levels of uncertainty - e.g., information that is very or just a bit uncertain - impacts perception or decision-making. Such knowledge may indicate how much uncertainty agents may tolerate before dismissing the information as unreliable. In the following, we present studies that experimentally manipulate the magnitude of uncertainty and compare response patterns to these different levels to test for a potential sensitivity in perception and decision-making. Simultaneously, these studies compare the different uncertainty levels to a benchmark without explicit information. This evaluation provides insights into how people respond to information without explicit statements on uncertainties and, therefore, uncovers how much uncertainty is implicitly assumed when uncertainties go unmentioned.

Van Der Bles et al. (2020) evaluated perceived uncertainty and trust in both the estimate and source following a short text on the number of unemployed in the UK in a previous period spanning three months. The experimental design follows a 2x3 in-between subject design; first, uncertainty is either presented through a numeric range around the estimate (numeric) or through the following verbal statement:

> *"The report states that there is some uncertainty around this estimate, it could be somewhat higher or lower"* (verbal condition).

Further, the authors manipulated the level of uncertainty to a low, medium or high. In the verbal uncertainty condition, the formulation "*somewhat higher or lower*" was labeled the medium uncertainty and was replaced with "*slightly higher or lower*" for low and " *a lot higher or lower*" in the high uncertainty manipulation.

For the numeric treatments, larger ranges were chosen to represent larger uncertainties. The ranges corresponded to statistical confidence intervals with differing confidence levels. Per definition, higher confidence levels increase the size of an interval as the confidence about the parameter of interest falling within the given range grows. Results revealed no statistical differences between the varying magnitude of uncertainty for perceived uncertainty. Still, they confirmed earlier results of increased perceived uncertainty in the verbal conditions over the numeric ones. Minimal effects of magnitude were found for the variables of trust in both numbers and source, which increased in the low uncertainty condition compared to the control. No significant differences emerged for the high uncertainty condition (neither as compared to low, nor medium uncertainty). To our knowledge, the differences between the numeric and verbal conditions were not analyzed separately. This study thus implies minimal sensitivity to the experimental manipulations of quantitative uncertainty.

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Two related studies vary uncertainty magnitude indirectly through manipulations on the underlying evidence quality. Both refute the results of Van Der Bles et al. (2020) by uncovering considerable sensitivity to various levels of uncertainty.

Schneider et al. (2022) provide participants with information regarding the estimated fatality rate for COVID-19 as the number of deaths among 100 infected and the quality of the underlying evidence. Their results reveal the expected effects of uncertainty cues, such that higher evidence quality increases trustworthiness and reported use of the information in decision-making. In contrast, low evidence quality has the opposite effect. Compared to a condition with no explicit mention of evidence quality, low-quality cues induce a more substantial effect than high-evidence cues. An ambiguous cue, which states that *"The quality of the evidence could be high or could be low,"* has similar effects in both directionality and size as low-quality cues.

Chinn et al. (2018) employ a similar manipulation by varying the level of expert agreement on five levels (24%, 45%, 65%, 85% and 95%), as well as a control with no explicit mention of such consensus on made-up newspaper articles on three made-up topics (whether the gravitational pull of the moon causes stronger earthquakes, whether repeated motions lead to bone damage, or whether artificial sweeteners affect the composition of gut microbiota). Their results indicate that low levels of expert agreement (25% and 45%) reduce perceived certainty. In contrast, the explicit statements on levels between 65% and 95% do not increase perceived certainty compared to the condition without information on expert consensus. This indicates that statements without mention are treated as if there was considerable (above 65%) consensus on the topic.

In conclusion, the revealed null effect of the experimental manipulations on perceived uncertainty in Van Der Bles et al. (2020) might be a result of insufficiently distinct categories: the labels of "slightly," "somewhat," and "a lot" in the verbal condition might not be different enough to produce an effect of measurable size in the given sample. Similarly, the increased ranges in the numeric uncertainty conditions might also not be sufficiently distinct. However, there are reasons to assume ranges are more informative (thus indicating less uncertainty), as described in more detail in the section “Moments of the distribution.”

The remaining two studies presented here and published by Schneider et al. (2022) and Chinn et al. (2018) imply sensitivity to quantitative variations of uncertainty through contributing factors such as expert consensus and data availability. Higher levels of uncertainty thus produce a more substantial effect on variables such as perceived certainty or intended use of the information for decision-making. Information provisions unaccompanied by any explicit statement of evidence quality tend to be perceived as closer to higher than lower evidence quality. None of the studies investigated the question of a potential threshold for the magnitude of uncertainty after which the provided information is dismissed as futile.

4.4 Moments of the distribution

Scientific research often aims to estimate future values of specific variables of interest, such as the global temperature increase or the average number of wildfires. These predictions are derived from a likelihood distribution function, which expresses the possible values a variable might take together with the likelihood of these values to occur. A prediction can either be expressed by a single number – typically the mean or median of the distribution – or by a confidence interval, defined by a range

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with a minimum and maximum value, and a confidence level that the actual value falls within this range.

The intervals are statistically more precise, providing a range within which the variable is expected to fall. Additionally, intervals present richer information about the expected interest value and might *reduce* uncertainty. Yet, they may be interpreted as less precise knowledge due to limitations in the underlying evidence or the quality of the estimation itself, and thus potentially *increase* the perceived uncertainty. Therefore, the interest in this section is to uncover the potential effect of presenting different moments of the distribution with a specific interest in its directionality. Thus, the interest is not to induce uncertainty and discover responses to uncertainty as has been done in previous sections[10] but to understand if the different modes of estimates affect the perception of uncertainty. Experimental studies addressing this question are discussed in the following section.

4.4.1 Point-estimates vs ranges

First, we consider studies investigating the potential effects of the provision of ranges instead of point estimates such as averages.

Several papers find mixed results. Kreps and Kriner (2020) test different presentation formats of scientific estimates regarding the estimated COVID-19 fatality rate. Their point estimate indicates 147,040 deaths, while the range condition predicts between 88,217 and 293,381 fatalities with no additional point estimate. The authors describe ranges as "[...] more accurate because small changes in assumptions and data upstream for a virus with exponential growth rates can lead to enormous downstream differences in projections. While emphasizing the enormous range in a model's estimates means that the eventual toll is less likely to be falsified, it could also backfire and undermine confidence because its nearly four-fold difference between lower and upper bound appears indeterminate" (p.6). The results reveal no significant difference in participants' elicited support for relying on scientific models to inform a potential reopening between a point estimate and a range after lockdown. Yet, an index measuring general support for science was found to be diminished when presented with ranges.

