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Unpacking the semantics of risk in climate change discourses

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Abstract. The climate change assessment community relies on widely accepted definitions of risk and its components, e.g. hazard, exposure, and vulnerability, provided by the well-known international organisation *Intergovernmental Panel on Climate Change* (IPCC). Those definitions of risk have been changing through the years and are presented in a general and "common sense" form as they need to be understandable by the public society and accommodate notions of risk as embraced by different research streams. However, these definitions have proven ineffective in operational climate risk assessment procedures, which exposes the critical need for disambiguation. This paper addresses the lack of semantic clarity of risk and cognate concepts in the context of climate change assessment by unpacking the ontological commitments underlying the IPCC's most recent definitions and glossary using the *Common Ontology of Value and Risk* (COVER) as a primary guideline. This study provides a more precise and refined ontological foundation of risk in climate change research that better aligns with the complexities of scenarios and assessments, and contributes to climate change research on mitigation and adaptation by supporting more effective communication and assessment of climate-related risks and humanity's responses to them.

Keywords. Risk, Climate change, IPCC, Ontological analysis

1. Introduction

The assessment of risk and its management have relatively recently emerged as central practices in many disciplines [1], e.g. engineering, computer science, health, law, environmental and climate sciences. Effective risk assessment and management [1] requires an appropriate understanding of the notion of risk and associated concepts, which is particularly relevant for multi-party decision-making in critical sustainability sectors of climate change adaptation and mitigation. The *Intergovernmental Panel on Climate Change* (IPCC)[2] is an authoritative voice concerning risk assessment. Providing an agreed definition of risk and cognate components, e.g. hazard, exposure, and vulnerability, has been

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one of the ongoing efforts of the panel, which culminated with the Guidance on the concept of risk for the IPCC Sixth Assessment Report (AR6) [2,3].

The risk definitions proposed by the IPCC are the subject of ongoing review and discussion [4,5,6,7], highlighting that despite the IPCC framework's usefulness to conceptualise climate change risk theoretically, it falls short as a guideline for the effective operationalisation of risk assessment procedures on the ground. Therefore, an unambiguous definition of risk and its components is needed to clarify what specific factors, indicators, and scenarios should be used in the analysis and modelling, to allow for more realistic and accurate studies of potential impacts. Standardising the definition of risk would ensure comparability and replicability of risk assessment outputs, wherein assessments conducted by different organisations or researchers can be compared, integrated, reproduced, and transferred to different contexts. Semantic consistency could also facilitate collaboration, peer review, and the prioritisation of urgent risks at scales to optimize resource allocation and design appropriate responses to climate threats. This work discusses and clarifies the notion of risk elaborated in the discourses of climate change, based on the most recent IPCC AR6 report [2,3], using the approaches of ontological unpacking and analysis [8] and taking, where possible, the *Common Ontology of Value and Risk* (COVER) [9] as a reference. Rather than proposing a computational ontology of risk in climate change, we present several ontological assumptions distilled from the IPCC definitions and related outputs, reflecting on these through COVER and its primary literature. We focus on four representative climate change discourses that arise from the AR6 definitions [2,3,10], which encapsulate some of the core notions of risk, namely: (i) *hazard, exposure, and vulnerability*, (ii) *impacts of climate change and human responses*, (iii) *value*, and (iv) *the role of uncertainty*. The main theoretical contributions of this work are (*a*) the ontological clarification of the focal aspects of climate change risk that can support more rigorous semantic assets for risk assessment and communication in climate change science and (*b*) an initial probe of the COVER ontology to determine its appropriateness for climate change risk applications.

The paper is organised as follows: Section 2 summarises COVER, Section 3 presents the IPCC definitions of risk and accompanying concepts. Section 4 delves into the ontological unpacking of IPCC risk's characteristics and their ontological commitments, Section 5 reviews related works, and Section 6 concludes the paper.

2. Baseline research: The Common Ontology of Value and Risk

The exploration of the concept of risk has been ongoing for more than five decades [11]. Despite significant advancements in elucidating the essence of risk, the term continues to be interpreted with a certain ambiguity (e.g. [12,13]). A definition that raised attention within the risk community was presented by sociologist Rosa [14]. According to Rosa, risk is defined as *"a situation or event where something of human value (including humans themselves) has been put at stake and where the outcome is uncertain."* Rosa contends that his definition encapsulates the three necessary and sufficient conditions to identify risk. First, risk pertains to a potential state of reality influencing someone's interests, either positively or negatively. Second, risk encompasses the *uncertainty* surrounding the likelihood of such a state materializing in the future. Consequently, it does not make sense to attribute risk to events happening with absolute certainty, such as the sun rising tomorrow. Third, risk is centered around a *possible* state of reality, thereby excluding discussions for example about the risk of someone transforming into a vampire.

