Reflections on critical uncertainties in biofutures

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Abstract: This paper reflects upon the concept of Critical Uncertainties, a term drawn from strategic foresight and risk management to identify issues that are highly uncertain and potentially highly impactful on a given strategic context. Given the daunting global challenges we face, the proposed biofutures associated with green transitions could be reimagined to encompass a broader spectrum of uncertainties, including existential risks and unknown unknowns. As global leadership acknowledges global risks, attention should be paid to how to engage these types of issues. This paper observes the participatory process of addressing and contextualising critical uncertainties and suggests that there may be a need for new frames. Planning for what is understood to be uncertain can be contrasted with the need for a new language of uncertainty that we do not yet contemplate. Low uncertainty issues may already be known, seen as sets of alternatives with direct implications, or then higher uncertainty involves even more complex fluid systems, and ultimately there is genuine uncertainty, which we cannot conceive. Within this context of utilising uncertainties, they are reflected upon through two key framings in this paper: imaginaries and future generations, both offering promising avenues for further exploration and inquiry of aspects of uncertainty. This reflexive text aims to reposition critical uncertainties for further study.

Keywords: critical uncertainties; future generations; transformative imaginaries; biofutures

1. Introduction

There is a pressing need for reflection on the nature of future Critical Uncertainties; on how key uncertainties are used and how they could be developed. Especially considering the merging of earth systems into these fast-paced uncertainties, what we might interpret to involve biofutures—or future developments of bio-based sectors or bioeconomies. This perspective adds another layer of complexity, where the framing and addressing of uncertainty can be seen to be changing. Critical uncertainties can be defined as "those elements of the future that are the most difficult to predict and that may have the greatest consequences on the ultimate outcomes of actions taken in the present" [1]. The term has often been used in the strategic foresight methods of scenario building, a method to express and frame critically important issues to be addressed in the foresight work. Once identified

these then can be addressed through many different approaches to rehearse, explore, or map and communicate alternative futures from a specific vantage for decision makers. These may evolve into speculative narratives, not predictions about the future, but causal in nature and explore underlying novel issues that require reflection. Specifically, the expression of the critical uncertainty has the function to identify and formulate the main problem-realm to be addressed, to give a name and form to it. One relevant characteristic of this approach is that it deals with exploring issues that are identified as being highly uncertain in nature and with a high level of impact. However, as a point of contention, it might be claimed that what is truly 'critical' is open for debate, and subjective, as well as what is actually 'uncertain'. Given that a foresight activity is often a participatory process, minor issues for some people, experts or disciplines may view some issues as more critical than others. The negotiation of uncertainties surrounding the context is very important to consider here, rather than to see it as producing an accurate model of an uncertain future state.

Uncertainty can come in many forms and within a foresight process, it is often utilised to identify both opportunities as well as threats. For the discipline of futures studies, the future is understood as inherently uncertain and there are multiple methods and approaches that seek to manage and explore uncertainty to better prepare for different futures [2]. This is used to reflect upon the present, as much as it can be to plan for different futures. Son suggests that looking at the history of the field of futures studies, it has been going through a transformation where its methods theory and approaches are shifting focus, since the 1990s reacting to a neo-liberalism, now where risk society discourses are on the rise that is in stark contrast with its origins as a human-oriented discipline [3]. If an era of foresight for organisations has dominated the field in the previous period, characterised by organisations engagement with the external world [4], then it might be understandable that perspectives shift attention wider again to global issues.

2. Biofutures and global uncertainties

Considering there is currently a shift where the UN and many governments of the world are giving serious attention to how to deal with global challenges and existential threats, it would be valuable to develop approaches to engage global uncertainties. One proposition as a solution to the overarching challenges of sustainability and climate change for the coming future decades, could be met by a transition to a Sustainable Circular Bioeconomy. The bioeconomy in its various forms (e.g., circular, sustainable, regenerative) can be understood to have been continuously and rapidly developing, and is defined as an economy that is derived from bio-based resources or services, and it represents a convergence with inherent pre-set notions and sectors that prescribe sectoral solutions and visions for the future [5]. Unfortunately, as Hikel *et al*. caution, there is limited sufficient evidence to support the idea that we can fully substitute the unsustainable components of our current economy with sustainable alternatives [6]. The effectiveness of biofutures interpreted as 'green growth' largely hinges on the premise that economic growth can be adequately decoupled from environmental harm [6]. If this transition from a fossil-based society to a sustainable bio-based

society is not viable in its current form without causing environmental harm, then we must seek out alternative just paths and roles for its future. Therefore, the current proposition for biofutures remains ambiguous and should be examined through different frames.