Van Der Bles et al. (2020) tests the effect of ranges (control) vs. point estimates (termed numeric treatment) alongside a verbal description of uncertainty (verbal treatment) on three topics (the rise in global average surface temperature between the years 1880 and 2010, the number of unemployed in the UK or of tigers in India). Again, ranges were not accompanied by point estimates but differed by topic in the value of the presented estimates. For example, participants in the control condition under the unemployment topic read the following statement:

> *"Recently, an official report came out with new information about the unemployment rate in the United Kingdom. This report stated that government statistics showed that between April and June 2017, an estimated 1,484,000 people in the UK were unemployed" (p. 7681).*

[10] Research presented in the previous section on the quantitative variation of uncertainty varied the magnitude of uncertainty, whereas the section on qualitative variation tested for possible effects of attributing uncertainties to different sources.

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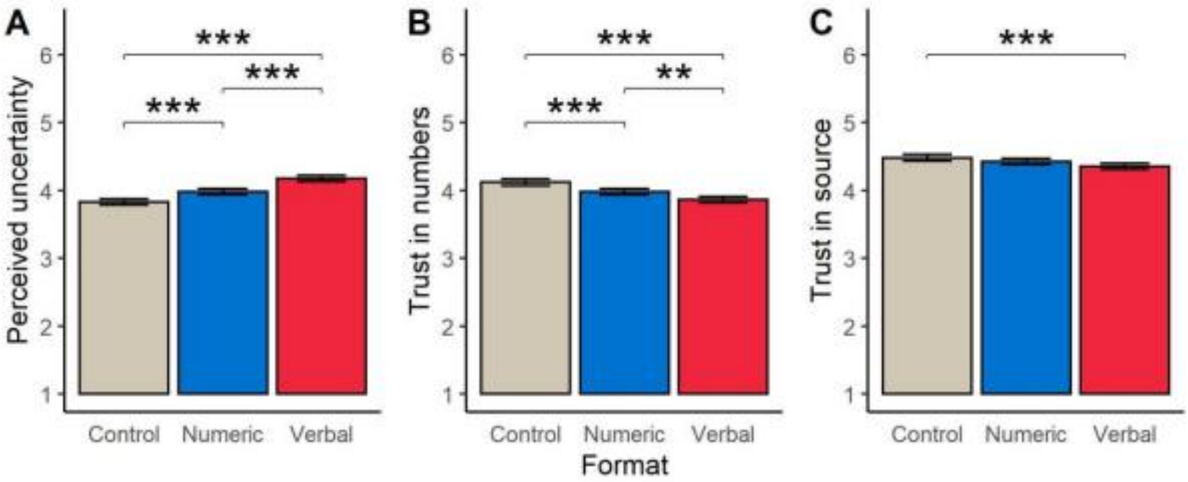
The numeric condition presented a range from 1,413,000 to 1,555,000. The estimate on the tiger population in India was 2,226, with a range of 1,945 to 2,491. The global surface temperature estimate was 0.85°C (0.65 to 1.06°C in the range). As no difference between the three topics – temperature increase, number of unemployed, and number of tigers -was found, the analysis was performed on the pooled sample. Results indicate an increase in participants' perceived uncertainty. However, the manipulation did not affect trust in the estimate or source. The result was replicated in four subsequent studies. Relatedly, Kerr et al. (2021) presented participants with information regarding the COVID-19 hospitalization rate with a point estimate of 17% and the range between 10% to 35% in addition to a verbal expression of uncertainty ("There is some uncertainty about that percentage, it could be somewhat higher or lower," p. 6). Results essentially replicate the pattern Van Der Bles et al. (2020) found, just with a decrease in trust in the estimate itself. Figure 5 plots the results of Kerr et al. (2021).

Figure 5: Results by Kerr et al., 2021.



Gaertig and Simmons (2023) present 12 incentivized studies testing the provision of ranges and a point estimate on the take-up of the given information. Participants placed bets on the outcomes of various events, including popular sports game outcomes, COVID-19 fatalities, or the average number of participants indicating a preference for politics over sports. After indicating their subjective beliefs, participants were presented with expert advice from either a model or a human advisor, presented with or without ranges. Figure 6 presents the experimental instructions shown to participants in one of the studies. Results reveal that participants were more likely to utilize the expert information when presented with ranges, either as switching from one's previous subjective belief to the expert guess or the change in posterior beliefs. Interestingly, the effect persisted over confidence intervals with confidence levels of either 75%, 90%, or 95%.

Figure 6: Experimental instructions in Gaertig and Simmons (2023).

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Figure 1
Sample Stimulus in Study 9

Sample Prediction Question, Advice Wording, and Final Prediction in Study 9

Sunday, November 24, 2019, 1:00 pm ET

Miami Dolphins @ Cleveland Browns

	Miami Dolphins	Cleveland Browns
Wins-Losses	2-8	4-6
Points Scored Per Game	13.9	19.2
Points Allowed Per Game	30.5	22.8

How many total points will the two teams score in this game?

No-confidence-interval Condition:

Model's prediction: The statistical model's best prediction is that the two teams will score 45 total points.

Confidence-interval Condition:

Model's prediction: According to the statistical model, there is a 75% chance that the two teams will score between 30 and 60 total points. Its best prediction is that the two teams will score 45 total points.

Your prediction: You predicted that the two teams would score 60 total points.

Which prediction would you like to submit as your official prediction - the model's (45 total points) or your own (60 total points)?

- The model's prediction: 45 total points
- My own prediction: 60 total points

Participants were randomly assigned to see only the model's best guess (no-confidence-interval condition) or to see the best guess accompanied by a confidence interval (confidence-interval condition).

Several studies from the field of economics and decision-making rebuke such positive effects. Cabantous (2007) samples actuaries and elicits hypothetical insurance premiums as normalized by the expected outcome of a prospect. Two events are considered, which differ in their expected loss (€1.5 or €7.5) and their likelihood to occur (p=0.002 or 0.02). The range condition produced significantly higher mean premiums for both scenarios. In a subsequent study, Cabantous et al. (2011) tested the mechanism with US insurers on catastrophic (hurricanes or floods) or non-catastrophic events (home fires) with the same likelihood and expected loss. The point estimate of the event's probability to occur was set to 1%, while the range equaled 0.5% to 2% chance. Thus, the geometric mean equals the point estimate, but not the (arguably more intuitive) arithmetic mean. Results again indicated higher insurance premiums when presented with a range rather than a point estimate. In two experiments, Baillon et al. (2012) sample both post-graduate civil engineering students and Bachelor and Master students by eliciting certainty equivalents to

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proposed gambles producing monetary losses[11]. Ranges were set to ± 0.1 of the point estimate. As the certainty equivalents for ranges over point estimates were significantly higher (€146 vs €221), losses associated with the ranges were perceived as costlier - despite the expected value being equal to the point estimate alone. The study differs from the others presented here as the range condition modified the outcome space.