We now summarise the view on the nature of risk formalised in COVER [9].[3] We use this ontology as a basis to guide the analysis of the definitions adopted in the climate change context, which, as we shall see, poses entirely new ontological issues w.r.t. the adopted ontology itself. We chose COVER because: *i*) it is based on a foundational ontology; *ii*) it embeds a domain-independent conceptualization of risk; *iii*) it is built upon widespread definitions of risk and shows how the risk is connected to the notion of value. Moreover, COVER has already been connected to different domain ontologies showing its utility in clarifying some related notions (e.g. *trust*, *prevention*).

COVER embeds several key assumptions about the nature of risk. The first is that risk is inherently **relative**, varying in perception between different observers who may interpret an event as either a risk or an opportunity. The second assumption emphasises that risk is contingent upon the **impact on goals** and the **importance of these goals** to a specific agent, highlighting the goal-oriented nature of risk assessment. Thirdly, risk is fundamentally **experiential**, and in COVER, risk is attributed to events rather than objects. This involves aggregating risks associated with events that could impact an object and highlights how assessing risk is a particular case of that of ascribing value.[4] Additionally, COVER suggests that risk is **contextual**, meaning the magnitude of risk for an object may vary even if its intrinsic properties remain constant, depending on surrounding circumstances. Finally, risk is grounded in **uncertainty** about events and outcomes. Together, these assumptions provide a comprehensive framework for understanding and evaluating risk within the COVER perspective.

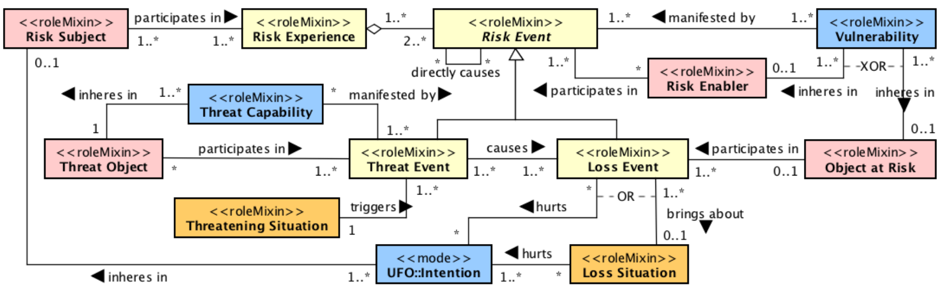

Figure 1. Risk experience view of the *Common Ontology of Value and Risk (COVER)* [9].

Figure 1 provides a view of COVER centered around the experiential perspective of risk. It depicts RISK EXPERIENCE as a complex envisioned event that can be decomposed into RISK EVENTS, which are further classified into THREAT EVENTS and LOSS EVENTS. THREAT EVENTS are envisioned events that can cause LOSS EVENTS, which

[3]Note that we took COVER as primitive, which was itself subject to validation and proper comparison to the literature of risk in risk analysis and management at large (e.g. [15]). Each reference ontology taken as primitive would entail a different analysis, so one is obliged to commit to a particular choice. The models in this paper are represented in the OntoUML language, which is grounded on a foundational ontology [16].

[4]Note that the relation between risk and value is deemed pivotal by other authors in the literature, with which the work on COVER compares. For example, Boholm and Coverllec [17] defended, in their relational theory of risk, that *"for an object to be considered 'at risk', it must be ascribed some kind of value"*, and Rosa [14] defined risk as *"a situation or event where something of human value [...] has been put at stake"*.

in turn are events that hurt some intention of a RISK SUBJECT, the AGENT whose perspective is being considered in the risk assessment. A LOSS EVENT may involve the participation of OBJECTS AT RISK and RISK ENABLERS. The former refers to things of value that the subject would like to protect, whilst the latter refers to things that are exploited or fail, thus allowing the loss to occur. For instance, consider that you have fishes in your aquaculture pens, which you fear might die for several reasons. The fishes are the object at risk, the pens are risk enablers, and the death of your fishes is the loss event. The disposition of objects at risk and risk enablers that can be manifested as threat and loss events are VULNERABILITIES.