In light of the interconnections between the re-defining of critical uncertainties toward global issues and the evolving landscape of bio-futures as a solution that is deeply linked to global natural systems and society, this paper seeks for reflection and re-positioning of the concept of critical uncertainties. I explore the concept of different formulations of uncertainties and critical uncertainties considering its newly elevated role in engaging global existential issues and through the framing of the maturing concepts of transformative imaginaries and future generations. According to Jasanoff *et al.* [7], transformative imaginaries are collective suggestions about how society, the economy, and global systems should develop, while future generations can refer to those generations to come that we may affect or be responsible for. Both of these framings can be understood as different ways for planning and strategizing for the future, yet they also expose assumptions that, when scrutinised, reveal new aspects for understanding further uncertainties and implications. For example, we do not know who future generations are and what they might decide in the future, or how societies use their imaginaries to cope with the uncertainties they face. Identifying, picking and reflecting on valid critical uncertainties that are contextually relevant is in of itself a sensemaking process that has value.

The framing of critical uncertainties then is of particular importance, uncertainties are not value free, they represent both a mental model of perceptions of future threats and possibilities, as well as actual threats and solutions known, unknown or yet unconceived. In foresight, typically the key issues to address can be interpreted from the organisation perspective, sector or even national level dealing with the complexity of rapid external change and how organisations can process that great amount of information [4]. This type of engagement with uncertainty I suggest is problematic, as uncertainty that is perceived as a threat that takes on radical and global proportions, this often forces a response through a problem-solution mindset, where only problem-oriented methods dominate and obscure all other situational appreciation [8]. This is understandable, however there remains the need for reflection on the changing meaning of uncertainties and what constitutes or is perceived as critical.

Increasingly, explicit critical uncertainties are being deliberated upon the global stage. For example, United Nations Secretary-General António Guterres has emphasised "existential threats" repeatedly in his report, "Our Common Agenda" [9]. In this future oriented document concepts of strategic foresight, preparedness for the future and future generations feature strongly for the first time in such a global strategy. For decision-makers, awareness of potential threats to humanity is on the rise, encompassing unexpected risks from Artificial Intelligence to biodiversity loss, as noted by the Millennium Project [10]. Some of the suggested potential key uncertain areas for the UN consideration, include: loss of control over future artificial intelligence developments, massive hydrogen sulphide (H_2S) releases due to deoxygenated oceans driven by advanced global warming, potential weakening of Earth's protective magnetic shield leading to significant electrical and internet disruptions,

nuclear war escalation, the emergence of uncontrollable, more severe pandemics (potentially of synthetic origin), and the risk of an asteroid collision [11]. These types of challenges are wicked challenges, that are risky combinations of complex issues, describing a world that is increasingly filled with features of volatility, uncertainty, complexity and ambiguity [12]. Anticipating these critical issues in the context of biofutures combines the need for sustainable and renewable solutions for the challenges that the planet faces, which then implies the need for broad structural transformations that must be envisaged [5]. It is important to actively acknowledge that there are also risks and unintended consequences that remain largely unknown or ignored in all propositions and aspirations for biofutures. Such strategic planning requires a mature approach. I suggest that the concept of critical uncertainties aligns closely with the fundamental principles of futures studies and strategic foresight; It involves the examination, management, and strategic planning to address uncertainty effectively, enabling a more precise articulation of potential issues across various futures, while also embracing uncertainty as something that cannot be fully modelled, predicted or managed [13]. This paper takes a reflexive stance and proposes useful framings for uncertainties, where by delving into diverse framings and considering wider definitions of uncertainties, it is possible to challenge assumptions and identify future issues. This supports an intersubjective and constructive approach to conversations on future possibilities and the representation of uncertainties they entail. The objective is to lay the foundation for identifying areas where methodological advancements could be further pursued, to take more effective use of uncertainties.