Overall, the evidence on presenting ranges instead of point estimates is mixed. Variations in methodology, domains, outcome variables, and the size of the considered ranges might cause the observed differences. Gaertig and Simmons (2023) who find a convincing and robust positive effect of ranges also present ranges *alongside* the point-estimate. Thus, the information they provide informs participants about further moments of the distribution - namely, the spread or skewness. This increases the richness of the information. Studies such as Cabantous (2007), Cabantous et al. (2011) and Baillon et al. (2012) consider potential losses (either through natural events such as hurricanes or pollution, or through hypothetical lotteries). In contrast, Gaertig and Simmons (2023) participants may win money with their choices. Literature from behavioral economics such as prospect theory (Kahneman & Tversky, 1979) frequently finds the loss and gain domains to produce contrary preferences such as risk-seeking for losses and risk avoidance for gains.

The limited number of studies considered in this review does not permit an in-depth analysis of the causes behind the unresolved research question.

4.4.2 Presenting individual data points

Instead of just presenting a range of sorts, one might also present individual data points upon which the estimation relies. This approach has been taken twice in the reviewed literature.

Bosetti et al. (2017) test three different formats of an infographic estimating the global surface temperature increase by amending a boxplot with outliers or all observations (see Figure 7). While the format was insignificant to the change of posterior beliefs in a sample of European MBA students, policymakers recruited at the COP21 in Paris were more convinced by the richer information as they updated their prior beliefs more than poorer information.

Fujimi et al. (2021) studied the effect of the presentation format on an estimate of global surface temperature increase, as inferred from 19 models. The authors find a positive effect on trust and perceived accuracy in a general population sample when presented with all individual data points instead of just the average or a range presenting the minimum and maximum values of the individual underlying models. While numeracy is insignificant to these effects, sensitivity to the format increases with participant's education levels.

[11] Certainty equivalents elicit a certain outcome, which makes the decision maker indifferent with the proposed gamble. As the setting discussed here concerns losses, a certainty equivalent can be thought of as the price a decision maker is willing to pay to avoid the gamble.

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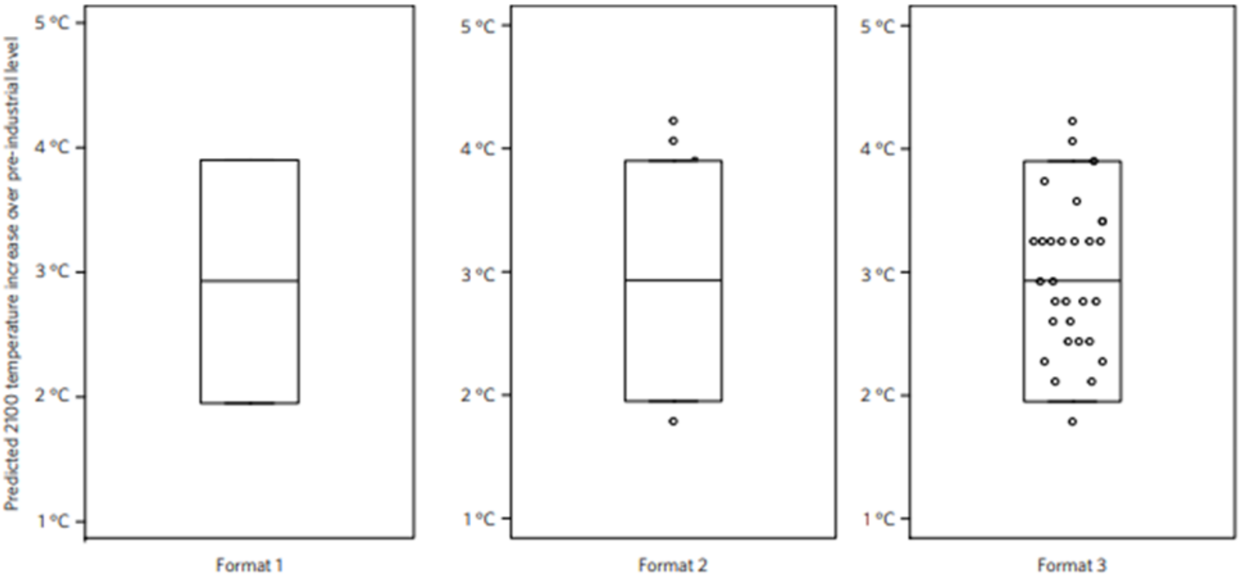
Figure 7: Results from Bosetti et al. (2017) showing differences in belief updating as a consequence of information richness



In short, while only two studies experimentally tested the provision of individual data points, their results suggest a sensitivity to such presentation formats at least in specific subgroups of the population (policymakers as indicated by Bosetti et al. (2017), more educated individuals in Fujimi et al. (2021). These effects are positive as they indicate an increased use of the information (Bosetti et al., 2017) and increased trust and accuracy of the estimate (Fujimi et al., 2021). The absence of harmful effects in any tested subgroups might encourage scientists to present their findings in a statistically more accurate and informatively richer, but more complex format. However, the minimal number of studies warrants further research.

5 Comparing Policymakers to Lay people

Unlike the general public, policymakers are regularly exposed to scientific research and must make decisions based on it. This familiarity may result in policymakers reacting differently to the uncertainties inherent in scientific findings. (For more information on how policymakers may differ from the general population, see Box 1 in Section 3). In this section, we focus on analyzing those potential differences. We start by presenting and discussing the results of existing studies that have directly collected data from policymakers and compared the results with those obtained from a general population sample. We then broaden the discussion and discuss personal characteristics (and mediators) that may affect an individual's reaction to uncertainty, thus creating individual heterogeneity. Finally, we summarize the results of papers having reported qualitative interviews with scientists to explore their perceptions of the challenges associated with effectively communicating uncertainties. These results reveal insightful for assessing effective communication from scientists to policymakers.

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5.1 Experimental evidence comparing policymakers and lay people

While a substantial body of research examines the perception and comprehension of scientific uncertainties, most research has focused on the general population or convenience samples (typically students). A limited number of studies have also specifically investigated the effect of uncertainties on specific groups, such as insurance workers (Cabantous, 2007; Cabantous et al., 2011). Only a few papers have directly sampled policymakers to participate in experiments and compared the results with those obtained from a general population sample.

Fischer et al. (2020) conducted a study comparing the comprehension of two infographics on the long-term consequences of climate change among a sample of IPCC policymakers and German junior diplomats. The study found more heterogeneous beliefs on the effect of climate change on health and heat extremes in the policymaker sample, where the former resulted in an almost bimodal distribution. For both groups, beliefs were not updated considerably after viewing the graphs. No differences were found in objective comprehension between the two groups for either the intuitively designed or the counter-intuitively designed graph. However, the study did reveal that both groups were overconfident in their subjective understanding of the graphs. Interestingly, the study also found a correlation between subjective and objective understanding among policymakers and junior diplomats for the intuitively designed graph. Still, no such correlation was observed among policymakers for the counterintuitive graph. It should be noted that calibration could not be performed for the diplomat sample due to data limitations, and the calibration graph mapping subjective to objective comprehension exhibited an irregular shape, indicating that the observed correlation may be a statistical artifact.