Figure 2 depicts RISK as a quantitative measure attributed to a RISK ASSESSMENT. The assumption here is that *risk* can be only ascribed to *envisioned experiences* that may (but are not certain to) occur. The ontology addresses this issue by accounting for the possibility of envisaged events as in [18].

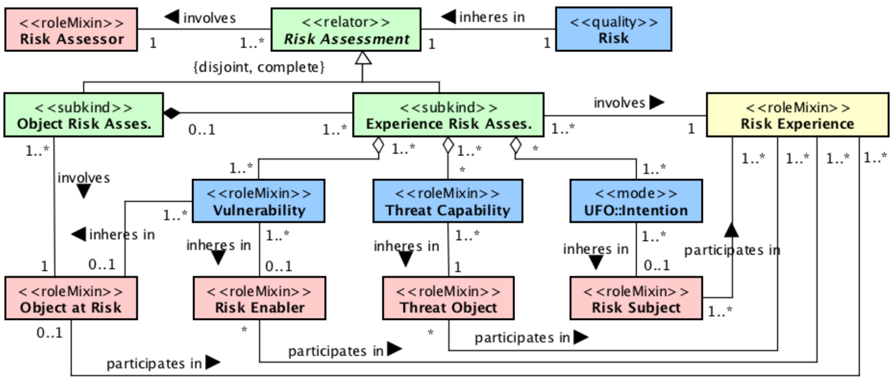

Figure 2. Risk assessment view of the *Common Ontology of Value and Risk (COVER)* [9].

3. The IPCC's discourses on risk

Since 1990, the IPCC has provided periodic assessment reports containing critical insights into the evolving comprehension of climate change risks. Despite the efforts of the IPCC to foster a common and integrated perspective, the concept of risk has not always been consistent across assessment reports and working groups, due to the evolutionary status of the concept itself and its use, and ongoing advances in scientific knowledge, methodologies, and understandings of the complexities of climate change impacts.[5]

Overall, the notion of risk in IPCC reports has progressed from a predominantly physical comprehension of climate effects to a broader and more integrated perspective that includes the effect of human decisions and behaviours. This encompasses socio-economic vulnerabilities, adaptation and mitigation strategies, as well as the inherent uncertainties in future climate projections, mirroring the increasing recognition of the complex and systemic nature of climate change risks.

[5]The full AR6 definitions of risks and related concepts can be found in the supplementary material.

> **[Risk]** *The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. [...] risks can arise from potential impacts of climate change as well as human responses to climate change. [...] risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence. [...]* [2]

The concept of risk has been explicitly introduced in IPCC reports since 2012's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) [19] and the Fifth Assessment Report (AR5) [20] from 2014. Before that time, assessments centered mostly on vulnerability [7]. In AR6 [2,3], the most recent report, the concept of risk, summarised in the aforementioned quote, has evolved to specify that risk, in the context of climate change, can arise from both potential *impacts of climate change* and *human responses* to them. When considering climate change impacts, risks result from dynamic interactions between climate-related hazards and the exposure and vulnerability of affected human or ecological systems to the hazards. Here the concept of *hazard* refers to climate-related physical events or trends that have the potential to cause loss of life, injury, and damage to infrastructure, natural ecosystems, and environmental resources. *Exposure* refers to elements at risk, such as people, assets, or ecosystems, or elements that could be adversely affected by a climate-related hazard. *Vulnerability* results from the combination of *sensitivity* or *susceptibility* to harm and the *capacity to cope* and *adapt* [20], which shape the propensity or predisposition of the system to be adversely affected by climate-related hazards. The AR6 risk can also result from human responses to climate change impacts, defined as the implementation of measures or strategies that do not achieve the intended objectives or even create trade-offs with other societal objectives. In such cases, we refer to *maladaptation* [3,10]. This represents a significant evolution and clarification compared with earlier assessments, as the report explicitly recognises the role of human actions and decisions in the potential occurrence or exacerbation of risk.