3. Defining critical uncertainties and the range of uncertainty

In futures studies, the conceptual mapping of uncertainty considers that the more long-term the more uncertain and wider range of uncertainties occur, this is evident in the illustrative modelling of the 'cone of uncertainty' [14] where wider and wider uncertainties occur or a 'futures cone' [15] where it is possible to differentiate between probable, preferable and even preposterous futures. As Shoemaker *et al.* have described it, with scenario approaches the aim is to sketch the boundaries of the cone of uncertainty rather than to document all possible outcomes [4]. The term uncertainty is inherently normative, suggesting that uncertainties are frequently linked to existing challenges or prevailing narratives, rather than genuine uncertain issues. The uncertainties often identified are perhaps hardly considered issues. Or represent conflicts in decision-making where uncertainty comes from an acute lack of understanding or ability to see differently an outcome. Derbyshire *et al.* broadly categorise uncertainty into two wide areas, where we might understand them as 'small world uncertainties' and 'large world uncertainties'[16]. These can be characterised as a 'closed uncertainty', that are not actually fully uncertain as they can be listed in full and the second characterisation of large world uncertainties requires an approach where issues have not or cannot be listed due to their complexity, this is open-ended uncertainty [16]. Therefore, what is often proposed as uncertain might already be well defined (as with the threat of climate change), but the response, its effects or the solutions might remain highly uncertain and open.

At the other extreme Ilmola *et al.* suggest that ontological uncertainties, those unknown-unknown issues are important to consider, and are often missing from most foresight work [17]. Ritchey [18] refers to this extreme as 'Genuine Uncertainty' and as being different from risk; "Risk is defined as a type of uncertainty based on a well-grounded (quantitative) probability", whereas on the other hand, he explains that Genuine Uncertainty embodies processes and outcomes which "cannot be ascribed (well-grounded) probabilities". Especially in the context of social uncertainties, Ritchey underlines that these are the hardest to assert probabilities due to their complexity. Another approach to the problem is through unconceived alternatives, Virmajoki suggests that there are limits to conceivability, and that we should be aware of the limits to our "ability to conceive nonbenign or interesting alternatives to the present states of affairs" [19]. This is the challenge that the futures field occupies, to bravely engage uncertainty and experiment with no guarantees. We can in this way play with uncertainty and design for multiple unknowns [20], we may focus on experiencing uncertainty to gain insight [21] or to engage in world-building to understand a functioning different world even it may seem impossible to us [22], or to envisage sudden unforeseen black swan events [23].

Table 1 formulates useful definitions of different uncertainties based on Shearer [24] and Ritchey [18]. These definitions can be placed in context with the different framings I have introduced through the sensemaking. We may then interpret then what these imply for biofutures and shift toward new frames.

Table 1. Uncertainty ranges of definitions.

Concept	Theoretical orientations and meanings	Examples for biofutures
Closed uncertainty	There is only a little uncertainty, the future can be understood and predicted through forecast techniques (Shearer [24]). The issues can be even listed (Derbyshire *et al.* [16]). We are able to attribute risk factors clearly. These maybe unspecified uncertainty or underexamined issues within a context.	Forest growth can be calculated and forecast to a certain degree, lifespan of biological such as algae to produce a certain amount of biomass to produce a specific quantity of biofuels and chemicals. Incremental innovations in some technologies can be anticipated and prepared for.
Uncertainty as sets of alternative possibilities	Uncertainty is located in the outcome of specific occurrences of known actions or events, then, the future can be understood as a finite set of alternative futures, which can be derived, through event tree mapping exercises and applications of game theory (Shearer [24]).	A proposed piece of legislation goes into effect or it fails to be implemented. Future of work skills can be mapped out to a certain degree depending on what sectors anticipate for, with some becoming more dominant than others to match potential trends.

Table 1. *Cont.*

Concept	Theoretical orientations and meanings	Examples for biofutures
Open uncertainty	Open uncertainty (Derbyshire *et al.* [16]). More than a selected set of alternative futures, there may be a continuous spectrum of possible futures resulting from the effects of several recognised variables (Shearer [24]).	The impacts of climate change, sea level rise can be predicted but its subset of affects cannot be anticipated. Society under new environmental conditions can be hard to estimate and even harder to model, but some alternatives could be proposed in which pathways are understood (like safe environmental conditions).
Genuine uncertainty, unknown unknowns	A representation of true ambiguity (Shearer [24]), or genuine uncertainty (Ritchey [18]). We cannot conceive the uncertainty (Virmajokin [19]), it is not yet shown to us or even then its complexity is beyond our current understanding. We have to deal with this uncertainty without specifically knowing its characteristics, or we have to attempt to form them. Also, unknown unknows, these are the issues we do not know we do not know (Ilmola *et al.* [17]). Long term future perspectives quickly become unknowable, as there are so many rapid shifts that the potential features of which we are unaware.	For future generations we cannot know what specific challenges they may face and what decisions they would make. How nature & earth systems will react is speculate, if new sudden disruptions would be added we cannot know how a new system will react. New yet to be conceived technologies combined with biology may produce new forms of living beings that act