Brick and Freeman (2021) defined comprehension in a related study as correctly interpreting different icons without an explanatory legend. They tested this ability in a general population sample and an "expert sample" consisting of subscribers to an NGO that aims to improve services in the public sector. The study found that participants in the expert sample had slightly higher comprehension levels than the subjects from the general population. However, it is worth noting that the icons used in the study were taken from materials published by the NGO, and participants in the expert sample may have been exposed to these icons before and with accompanying explanatory legends. This suggests that the observed differences in comprehension may be at least partially driven by prior knowledge or exposure to the specific icons used in the study. Additionally, the same authors directly elicited participants' ranking of information for a policy decision, finding that the general population and expert samples had similar preferences and assigning the highest priority to effectiveness and evidence quality. Although some differences in the ranking of other information emerged, the authors did not provide any statistical analysis, which limits the ability to draw robust comparisons between the two samples. Opposing the direct elicitation of preferences for information, Fisher (1993) argues the aversion towards being "perceived as being ignorant" will lead to dishonest and biased responses.

Another significant dimension on which policymakers might set themselves apart is the confidence in or strength of prior beliefs, shaped by the consistent exposure to scientific evidence in a policymaker's respective field. Bosetti et al. (2017) found higher confidence in prior beliefs and higher reluctance to belief updating with new information in a sample of IPCC policymakers as compared to a student sample. Additionally, policymakers reacted to the richness of information

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provided as they increased the updating when provided not only point estimates or ranges but also individual data points. No such sensitivity was found in the student sample.

In a related study, Berger and Bosetti (2020) conducted an experiment with policymakers at COP21 to investigate their attitudes toward risk and ambiguity. Leveraging a simple design with four different urns, the authors find most policymakers (72%) are not ambiguity-neutral. About half of the sample reduces compound lotteries and a large share (71%) treats model uncertainty differently from risk. In analyzing the share of respondents who reduce compound risk and simultaneously exhibit ambiguity aversion, the authors can reject the assumption of ambiguity aversion stemming from an insufficient understanding of the statistical equivalence of compound and simple risk. However, participants' reduction of model uncertainty significantly predicts ambiguity neutrality. The authors recruit a student sample and compare their findings to detect potential differences between policymakers. On average, policymakers are found to be less averse to ambiguity and model uncertainty but less disposed to reduce compound risk. Considerable heterogeneity about country origin and quantitative sophistication exists within the sample of policymakers. Policymakers from OECD countries and those with high quantitative sophistication resemble the attitudes shown by students more closely. While higher quantitative sophistication in the policymaker sample is insignificant for ambiguity neutrality, it increases the likelihood of compound risk reduction.

Sterman (2011) provides arguments in line with the similarity found for (some) policymakers by Berger and Bosetti (2020), as the author points out three common misconceptions about the correct understanding of climate change and which root in cognitive biases. The author prescribes policymakers to be equally prone to cognitive biases related to time delays, or common misunderstanding of positive and negative feedback as well as stocks and flows, which impact the understanding of climate change dynamics as laypeople, particularly under conditions of uncertainty.

Overall, the literature comparing policymakers to non-policymakers in a quest to find potential differences is sparse. The available studies point to differences in confidence in prior beliefs (Bosetti et al. 2017). Regarding comprehension of graphs, the evidence is somewhat contradictory; Fischer et al. (2020) find no significant differences regarding IPCC infographics, while Brick and Freeman (2021) find an expert sample to show an increased comprehension of icons. However, the two studies differ regarding recruiting policymakers or experts in their respective samples. As Berger and Bosetti (2020) provide evidence for considerable heterogeneity within the population of policymakers, differences in recruiting might contribute to diverging results. The following sections aim to provide further information on individual factors that give rise to heterogeneity in general population samples to guide future research.

5.2 Individual differences: What factors impact the perception of uncertainties and their behavioral reactance to them?

5.2.1 Individual differences

Three studies focus on personal characteristics that affect an individual's reaction to uncertainty and may thus create heterogeneity between individuals. While neither of these studies are

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conducted directly on policymakers, the uncovered factors may guide future research in what kind of differences to look for in a sample of policymakers.

The social psychologist Breakwell (2000) emphasizes the significance of individual factors - and their multitude - in shaping risk perception and the efficacy of risk communication. The perception of risk is influenced by qualitative aspects such as perceived threat, perceived control, and catastrophic potential, as well as the audience's demographic characteristics. These demographic factors include culture, previous experiences, personality traits, and age.
Broomell and Kane (2017) conducted experiments that provide evidence linking political orientation to how uncertainty is handled. Their findings suggest that Republicans tend to have stronger reactions to manipulations of uncertainty than Democrats, across multiple dimensions such as scientific quality, societal benefit, funding allocation, and personal influence. Therefore, political orientation plays a significant role in the perception of uncertainties.

Relatedly, Kahan et al. (2011) examined the potential impact of cultural worldviews on the perception of scientific consensus. Participants were presented with statements on various topics that supported or contradicted egalitarian, communitarian, or hierarchical individualistic values. They were then asked to indicate their perception of scientific consensus regarding those statements. The results revealed a significant effect on individuals' cultural worldviews, as congruence between the statement and individual orientation increased the perceived expert consensus, while conflict reduced it. Furthermore, the participants' trust in subsequently presented experts supporting the statements mirrored the previous pattern. This effect persisted when an experimental manipulation was introduced, in which the proposed expert rated the risks as either high or low. The trustworthiness of the scientist was still largely dependent on the respondent's cultural worldviews and the congruency between the expert statement and their views.

These studies highlight the importance of considering individual factors, including demographic characteristics and political orientation, when examining how individuals react to and perceive uncertainties. Like any other individuals, policymakers are likely influenced by those factors, which can shape their understanding and decision-making related to scientific uncertainties. Future research might therefore benefit from indirect inference and analysis of the distribution of these factors among policymakers. The hypotheses would still need to be validated by experimental data at a later stage but might be informative to the experimental design.

5.2.2 Mediating variables

Several studies employ mediation models to test for indirect effects of personal characteristics. Analyzing differences across these domains between policymakers and a general population sample might indicate potential differences and can inform future research seeking to identify such differences.