Another important specification concerns the treatment of *uncertainty*. This notion should be applied to each of the three components of risk (hazard, exposure, vulnerability), not only to hazard. In addition, uncertainty in the magnitude and likelihood of occurrences involves all three components and is related to responses such as socioeconomic changes and human decisions. Thus, uncertainty may dynamically change over space and time. In AR6 the concept of *value* is also stressed.[6] It is mentioned that different individuals will evaluate the potential consequences for human and ecological systems, thus the risk, from different perspectives based on their own values and objectives. Risk here can be applied, for instance, to material, cultural, aesthetic, and spiritual aspects of human or ecological systems, but also to natural systems in themselves without reference to human benefits [2,3]. Finally, the IPCC risk guidance states that risk should be used only to refer to negative consequences and suggests that the potential for positive outcomes should be described using other concepts, e.g. *opportunity* and *potential benefits*.

[6] The IPCC Glossary pairs the definition of value with belief [10].

4. Ontological unpacking

The IPCC definitions of risk and related elements have been continually re-elaborated to provide increasingly precise interpretations of the risk panorama. However, those present several overloaded notions, compacted semantics, and blurred boundaries; for example, risk alone includes several more complex concepts, such as vulnerability, value, and uncertainty. We leverage COVER [9] (focusing only on negative consequences, i.e. "pure risk") to analyze the IPCC definitions to unveil their ontological commitment(s). We focus on four emblematic discourses derived from the AR6 Guidance on risk [2], namely (i) hazard, exposure, and vulnerability, (ii) impacts of climate change and human responses, (iii) value and (iv) the role of uncertainty.

4.1. The three pillars of risk: Hazard, exposure, and vulnerability

Risk in climate change research and the IPCC considers complex and dynamic feedbacks between three elements, *hazard*, *exposure*, and *vulnerability* that are affected by spatio-temporal considerations and scale of observation [2].

Hazards. The IPCC defines **hazard** as "*The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources*" [10]. Classic examples of hazards are floods, heatwaves, droughts, and wildfires.

A characteristic of hazards reported by this definition is that they are possible - or future - events. As discussed by Guarino [18], conceptualising future events can be challenging (i.e. they have not yet occurred, are uncertain and flexible). That is why most philosophical literature assumes that events are "frozen in the past." A way around committing to the existence of future events is to consider them as *plans* [13], which are ontologically better understood. For instance, when talking about "the multi-stakeholder meeting I will have tomorrow", I may not be referring to a future event but to a commitment to participate in a meeting. In climate change contexts, interpreting hazards as plans is problematic since many of them are undesired physical events to which it is difficult to attribute intentionality. Alternatively, one may understand future events as actual references to *event types*. So, in the meeting example, we are referring to a type of event that could be instantiated by a number of actual events, i.e. "having the multi-stakeholder meeting at the municipal building" or "having the multi-stakeholder meeting at the university". Very often these references would be to *semi-saturated event types* [21], i.e. types of events that still allow for multiple instances but which necessary involve some fixed participants in (perhaps vague) fixed spatio-temporal locations [21]. A commitment to the existence of future events in IPCC discourses is unclear.

A second characteristic of hazards implied by the IPCC definition is that they are expected to cause other events that damage objects of value thus negatively impacting AGENTS and/or groups of agents. We extrapolate this general notion of impact from the very broad categories of explicitly mentioned consequences (e.g. health impacts, damage to property, and ecosystems). Thus, an impact can be understood as an event that hurts the goal(s) (INTENTION) of an agent.[7]

[7] We are not restricting agency to human beings, allowing for organizations, societies, animals, and other living beings to be considered as agents.

These characteristics of hazard apply to the notion of THREAT EVENT defined in COVER [9]. The negative consequences expected to follow threat events, in turn, can be mapped to LOSS EVENTS in COVER. The main difference would be that the types of threats the IPCC is concerned with by are those caused by, or exacerbated, by natural or human-influenced events. We summarize our interpretation of hazard as:

> A **hazard** (i.e. a THREAT EVENT) is a natural or anthropogenic event that is likely to cause a LOSS EVENT.

Exposure. The AR6 definition of **exposure** is *"The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected"* [10]. This definition suggests an interpretation of exposures as SITUATIONS (i.e. complex configurations in the world) in which objects of value could be damaged by the occurrence of hazards. Consider an example in which a village is at risk of water shortage. This situation is an exposure because the water shortage might impact the health of people, as well as human activities, e.g. agriculture, and affect local flora and fauna.