4. Critical uncertainties in practice

As a personal reflection, based on my experience conducting research, teaching, and facilitating participatory futures workshops at the Finland Futures Research Centre, I have observed how students, experts, and workshop participants navigate the challenge of negotiating, deliberating, and categorizing impacts and uncertainties. They identify weak signals and seek out discontinuities. Weak signals and horizon scanning are the most established means to engage uncertainties and can be utilised in many bespoke ways [25]. For a participatory foresight process, the challenge in envisioning these futures lies in transcending our current understanding of society, technology, politics, culture, economy, and the environment, by digging into territories of increasing uncertainty where novel and unforeseen elements begin to emerge, bringing forth new challenges. Additionally, this type of foresight exercise functions as a process in order to prompt contemplation of our present actions and how they may influence the course of tomorrow. It compels us to consider the

manifold alternative futures, their broader collective visions, and how our well-considered plans can shape the opening or closing of pathways for future generations and ourselves [26]. Admittedly, the mental endeavour of projecting oneself into the future, especially over extended long-term horizons can be intellectually demanding. Additionally, it may be demanding to identify and articulate adequately the relevant problems to be addressed. Therefore, the development of approaches, methods and tools to manage these complex issues can be seen to be constantly in demand. For those involved in the participatory foresight process, it potentially offers a liberating ideation space of opportunity and solutions, allowing participants to discern uncertainties today that might unveil novel paths forward. Derbyshire *et al.* suggest that the objective of such foresight approaches should be to challenge the mental models where a business-as-usual approach would be the only solution [16].

In the scenario planning method, as one example from many, a key stage in the process that aids in identifying critical uncertainties, is to identify and categorise issues of importance and then force a selection of those that are high in impact and low in likelihood, and that "prepare for the worst" rather than to "plan for what's likely", as Wood *et al.* have phrased it [27]. Rowe *et al.* [25] further explain that identified uncertainties are organised according to both the degree of importance and the degree of predictability and then used as the framework for scenario development. Then once the critical issues have been identified, they can be expressed in a dynamic way to represent the problem. The selected issues can be combined on a scale to form a framework to be used as the X and Y axis of two aspects of the converging critical uncertainties to be taken forward. For example, 'Command X and Control Y' as Sweeney has used for 'radical geoengineering scenarios' where extremes are expressed as each X and Y endpoints [28]. These can typically be divided to produce a 2×2 framework of four distinct scenario outcomes for example, or by following the Mānoa school approach that matches them with future archetype variables of Transform, Growth, Discipline or Collapse to force more radical outcomes [28]. However, there are many scenario methods, at least 21 scenario approaches by one count by Derbyshire *et al.*, that have different processes and are not limited by a number or even format, some logical, some plausible and others dealing with the implausible [16]. The point here is that in such a process the complexity and breadth of issues are in some way explored, deliberated and managed, to communicate possibilities of the core issues at hand. The elaborated scenarios, or even a chosen singular narrative produced can be seen to chiefly act as an extension of the critical uncertainties themselves as a core framework. These foresight products should not be seen as an end-point in the process, but as actionable issues and feedback loops that should be sought to test assertions and demystify the issues. Therefore, I want to highlight this initial step of seeing critical uncertainties as a framework for deliberation and categorisation that merits further attention and can be utilised in its own right. They are not benign. The above example of a mechanistic matrix approach to force and categorise impactful-uncertain issues is just one option, and not without limitations and challenges [25]. Other functional approaches could be proposed like voting to select uncertainties by participants in a workshop, or by picking at random with foresight game cards, or deliberating through an

expert Delphi or using interviews. Diversity of uncertainties warrants the need for experimentation through diverse approaches.

5. Uncertainties as existential threats & catastrophic risk

As previously mentioned, the concept of "existential threats" has been recently emphasised, that we might interpret to represent perhaps the most Critical of Uncertainties, which we might face. This heightened emphasis on uncertainties that are viewed as potentially catastrophic challenges, signals an increased awareness among decision-makers regarding the most severe threats to humanity, for example from Artificial General Intelligence to asteroid collision [10,11].