Numeracy has frequently been tested as a potential mediator. Significant effects include an improved understanding of scientific information on medical treatments (Brick et al., 2020) and higher compliance rates to a lexicon matching numeric and verbal expressions of uncertainties (Budescu et al., 2012). Fujimi et al. (2021) find a positive main effect of numeracy on trust and perceived accuracy, but no moderation of contextual understanding by numeracy. By reviewing the literature on the communication of epistemic uncertainties, Fujimi et al. (2021) find a negative effect

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of presenting ranges (as opposed to point estimates) on trust in information, and that this relationship is mediated by numeracy. In a review of the communication of all scientific uncertainties, Spiegelhalter (2017) advises scientists to adjust their communication based on the audience's numeracy and to assume low numeracy with the general public, thus underlining both the critical role numeracy plays in the comprehension of uncertainties and potential differences in numeracy between specialists such as policymakers and the general public.

Other mediating variables of interest directly relate to science: Kreps and Kriner (2020) test the effects of catastrophizing the consequences of ignoring scientific COVID-19 models by emphasizing the potentially significant increase in deaths associated with the disease. They find an immense increase in participants' expressed support for adhering to these models - but only among subjects with low scientific literacy. Participants with higher levels of scientific literacy presented no susceptibility to the treatment. Chinn et al. (2018) find the link between scientific consensus and perceptions of certainty and the indirect effects on personal agreement and funding support to be moderated by trust in science.

Relatedly, two studies investigated the potential moderating effects of epistemic beliefs, which capture how an individual thinks about knowledge and learning. Epistemic beliefs can capture scientific research and corresponding knowledge as evolving and therefore as potentially indefinite. We follow the terminology of Ratcliff et al. (2023) in referring to such beliefs as "process-oriented". Focusing on medical epistemic beliefs, Ratcliff et al. (2023) find a directional effect of less vs. more "process-oriented" beliefs; less-process-oriented believers show more *negative* attitudes towards COVID-19 vaccines following information presented as tentative, whereas respondents with strong process-oriented beliefs react with more *positive* attitudes. An effect on the intention to get vaccinated following the tentative information presentation was only found for those less process-oriented: they showed lower such intentions. Simultaneously, the authors also assessed the effect of individual preferences for communicating complexity and uncertainty in research findings. This preference triggered a similar pattern, such that a preference for more definitive communication predicted negative reactions to tentative information on the expert's competence, the information's credibility, vaccine attitudes and intentions. No effects occurred for the opposite preference for communicating complexity and uncertainty.

5.3 Scientists' perception of policymakers' comprehension of uncertainties

The literature has conducted qualitative interviews with scientists to understand how scientists communicate uncertainties to policymakers and the general audience. These interviews provided valuable information regarding the expectations and experiences of scientists when conveying their findings. While we are only aware of a single study on the interaction between scientists and policymakers, several studies have explored scientists' perceptions of the general public's understanding of scientific uncertainties and the challenges associated with effectively communicating such uncertainties. In what follows, we summarize the findings from both areas of investigation.

Landström et al. (2015) examined the communication between scientists and policymakers through interviews with scientists, focusing on their perceptions of policymakers' comprehension of scientific uncertainties. The study revealed that scientists' trust in policymakers' understanding of

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uncertainties increased with their experience interacting with policymakers. Additionally, scientists reported a tendency to communicate their findings in a complex manner, without attempting to reduce uncertainties.

Frewer et al. (2003) conducted interviews with scientists to explore their perceptions of the general public's comprehension of scientific uncertainties. The study highlighted scientists' concerns that the public might not adequately understand uncertainties and could react negatively to uncertainty communication. For instance, scientists strongly agreed with statements indicating divergent understandings of uncertainties between scientists and the public, diminished confidence in scientists due to risk-related issues, and the public's limited understanding of probabilities associated with scientific risk estimates.

In another study, Folker and Sandøe (2008) interviewed nutrition scientists to investigate their role in communicating uncertainties in their findings to the public. The scientists reported a perceived conflict between their role as scientists, who acknowledge and value uncertainty in their findings, and their role as communicators to a public seeking guidance but not scientific debate. This suggests that scientists may believe the public is averse to discussing or being presented with scientific uncertainties.
Similarly, Bell (2006) discussed the case of the Wentworth Group, a collective of "concerned scientists" in Australia invited by the WWF in response to severe drought and a public debate favoring environmentally harmful preventive measures, such as altering river flows. The scientists attributed their success in shifting public opinion and policy to a persuasive communication strategy that omitted scientific uncertainties. They argued that the public did not demand a scientific debate but sought guidance.

Overall, these studies shed light on the communication of uncertainties by scientists to policymakers and the general audience. Scientists perceive a divergence in the interest and understanding of uncertainties associated with scientific findings between the scientific community and the general public. However, the findings from Landström et al. (2015), which focused on policymakers, suggest that scientists' initial concerns about policymakers' limited comprehension of uncertainties may be misplaced. The study indicates that trust in policymakers' understanding of uncertainties increases with more frequent interactions between scientists and policymakers, implying that scientists' apprehension may diminish over time. These findings highlight the importance of ongoing communication and engagement between scientists and policymakers to bridge the gap in understanding and effectively convey scientific uncertainties.

6 Communication strategies

In this section, we summarize and discuss the communication strategies that have been proposed in the literature to convey scientific evidence. We start by summarizing the practical guidelines proposed in different studies for communicating risks and uncertainties in a way that promotes the audience's understanding and overcomes common misperceptions. We then present, in a case study, the approach followed by the Intergovernmental Panel on Climate Change (IPCC) to use a calibrated language for developing expert judgments and for evaluating and communicating the degree of certainty in findings of the assessment process.

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6.1 Overview of communication strategies presented in the literature

The literature has proposed several strategies for communicating scientific evidence. These strategies differ in their proclaimed aim: some are designed to promote transparent communication of uncertainties, while others aim to provide guidelines that improve the audience's comprehension of uncertainties and risks. Strategies are also devised to trigger more immediate and more effective climate policies. In the following, we present a brief selection.

Making the case for a transparent communication of uncertainties, Blastland et al. (2020) suggest five rules for scientific evidence communication:

1. The aim of communication should be to inform and not to persuade, as perceived persuasion risks reduce (public) trust.
2. Communicators are advised to present an objective balance of the findings by sharing all available evidence, including disconfirming evidence. To aid overview and comprehension, scientists are advised to present the pros and cons of their findings in tables.
3. Unknowns and uncertainties must be disclosed, following a famous quote by the zoologist John Krebs: "Say what you know; what you don't know; what you are doing to find out; what people can do in the meantime to be on the safe side; and that advice will change."
4. Evidence quality should be communicated, too. The authors warn against underestimating the audience's ability to comprehend different qualities in evidence and the use they make of it.
5. Finally, communicators should anticipate misunderstandings or misinformation and proactively address them.