The interpretation of exposure as situations involves OBJECTS AT RISK exposed to possible adverse effects and valuable for agents, thus potentially impacting agents' goals. That OBJECTS AT RISK can fall into different ontological categories, such as physical objects (e.g. roads, trees), agents (e.g. human beings, animals), types (e.g. species), ecosystem functions (e.g. seed dispersal), ecosystems (e.g. forest), and economic activities (e.g. tourism). Yet, one could argue, that there is always a physical entity that will be affected by the chain of events triggered by hazards. If we consider as an exposure the situation in which a plant species (a type) is at risk of extinction following increase in global temperature, the actual objects at risk are the individual plants of that species.

A last comment on the notion of exposure regards its variability based on the level of granularity, perspective, and goal of the observation. Indeed depending on the scope of risk assessment, exposure could include small-sized entities (e.g. particles, physical properties in isolation), medium-sized entities (e.g. animals, artefacts) and/or large-sized entities (e.g. social-ecological systems). Deciding whether the focus of an assessment should be on the elements, the whole system, or both is a methodological and practical matter rather than a purely ontological one. However, the inclusion of which OBJECTS AT RISK to consider ultimately will shape the worldview of risk assessments. From this analysis, we synthesize the following interpretation of exposure:

> An **exposure** is a SITUATION in which OBJECTS AT RISK valuable to AGENTS might be negatively affected by the occurrence of hazards.

Vulnerability. For IPCC, a **vulnerability** is *"The propensity or predisposition to be adversely affected. [...]"* [10]. Considering flood risk [2], buildings and river maintenance conditions account for factors that could affect vulnerability during a flood.

From an ontological point of view, vulnerabilities have been defined as *dispositions* [22] (i.e. *"predispositions"* in IPCC's terms), which are properties that can be manifested under certain circumstances, and which give rise to THREAT or LOSS EVENTS [9]. For example, streams have the dispositions to be eroded due to the passage of water and sediments, vegetation have the disposition to burn due to to fire, and living beings have the dispositions to be injured and to die. What makes any disposition a vulnerability is the assessment of whether its manifestation is of interest to a certain subject.

This characterisation of vulnerability is a good starting point, however there are still open issues in the IPCC definition, particularly the vague application target of vulnerability. The first part of the definition (*"predisposition to be adversely affected"*), suggests that vulnerabilities inhere in the OBJECTS AT RISK. But if we look at examples of hazards, this is not always the case. Consider flood risk again; the disposition of a river to overflow its banks is a vulnerability that inheres in an object (deemed a RISK ENABLER in COVER) that participates in a threat event, but that, in this case, is not damaged in any way (eventually, the flow of water will return to its normal level and the river will continue to exist as it was). Climate change vulnerability is also often measured through "proxies" (indicators) that can be observed to assess the vulnerability. Think, for example, about poverty; this is not directly a vulnerability to heat waves. Yet it might contribute to vulnerabilities, for instance, because of inadequate shelters and access to drinkable water. Thus, vulnerability indicators describe and correlates with dispositions associated with hazards.

It is worth mentioning that although the IPCC does not mention a classification of vulnerabilities, the AR6 reports that those are associated to a wide variety of factors, such as "*[...] socioeconomic development, unsustainable ocean and land use, inequity, marginalization, historical and ongoing patterns of inequity such as colonialism, and governance.*" ([23] p. 12), alluding to the existence of several types and causes of vulnerability. This is corroborated by several works that discuss the need for a more comprehensive and value-oriented account of vulnerabilities (see e.g. [24,25]).

Given the more common and widespread interpretation of vulnerability as a disposition, we propose the following technical definition:

> A **vulnerability** is a disposition whose manifestation constitutes a THREAT EVENT or LOSS EVENT. It may inhere in OBJECTS AT RISK or RISK ENABLERS.

4.2. Impacts of climate change and human responses to climate change

The IPCC risk definition expands its application beyond (i) potential impacts of climate change, including also (ii) (human) responses to climate change [2]. The IPCC definition of **impact** reads as follows: *"The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. [...] Impacts may be referred to as consequences or outcomes and can be adverse or beneficial"* [10].

We see two ways in which this definition can be interpreted. First, that impact is the objective change in the world as a consequence of the occurrence of a climate-related hazard. For instance, there was a flood that caused some vegetation to die and some houses to be destroyed. Whether or not someone cares about the vegetation or the houses does not matter. Second, that impact is an event that contributes to or hinders the satisfaction of the goals of an agent. In this sense, being an impact is not an intrinsic property of an event, but one that is relative to a certain goal. This entails that the same event may positively impact an agent, negatively impact another, and not impact at all a third. Let us use an IPCC example to clarify impact in this second sense. The increase of seasonal snow cover negatively impacts farmers, as it destroys their crops (LOSS EVENT); positively impact operators in the tourism sector, as it improves the quality of skiing trails, thus attracting more tourists (a GAIN EVENT in COVER), and not impact companies in the aquaculture sector, as they do not lose or gain anything from the additional snow [26]. We believe this second interpretation is the most useful one here and better adheres to the IPCC conception of risk ("potential negative consequences") [2] because it focuses on the changes in the world that (negatively) affect us and will trigger responses.