Other useful interpretations of this topic can be sought, as presented in the work of Avin *et al.* [29], which deals with classifying global catastrophic risks. It sheds light on critical uncertainties and often-overlooked aspects of those risks, offering chilling examples like the potential for human or nature induced 'multi-year winters'. This line of approach further requires the identification of systemic failures within various sub-systems, including institutional breakdowns and misaligned incentives, as well as shortcomings in prevention and mitigation strategies. These multifaceted risks afford a multidimensional perspective, where Avin *et al.* propose that such approaches are essential for addressing complex, human-induced risks that carry a substantial likelihood of precipitating severe global catastrophes [29]. From their risk-focused standpoint, it is essential to pinpoint 'critical systems' that, if compromised on a global scale, could hinder our ability to further recover from catastrophes. Interestingly Avin *et al.* highlight human-induced risks. They illustrate an example of a 'cloud of dust' that spreads across the globe capable of blocking sunlight for an extended period, thereby undermining the global food system to an unrecoverable extent [29]. In this biofutures perspective, critical uncertainties could be interpreted as the secondary and third order impacts, spillovers and implications involving human error, with subsystem failures. I am not suggesting that foresight approaches do not already, in some form, acknowledge these cascading impacts, for example, the Futures Wheel method introduced by Glenn in 1971, clearly aids such a second and third order impact discussion; however more attention could be given to development of diverse methods from diverse origins.

These types of engagement with challenges can be described as VUCA, which are risky combinations of complex issues, describing a world that is increasingly filled with features of Volatility, Uncertainty, Complexity and Ambiguity [12]. Tackling crisis issues is currently also being explored with decision-makers in another useful approach by Hukkinen *et al.*, the 'Policy Operation Room' workshops [30], that test city policy implications and responsiveness to threats. This approach addresses the need for a broad range of experts and professionals to weigh evidence, test future crisis situations and analyse decision-making under pressure to avoid future unwanted socio-ecological disruptions. The premise for this intervention is that crisis mode decision-making made in haste often reverts to path-dependencies and the Policy Operations Room tests and analyses these use long-term scenarios in real time [30]. The benefit of using scenarios with this control room model, where emergency

response and critical infrastructures are shown scaled in different combinations, is that they can offer insights into the path-dependencies and long-term implications that usually lie beyond their political or knowledge realms [30]. The aim of this workshop experiment was to identify probable uncertainties and poorly-known uncertainties.

Another relevant concept is Polycrisis, which suggests complex combinations of uncertainties. For example, pandemics have been seen to significantly impact our capacity to address sustainable development goals, leading to a state of 'polycrisis', or multiple combined crises in plural [31]. Addressing these compounded challenges that we may confront in the future demands a comprehensive global perspective. Such an approach encompasses the interests of both humans and non-human entities within potential trajectories, while operating within the safe and equitable boundaries of Earth's systems, as emphasised by Rockström *et al.* [32]. A just approach extends its considerations to not only the consequences of human actions on the planet, but also the reciprocal effects of climate changes on humans. The Intergovernmental Panel on Climate Change IPCC, Climate Change 2023: Synthesis Report [33], acknowledges the implications for future generations in its latest report, visualising how humans will be challenged at different climate change pathways. The World Wildlife Fund, reacting to what they saw as a narrow human-centric perspective by IPCC, elaborated on this same pathway visualisation of warming stripes to include a visual representation of the impacts of climate change on present and future non-human species, e.g., whales, elephants, trees and coral reef [34]. This example is an effective development in the representation of critical issues for future generations being engaged in the public sphere.

6. The language of uncertainty

The above examples suggest preparing for already identified formidable impending futures that are uncertain. Another approach would be to consider as Miller phrases it 'change in the conditions of change' [35] where we do not yet have the language to name what is coming through the change. This shift considers that there are issues we have no tangible knowledge about yet. This could be understood to be a Postnormal Times approach that Sardar *et al.* describe [36] that considers challenging deeply held convictions and deeply uncertain futures that suggest that existing methods are unable to cope with futures that are "intrinsically complex, chaotic, contradictory, uncertain, and rapidly collapsing in and upon themselves", and therefore it must be asked "what is probable in a world where uncertainty and chaos is the norm?". Considering this type of rapid emergence, engaging uncertainties must also therefore be mindful of the broader collective construction of knowledge, where language, names and concepts will arise that will seem radically different from now, even implausible, that potentially supersede our current understanding through new convergences. We may not have the parameters to understand what scientific or technological or social innovations will fill this uncertainty [18], but it would be important to attempt to explore and even design what those might be [20,21], and even assume that at a point in the future these unfamiliarity's could become the new established norm. This transition to a new normal is not only to define a concrete new regime, but rather to reflect on what has constituted normal

before and that it will never be the same. This cognitive shift is also important, as it opens up the possibility of accepting new thinking about future phenomena and redefining the boundaries of plausibility and possibility.