Several articles provide practical guidelines to scientists to promote the audience's understanding and overcome common misperceptions. Spiegelhalter (2017) provides a practical guideline for evidence communication and recommends an audience-specific approach. Common biases are considered, and advice on how to avoid their emergence is provided. Visschers et al. (2009) focus on communication and common misunderstandings of probabilities and numeric risk. Instead of focusing mainly on the audience, this paper focuses on the context and situation in which information is presented. Again, heuristics and biases are integrated and the communication is adjusted accordingly. Shackley and Wynne (1996) introduce boundary-ordering devices to prevent the communication of uncertainty from undermining the authority of science and strengthen it instead. Among others, the authors advise taking uncertainty rooted in nature into account and communicating the link to aleatory uncertainties to increase the credibility of science. They also recommend condensing multiple uncertainties into one whenever possible to aid comprehension. More detailed information on the recommendations of each paper is listed in Tables 5.1-5.3.

Table 5.1: Recommendations by Spiegelhalter (2017)
1. General issues when communicating risks based on statistical analysis
- Be clear about objectives. - Segment the audience into target groups and identify their needs, beliefs, and skills. - Develop, test, and evaluate material with target groups. - Build trust by being trustworthy. - Use plain language and limit information to only what is necessary. - Allow for different levels of interest, knowledge, and numeracy, for example, a top gist level, numerical information, evidence, and uncertainty.

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- Have the humility to admit uncertainty.
2. Communicating numerical risks
- Use absolute risks (but also provide relative risks when dealing with potentially catastrophic events). - For single unique events, use percent chance if possible, or if necessary, “1 in X.” - When appropriate, express chance as a proportion, a frequency, or a percentage—it is crucial to be clear about the reference class. - To avoid framing bias, provide percentages or frequencies both with and without the outcome. - Keep the denominator fixed when comparing frequencies, and use an incremental risk format. - Be explicit about the time interval. - Be aware that comparators can create an emotional response. - For more knowledgeable audiences, consider providing quantitative epistemic uncertainty about the numbers and qualitative assessment of confidence in the analysis. - More sophisticated metrics can be made for technical audiences, but this only serves to exclude others.
3. Visualizations These are derived primarily from Spiegelhalter et al. (2011).
- Consider a good summary table as a visualization. - Use multiple formats, because no representation suits all audience members. - Illuminate graphics with words and numbers. - Design graphics to allow part-to-whole comparisons on an appropriate scale. - Helpful narrative labels are important. Compare magnitudes through tick marks and clearly label comparators and differences. - Use narratives, images and metaphors that are sufficiently vivid to gain and retain attention but do not arouse undue emotion. It is important to be aware of affective responses. - Assume the low numeracy of a general public audience and adopt a less-is-more approach by reducing the need for inferences, making clear and explicit comparisons, and providing optional additional detail. - Be cautious about interactivity and animations—they may introduce unnecessary complexity. - Acknowledge the limitations of the information conveyed in its quality and relevance. - Avoid chart junk, such as three-dimensional bar charts, and obvious manipulation through misleading use of area to represent magnitude. - Most notably, assess the audience's needs, experiment, test, and iterate toward a final design.

Table 5.2: Recommendations by Visschers et al. (2009)
1. Use the same denominator in probability information throughout the risk message, so that people who neglect the denominator can still compare the probability information. 2. A detailed description of a probability calculation is recommended to present risky situations that include false positives, such as screening test results, because step-by-step probability descriptions are relatively easy to understand and are likely to result in adequate risk estimates. 3. Be careful about presenting relative risk reduction, as this may be mistaken for absolute risk reduction.

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4. Information about the number needed to treat (NNT) should be used carefully because people do not like this format and have difficulty understanding it. 5. Consider the context of risk communication when selecting appropriate verbal probability expressions for a risk message. 6. Present both numerical and verbal probability information in a risk message. People prefer numerical information for accuracy but use a verbal statement to express a probability to others. Presenting both ensures that people have the correct information no matter the purpose for which it is used. 7. Graphs are useful means to present the probability of harm, as they are more likely to draw people's attention to a probability of harm than numerical information (except for pie charts)

Table 5.3: Recommendations by Shackley and Wynne (1996)
Boundary-ordering devices
- Clarification and Management of Uncertainty: The authors suggest communicating the qualitative indications of the uncertainties involved in scientific findings following the IPCC recommendations. The authors acknowledge the difficulty of obtaining precise estimates withstanding scientific debate, but suggest policymakers be satisfied with less precise information. - Reduction of Uncertainty: Appeals to scientists to focus research efforts on reducing uncertainties. - Transformation of uncertainty: Relates to different layers of uncertainty, such as indeterminacy and ignorance. Research should aim to transform these into more tractable sources of uncertainty. - Condensation of Uncertainty: If more than one source of uncertainty exists, condensing them into one will aid policymakers' understanding. - Scheduling into the Future: Times at which uncertainties will be resolved should be identified and communicated. - Displacement of Uncertainty: Removing the source of uncertainty from science and scientific models back to nature increases the credibility of science.

Adding to the list of communication strategies focused on the audience, Breakwell (2000) advises communicators to examine the audiences' existing mental models specific to the risk to be communicated and devise their strategy based on these models.

Another noteworthy guideline adjusts the communication to the nature of the decision to be taken instead of focusing on the audience primarily. Fischhoff and Davis (2013) differentiate between three decisions: (1) "Decisions about action thresholds: Is it time to act?", (2) "Decisions with fixed options (which of the given options is best?)" and (3) "Decisions about potential options (What is possible?)". For a decision of the first category, the authors draw on signal detection theory in their advice for scientists to define both the discrimination ability *d'* (the distance between the two distributions one wants to differentiate between) and the decision criteria *β* (specificity and sensitivity, which relate to the rate of false positives or false negatives). Further, definitions of each outcome should be given (e.g., what defines extreme weather or a rise in sea level). For the second category ("Decisions with fixed options"), scientists should provide information on the probability distribution over possible parameters whenever possible. Further suggestions include sharing information on the source(s) of uncertainty, allowing decision-makers to understand potential cures

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to uncertainty. Lastly, uncertainties arising due to methodological choices must be disclosed. Recommendations for the third category ("Decisions about potential options"): Scientists should identify generic uncertainties due to omitted variables (e.g., hard-to-quantify factors) and focus on lay peoples' (mis)understanding of science to ensure biases or heuristics are corrected. Creating mental models may aid this process.

A group of communication strategies also stems from the field of psychology and aims to trigger more climate change mitigation actions. As these strategies share a common goal - adjusting communication such that more stringent policy actions are being taken - they are somewhat persuasive. Several communication strategies highlight the importance of addressing response efficiency (McLoughlin, 2021; Poortvliet et al., 2020; Richards and Den Hoed, 2017). Response efficiency expresses the ability of actions to reduce the associated risk and thus motivates action (see Social Cognitive Theory (SCT) by Bandura, (1986). In the context of climate policies, the authors urge scientists to communicate not only the risk of climate change, but also to present effective policies that can reduce the associated risks. Some authors also emphasize the necessity of making risks less abstract and more graspable by reducing the psychological distance (drawing on construal level theory, CLT by Trope and Liberman, 2010; Poortvliet et al., 2020; Richards and DenHoed, 2017).