When risk is assessed based on human responses of climate change, the potential for negative consequences is applied to *mitigation* and *adaptation*. In this case risks are assessed for the implementation of policies, liability, markets, and technology design and deployment [2] that could cause vulnerability shifts [3].

The Glossary defines mitigation as *"A human intervention to reduce emissions or enhance the sinks of greenhouse gases"* [10]. For example, the introduction of a policy to provide economic incentives for the adoption of renewable energy. Adaptation is defined according to the type of system undergoing it: *"In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects [...]"* [10]. For the former, consider the adoption of early warning systems to protect the coastal zone from rising sea levels [23]. Adaptation of social systems are particularly important because, in the process of conforming and evolving to climate change impacts, we can have adaptations that might become *maladaptive* and increase climate change risks, exposure, and vulnerability [10,23]. Typically maladaptations are unplanned negative impacts that increase carbon emissions instead of reducing them.

Climate change responses are plans designed by actors involving several resources, for example technologies. Those plans are either established by recognised legal bodies, e.g. NGOs, and enacted in governance settings through policies [27], or are isolated actions sometimes coordinated and sometimes not [23]. When mitigation and adaptation plans are implemented, those are executed into actions involving several participants, for instance local organisations, stakeholders, and infrastructures. Risk that emerges from human responses to climate change, also regards impacts that affect negatively an agent. Yet in this case, impact does not derive from climate-related hazards, interacting *directly* with the three pillars [2], rather it is caused by plans in response to climate change. Because those plans are designed to reduce and adjust to climate change effects and lower vulnerabilities, mitigation and adaptation are *countermeasure* plans, programmed to contain dispositions and their manifestations [28]. We generalise the definition of impacts as follows:

> An **impact** is an event that contributes to or hinders the satisfaction of some INTENTION of an AGENT, being the consequence of climate-related hazards or human responses to climate change.

4.3. Value

COVER highlights the affinities between the concept of risk and the one of value, considering risk ascription as a type of value ascription [9]. The two notions exhibit (i) *goal-dependency*, i.e. things are valuable or risky based on perspectives and goals of agents, (ii) *context-dependency*, i.e. values and risks are ascribed to events in which objects participate in, and finally (iii) close connections to the concepts of impact and uncertainty. Thus a comprehensive analysis of risk requires a proper understanding of values.

In the broader context of environmental science, biodiversity, and conservation, values of nature and their importance for policy and decision-making have been discussed for many years [29]. The IPCC Guidance on risk [2] acknowledges the diversity of values, e.g. monetary, non-monetary, and values of ecosystems in themselves; however, it does not offer a dedicated definition of value. The accompanying IPCC Glossary [10] includes a definition of **value**, which is coupled with the one of **belief**. It reads as follows: values and beliefs are *"Fundamental attitudes about what is important, good, and right; strongly held principles or qualities intrinsically valuable or desirable, often enshrined in laws, traditions, and religions."* This coupling might suggest that the two entities carry similar meanings. This implication is not justified and does not fully match the existent ontological contributions in which the two entities are often related but distinct [30,31]. In addition, that definition introduces these notions as *"fundamental"* without explaining the reasons for this statement and seems to exemplify mainly values rather than beliefs. A proposal is to decouple values-beliefs and provide more sharp distinctions of the notion of value in IPCC as functioning in support of risk.

Mainstream philosophical interpretations [32] consider belief as a propositional attitude, which is grouped with other types of mental attitudes, such as desires and intentions, inhering in an AGENT. For example, a policy maker *x* [the agent], believes that [the attitude] the assembly concerning the city's hydrological risk is planned for this week [the proposition] [32]. This conceptualisation is also reflected in applied ontology, e.g. the UFO module for social entities [30], which COVER reuses, where beliefs are modes having a mind-to-world direction of fit, i.e. a belief it is true if corroborated by a state of affairs in reality that satisfies its propositional content. Below, we provide a simple standalone definition of belief:

A **belief** is a mental attitude inhering in an AGENT.