Considering the points above, we should also reflect on the current tentative terminology associated with solutions for a Green Transition, as policymakers have coined as a term for the shift to a sustainable biofuture. They have uncertain characteristics and novel names of their own, such as 'carbon capture', 'net-negative emissions', 'regenerative', 'circular sustainable bioeconomy', and 'renewables' to name a few. These terms are filled with valid propositions for how the future and present 'should be transformed'; mechanisms for the transition to occur that imply broad transformative structural change, but as yet are not fully realised and are still emerging. One illustrative example, is the uncertainty involved in achieving ambitious net-negative emissions targets, as they currently often rely on the promise of carbon capture technologies that do not yet exist, as warned by Anderson *et al.* [37], that policy makers' reliance on them risks failing to avoid the scenario of a global high-temperature pathway. However, in light of this warning, from a futures perspective it would also be valid to acknowledge that any long-term strategy must not only accept the likelihood of a meaningful paradigm-shift but also that there is a need to bravely engage with critical uncertainties, to push meaningful solutions toward the potential for fundamentally different futures. This is a paradox. I propose that identifying this kind of uncertainty serves as a metaphorical purpose—where the cognitive process of creating and naming a metaphorical "monster" that demands our attention is important in managing complexity, but may also distract from truly engaging within the intricacies of an issue [35]. There is a risk that in exploring extreme outcomes of the uncertainty that an exploratory futures process becomes railroaded into a 'problem-solution mindset', of allowing a fascination with problem-oriented methods to replace insights into the context or situation, resulting in a misaligned outcome, as Miller has warned [35]. Considering such future monstrous global-impactful issues like extreme climate emergency, with rapid sea rise, Artificial Intelligence development, synthetic biology, or broad biodiversity collapse; directly contemplating these issues exerts initially fear and awe through these imaginaries that require bold solutions for the daunting scale of change and complexity, but where action as well as inaction also bears risk. For critical uncertainties we need to 'name-them-to-tame-them' and it is important to also address what is monstrous to us, and to seek new ways to engage them. In order to do this, it seems important to adopt different frames and be willing to engage in creating new language.

Table 2 illustrates distinct framings of uncertainties across different levels. Firstly, critical uncertainty functions as a framing tool. For the context of biofutures, it may involve examining the consequences of various bioeconomic decisions over time, and determining which decisions and actors bear responsibility [38]. Secondly, scenarios depict uncertainties through variables. In biofutures, this can involve considering emerging innovation sectors and drivers such as forest, algae, agriculture, synthetic biology, and aquatic states [38]. Thirdly, existential risks involve envisioning extreme threats, such as 'ghost forests' repurposed for industrial use, impacting broader ecosystems, or a megacity being devastated

by floods, forcing neighbouring cities to prioritize between food production and housing [38]. Fourthly, in participatory processes, uncertainty may manifest through conflicting worldviews, where solutions range from controlling, augmenting, or restoring nature [38]. Lastly, framing uncertainty as a polycrisis in a biofuture involves the intersection of complex crises resulting where usual boundaries of sectors and areas of life become blurred by the cascading crises [39]. For example, an armed conflict in the Amazon (crisis 1) disrupting ecosystem restoration efforts, exacerbated by rising ocean temperatures from El Niño (crisis 2), while innovation of high-value natural resources in the Amazon competes for attention amidst political turmoil.

Table 2. Framing different uncertainties.