Briefly stated, several communication strategies have been devised in the literature. Some provide advice on comprehensively presenting scientific research and its complex methodology, aiming to best inform the audience about potential unknowns and alternative scenarios. Others focus on political action and strive to mobilize stakeholders and decision-makers towards effective climate change mitigation and adaptation. While these strategies are persuasive in their intention of triggering specific action, they also acknowledge the pressing concern regarding the gap between the widespread acknowledgment of the catastrophic nature of climate change and the urgency for immediate action, juxtaposed with the inadequate implementation of sufficiently stringent and effective policies. To the best of our knowledge, the literature does not present strategies informing scientists on how and which uncertainties to present to their audience, not specifically to policymakers.

6.2 Case study: The IPCC strategy combining numeric probabilities and linguistic statements

As highlighted in this report, the language of uncertainty may itself be a source of confusion. Uncertainties can be communicated as precise values (e.g., there is a 0.5 chance), as ranges (e.g., the probability is between 0.3 and 0.6, or the probability is at least 0.75), as phrases (e.g., it is not very likely), or by combining some of these modalities.

Given that people's interpretations of probability phrases may vary greatly, the Intergovernmental Panel on Climate Change (IPCC) has, since the preceding cycle of reports (AR5), followed the approach of developing "standardized lexicons of uncertainty" by issuing a guidance note, ensuring that uncertainties are treated consistently between working groups (see Mastrandrea et al., 2010). This note proposes a conversion table that links a finite set of phrases with specific (overlapping) ranges of probabilities (e.g., unlikely < 33%; very likely> 90%). All report contributors are instructed

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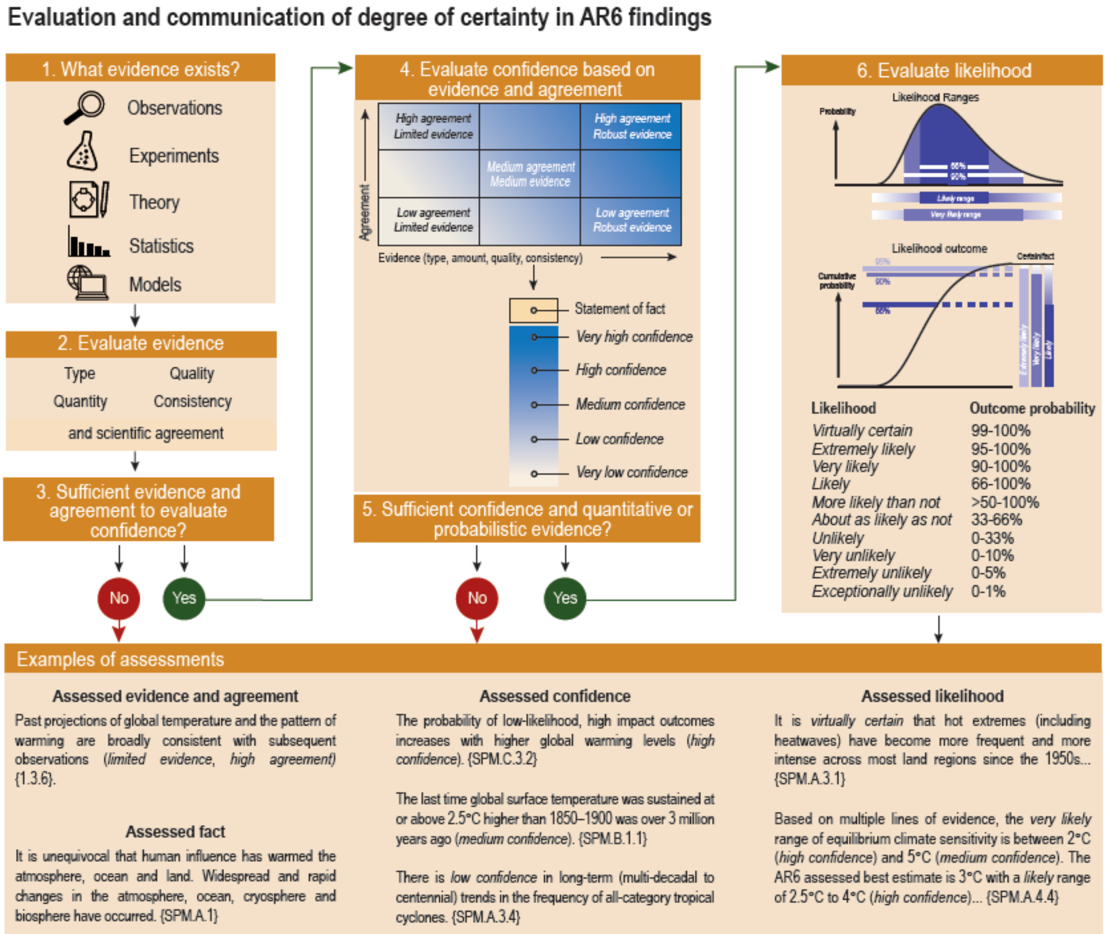
to refer to this table when making probabilistic pronouncements. The table is also included in all IPCC reports to help readers make sense of the assessment.

The latest report (AR6) went even further, clarifying more precisely the relationship between qualitative and quantitative estimates of confidence and certainties. Specifically, the degree of certainty communicated in the reports is contingent on confidence and likelihood in a manner such that evidence collected is first evaluated in terms of type, quality, quantity, consistency, and scientific agreement. This is done to ensure sufficient evidence and agreement to evaluate confidence. If this is the case, confidence can be evaluated. When sufficient confidence exists, together with quantitative or probabilistic evidence, then the likelihood of an outcome can be evaluated (detailed in Figure 8).

Figure 8. IPCC's adopted guidelines to assess and communicate the degree of certainty in AR6 (p. 170)



6.2.1 *Experimental evidence on the comprehension of IPCC language*

The understanding of IPCC standardization has been studied along several dimensions. In particular, experimental literature uncovers considerable heterogeneity in the understanding and interpreting of lexicons.