Focusing on values, because the definition of the IPCC Glossary is brief [10] and the Guidance on risk only coarsely mentions values [2], there are a number of unresolved issues - particularly the ontological status of value for IPCC and its application. From the Glossary definition, it emerges that values, as beliefs, are attitudes that inhere to agents and are justified by qualities of the valued entities, practices, and norms. In this sense, values are ontologically classified as another mental attitude, such as beliefs, desires, and hopes inherent in AGENTS. If we consider value as a mental attitude, it is associated with a propositional content, which, in this case, is a quality that objectifies a property, intrinsic and not, justified by reasons, such as preferences. For instance, the farmer's value towards a crop field specified as qualitative discretisation (e.g. high value) due to its monetary rewards. The IPCC Glossary definition also provides a possible hint concerning the types of agents inhering values. Based on the last part of the definition *"[...] often enshrined in laws, traditions, and religions."* [10], it seems that values (and beliefs) are often preserved in artefacts, activities, and practices dependent upon human agents and groups of human agents, meaning that probably only human beings inhere values (and beliefs). We are unsure if this conclusion is intended.

A second interpretation of value, maps closely to the one proposed in COVER following [13]. This view models *use values* as a relational judgment of agents (value beholders) that ascribe values to entities (value bearers), such as objects and events. Consider, as an example, local citizens who ascribe value to the city's recreational activities in public parks. The value beholder can ascribe values to bearers also as an action on behalf of a third entity (value beneficiary). For instance, x ascribes values to y because z would enjoy that y. Considering the previous example, the local city council ascribes value to the city's recreational activities in the interest of its citizens, such as improving their well-being. Note that, according to COVER's application of values, the bearers are not intrinsically valuable; instead, the ascription depends on the value beholder(s) that ascribe value to entities because of contextualised goals and needs. Nevertheless, in COVER, intrinsic characteristics of the valued entities, such as qualities, capabilities, and dispositions, also influence and justify the valuation. This aspect reflects the IPCC claim on values (and beliefs) as *"[...] principles or qualities intrinsically valuable or desirable [...]"* [10].

As for the IPCC, COVER's value ascription does not need to be motivated merely by monetary goals; indeed use values refer to a relational, goal-oriented application of values without restricting them to a specific justification. Therefore, those values also capture non-monetary attributions. Reflect on, for instance, indigenous people who ascribe value to a river for its spiritual and emotional connections. As highlighted by this and previous examples, we include formal, informal, large, and small groups of agents as value beholders, such as NGOs, governments, and stakeholders. This value attribution encompasses shared ascription from agents' collective due to shared and agreed commitments, e.g. legal declarations. Finally, the IPCC Guidance of risk mentions values that are not attributed by humans, yet it does not provide further explanations [2]. To accommodate this perspective, COVER allows for the ascription of values for third entities, as indicated above. E.g. a group of people can ascribe values to health and welfare for themselves and other living beings, such as non-human animals and plants.

A **value** can be interpreted as (i) a mental attitude inherent to AGENTS; (ii) an emergent quality inhering in the relation between a value bearer and AGENT's GOALS.

4.4. The role of uncertainty

Risk and risk assessments are closely related to the notion of uncertainty [1,9]. According to the IPCC, **uncertainty** regards *"A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. [...] Uncertainty can therefore be represented by quantitative measures [...] or by qualitative statements [...]"* [10]. Uncertainty in climate change encompasses all the three pillars of risk, and concerns the chance of an event to occur (likelihood), its possible scale, magnitude, consequences, the confidence associated with a specific uncertainty assessment, and the management plans to tackle such potential adverse consequences [2]. Yet, what exactly is uncertainty for the IPCC? The Glossary reports that it is a *"A state of incomplete knowledge [...]"* derived by many factors, such as partial, missing, or biased information, and unclear terminologies. Although in the literature emerges that the main approach used to deal with uncertainty is the probabilistic [1], which uses, for example, variation and Bayesian probability as the degree of belief of an assessor [1,9], the IPCC opted for a mixed method.