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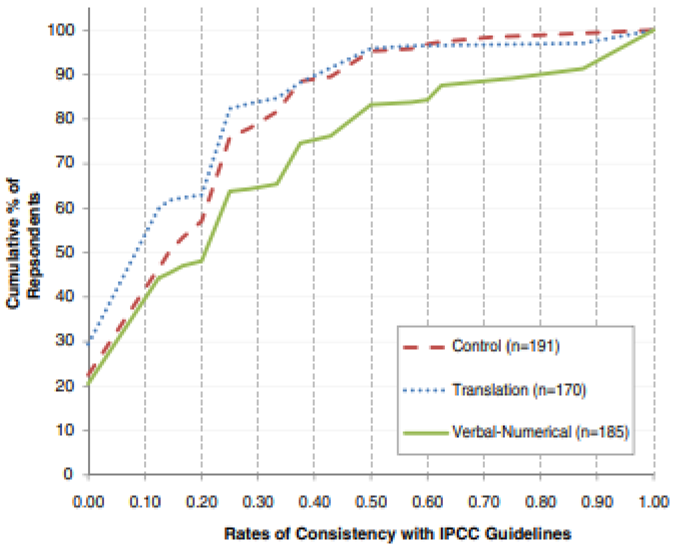
For instance, Dhami and Mandel (2021) find verbal expressions of uncertainty inconsistent due to a strong dependency on context, outcome severity and valence, and a high susceptibility to biases such as order effects and base rate neglect. Yet, verbal expressions may be preferred, partially due to often being perceived as more natural compared to numeric expressions of likelihood. The authors do not recommend using lexicons that match the more intuitive verbal expression with a numeric one, as readers struggle to replace their own and individualistic matching with the external lexicon.

Budescu et al. (2012) measure adherence and consistency with the IPCC standardization by supplying participants with verbal expressions and eliciting the respondent's corresponding best numerical estimate of the likelihood. Consistency with the IPCC lexicon was generally low - for roughly half of all participants, just one or two out of the eight responses corresponded with the IPCC standardization. The provision of the standardization in the form of a table (Translation condition in Figure 9 below) did not significantly increase consistency. However, providing numeric probabilities alongside verbal statements (Verbal-numerical condition in the figure below) significantly increased the consistency rate to approximately 30% (compared to roughly 21% in the control and 19% in the translation treatment group). In a separate analysis, the authors further revealed a significant relationship with personal control variables such as attitudes towards the environment or political ideology, pointing to notable individual differences in the interpretation of likelihoods.

Figure 9: Results from Budescu et al. (2012) showing consistency rates as a function of the number of respondents



Relatedly, Harris et al. (2013) compare consistency with the IPCC lexicon between a British and Chinese sample. In both samples, consistency was lower at both tails of the likelihood distribution. Additionally, the Chinese sample presents a significantly lower consistency than the British counterpart, thus indicating linguistic cross-country heterogeneity. Lastly, Patt and Schrag (2003) randomly assigned participants either the role of senders or receivers of uncertainty messages, where senders attach a linguistic label to a given numeric likelihood and receivers assign a numeric likelihood to a linguistic label. They found that senders assigned higher probabilities to a more severe event; and on the other hand, receivers expected some exaggeration in the communicated

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likelihood of severe events. Their results show an interaction as the verbal label as assigned by senders is categorized as l**ess likely** for a more severe event. In contrast, the numeric probability assigned by receivers indicates a **higher** likelihood for the more severe event. From this, the authors derive the potential for low-probability but high-impact events to be underestimated in their likelihood to occur by the audience.

6.2.2 More general criticism

Both Poortvliet et al. (2020) and McLoughlin (2021) scold the IPCC report for insufficiently addressing efficacy - notably, the ability to mitigate climate change and its risks. The lack of such mentions hinders behavioral change and the uptake and implementation of mitigation policies. Poortvliet et al. (2020) also condemn the predominance of abstract messages over concrete ones in the report, which, according to CLT, further diminishes the inclination to take preventive measures against climate risks.
Frank (2017) and Winsberg (2018) advocate for objective and value-free communication of scientific findings and their corresponding uncertainties. They contend that while the IPCC's objective of providing information on both consensus and certainty of findings is commendable, the approach is inevitably influenced by subjective value judgments, preventing it from achieving the ideal of objectivity. Winsberg (2018) particularly highlights the challenge scientists face in striking a balance between confidence and precision, stating that "this means that could have made a more precise estimate with less confidence, or a less precise estimate with more confidence. And choosing the right balance of precision and confidence here is a value judgment."

Adler and Hadorn (2014) criticize the attempt to provide a simple statement of the level of uncertainty, as this approach does not permit to express the complexity of the unknown, nor is it able to point out where uncertainties originate from. This undermines scientific discussions and fine-grained reporting of diverse findings and value judgments. Transparency over the dissensus is missing. Wüthrich (2017) echoes this criticism by highlighting the omission of causes and sources of uncertainty, providing valuable information. The author advocates for a more consistent and transparent use of terminology to describe uncertainty, and overall, a more nuanced and comprehensive understanding of uncertainty.

7 Concluding remarks

This report has comprehensively examined various facets pertaining to the communication of scientific uncertainties to policymakers. Specifically, the discourse delved into the foundational debate surrounding the merits and drawbacks of fully transparent uncertainty communication. The literature review revealed a prevailing consensus endorsing the necessity of judiciously selecting uncertainties for disclosure, favoring a neutral and "value-free" approach.
We then reviewed the existing experimental evidence on how uncertainties are generally perceived and dealt with, among different subject pools, domains and format presentations. This evidence serves as a basis for assessing policymakers' proficiency in comprehending and utilizing information embedded in communicated uncertainties. An additional focus was placed on discerning potential divergences between policymakers and other targeted groups, drawing from empirical studies.

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Additionally, insights from qualitative interviews with scientists were summarized, providing valuable perspectives for evaluating effective communication strategies directed at policymakers.
The report culminated in a discussion of various communication strategies, offering guidelines to enhance the transparency of uncertainty communication and facilitate policymakers' comprehension. While the existing literature underscores the imperative for scientists to inform policymakers about the inherent uncertainties in their findings, the report underscores the need for further research. Specifically, more in-depth investigations are warranted to precisely delineate how policymakers respond to diverse presentation formats or framing of uncertainties and to optimize their understanding of these uncertainties.

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8 Appendix

8.1 Methods

A first search was conducted on February 13, 2023 with the following code: TITLE-ABS-KEY ("communicating climate science" OR "communicating science" OR (communicat* AND (uncertaint* OR risk OR ambiguity)) AND ("policy maker*" OR "policy making") AND climate). From the 257 produced papers, about 40 were deemed relevant. A second search on March 13, 2023 resulted in 259 papers, of which 27 papers were relevant to this review. Five of the papers were already identified in the previous search. The code employed was TITLE-ABS-KEY ("Scientific uncertaint*" AND communicat*). Two exclusion criteria were applied: First, Case studies which do not directly relate to communication of scientific uncertainty were discarded. Second, studies on the communication of scientific uncertainty in regards to health and individual patient choice were excluded, too. The list of publications from the Winton Centre was obtained from
https://wintoncentre.maths.cam.ac.uk/about/publications/ on March 24, 2023.

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