For the AR5 release, the IPCC published guidance on the proper and consistent use of uncertainty across working groups [33]. Two approaches to uncertainty assessments and claims are mentioned in the guidance: *qualitative* and *quantitative*. The former expresses the (i) experts' *confidence* with the results and consistency of evidence and (ii) the degree of *agreement*. The latter expresses the (iii) level of uncertainty using probabilities, i.e. *likelihood*. Thus, a total of three scales are provided: confidence, evidence/agreement, and likelihood [34]. Example of those scales are: “Human influence has *likely* increased the chance of compound extreme events since the 1950s. [...]” ([3], p. 16), and “[...] The media helps shape the public discourse about climate change. This can usefully build public support to accelerate climate action (*medium evidence, high agreement*). [...]” ([3], p. 18). Concerning (i) and (ii), the IPCC commits to en epistemic interpretation of uncertainty in which this is a property of a set of beliefs of human agents and collectives, for example the IPCC’s working groups. In particular, confidence is interpreted as a meta-belief, i.e. a belief about another belief, in this case, a belief about the relation between evidence (e.g. information, data) and another belief. Instead, agreement is a quality of the relationship between beliefs of the members of a relevant collective. Finally, (iii) likelihood is closely related to the notion of probability [1] and can be considered a property of a situation that is externally dependent on an event type, i.e. in a given state of the world (SITUATION), there is a probability/propensity instances of a given event type being manifested.

An **uncertainty** can be interpreted as (i) a meta-belief about the relation between evidence and another belief (confidence); (ii) an emergent quality of the relationships between the beliefs of AGENTS in a collective, including confidence beliefs (agreement); (iii) an aspect of a SITUATION that is externally dependent on an event type representing the likelihood in that situation of future manifestations of events of that type.

5. Related work

Several authors have advanced critical interpretations and improvements of climate change risk and risk assessment. Most of this material regards definitions and approaches proposed by the IPCC in previous assessment reports since the latest one is particularly recent. Despite our efforts, we were not able to retrieve any previous ontological analyses specific to the notion of risk in AR6. However, some scholars do provide in-depth discussions and possible solutions for improving the understanding of IPCC risks, also focusing on its components. For example, Aven [35] offers incremental advances to the characterisation of risk in climate change and IPCC, including its surrounding notions, by addressing some of its weaknesses in decision-making and communication. A previous work by Aven and Renn, [6] specifically discussed uncertainty in IPCC and how it could be sharpened by servicing the risk framework in a more pertinent manner. More recently, Estoque et al. [7] targeted the concept of vulnerability, finding that the IPCC’s recommended concepts have rarely been well adopted in vulnerability assessment studies. Possible technical and practical reasons for their low adoption rate can be attributed to researchers’ preference, potential unawareness of terms, their misinterpretation, and confusion. Füssel instead [24] proposed a more comprehensive vulnerability framework to supplement the definition of vulnerability in the IPCC Third Assessment Report. Some researchers propose deep-dive analyses on the importance of assessing dynamic and complex characteristics of risk, its components, and their reciprocal interactions for more integrated assessments and informed decisions [4,5].

Focusing on ontological artefacts, Mazimwe et al. [36] provides a Systematic Literature. Review of the implementation of FAIR principles in domain-specific ontologies, e.g. disaster response, hazard, exposure, vulnerability, prevention and mitigation. Still, many of those artefacts focus on specific risks, e.g. floods. In addition, the literature on disaster risk reduction, despite sharing many common traits with climate change risk assessment, presents its own historical, notional, and technical differences. Thus, in this study, we did not include works derived from the disaster risk reduction literature.

6. Final remarks

This paper addresses the ontological assumptions behind the risk definitions included in the latest IPCC report following approaches of ontological analysis and unpacking. We analysed four climate change risk discourses through the interpretative lens of COVER, which in turn allows to probe the appropriateness of the ontology for capturing climate change risk concepts. Although this is only an initial assessment, it was successful.

Our analysis can be extended to further notions relevant to risk, e.g., risk assessment; however, for this first writing, we privileged the more iconic risk concepts over others, e.g. vulnerability over sensitivity. We do not propose an ontological implementation aligned with COVER. Nevertheless, a formal characterisation of the IPCC risk could offer more precise semantic support in operational assessment settings. For future works, we envision (i) extending this analysis, including risk assessment and dynamic interactions of hazard, exposure, and vulnerability under a risk propagation lens; (ii) sharpening those more challenging concepts, particularly vulnerability and value; and (iii) broadening the discourse in this work to include key social-ecological systems notions relevant to climate change risk, such as resilience. The next steps will be to evaluate our ontological proposals with the climate change community and to extend COVER with a module dedicated to climate change risk.

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