Framing	
Critical uncertainty	Possibly engaging different uncertainties, used as a contextual sensitive framing mechanism for strategic level foresight activities to identify important issues for a study. They may act as temporal anchors within a study and it is important to identify the forces of change that produce such critical uncertainty (Shearer [24]).
Framing uncertainty for scenarios	When approaching scenarios, an uncertainty can mean a variable to consider when making scenarios: a chosen critical or key uncertainty has various sets of relevant values that it may have. Values that represent variables mean the different ways that an uncertainty may develop, often with the aim of identifying extremes or endpoints (Schwartz [40]).
Framing uncertainty of existential risks	When considering existential risks, uncertainty is approached through the cautionary principle: we don't know how this development with possible catastrophic consequences will play out, so we should seriously pay attention to it. This implies action and preparation to 'think the unthinkable' as Herman Kahn (1962) [41] famously stated.
Framing participatory processes & uncertainty	When considering a participatory process, uncertainty often arises from different viewpoints or mental models. The developments themselves would not be de facto uncertain, but there are differing views and uncertainty might even be used as a way to delay action: "Things are uncertain and therefore we need more knowledge" or a lack of political will "We know we need to act boldly, but how to do it and survive the next election year?".
Framing uncertainty of polycrisis	Polycrisis does not mean just listing together different problems, when several crises occur at the same moment and converge they strengthening each other that becomes a greater than the sum of its parts (Lähde [39]). In a polycrisis the uncertainty points to the interdependence of the crisis and the unexpected phenomena that might emerge from it. It is the uncertainty of highly complex non-linear systems, and not uncertainty of viewpoints.

7. Framing uncertainty through transformative imaginaries and future generations

Based on the need for reflection on critical uncertainties from new frames or vantages, I propose the exploration of two additional thematic frames: transformative imaginaries and future generations. These frames offer valuable viewpoints for re-evaluating risk and critical uncertainties within the realm of biofutures. I perceive these as dynamic domains with both relevance for research and decision-making, that offer alternative approaches to tackling and making sense of these complex issues. They are dynamic in the sense that these are being currently constructed and developed traversing disciplinary lines from policy, innovation, and economics, to creative fields. In engaging them, I consider how they can be also applied to new challenges.

The first approach involves the concept of sociotechnical imaginaries, which are defined by Jasanoff *et al.* [7] as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures.". Over the years imaginaries have been developed as philosophical and theoretical approaches, where Binder elaborates: (social) "imaginary, represents a 'reservoir of meaning and condition for the emergence of new meanings, [that] has the potential to transform our thinking about culture and society." [42]. To unpack this term a little, the "imaginary" can take various forms, for example, the 'social imaginary' is described to conceptualise "the way ordinary people imagine their 'social' surroundings", they are "diffuse "magmas" of imaginary significations, which account for the historicity and creativity of meaning-making" [43]. Others such as a socio-technical imaginary, highlighting the interplay between social and technological aspects; or a socio-ecological imaginary, emphasising the social relationship with the environment. The term "future imaginary" encompasses all such aspirations as a future umbrella term, or even points to new unrealised imaginaries that may come in the future. This concept has been explored in a recent relevant study I want to highlight by Giurca *et al.* [43], focusing on 'post-pandemic transformative policy imaginaries', or more simply: what type of socially perceived transformation should happen after the pandemic? When discussing transformative policy imaginaries, it specifically underscores institutional aspirations and settings. For example, the study explored the green transformative possibilities that emerged within the public's vision of a post-COVID-19 world, captured early on in the pandemic. The central question revolves around the uncertainty of whether the existing EU policy initiatives are adequately equipped to realise the public imaginaries for the future. Namely the European Green Deal, the Bioeconomy Strategy, and the Circular Economy Action Plan were compared with the hopes for a post pandemic society drawn from media discourse during the pandemic. To evaluate these in the study, relevant experts related to the topic of the Bioeconomy and Circular Economy were invited to a two-round online Delphi questionnaire. Their role was to explore if these initiatives genuinely do drive diverse sustainability visions that represent expressed imaginaries of the public. The transitional pathways that were identified by respondents were often found to be conflicting or overlapping in nature. Experts evaluated and iterated upon issues from the first round, and developed more in the second.

As imaginaries follow their own "fuzzy logic", they are inherently uncertain as they are understood through their symbolic meanings [42]. One type of critical uncertainty concerning imaginaries, is where established imaginaries can begin to quickly shift or be replaced with new future imaginaries. When societies face and are forced to adapt to unanticipated challenges (as well as opportunities), their collective visions of the future may shift to reflect new priorities, values and understandings. In this above case [43], as the global crisis has been perceived in the popular media as an opportunity and catalyst for envisioning the necessary transformation, including various different imaginaries serving as attractors; these were understood to articulate more concrete desirable future scenarios with the means to achieve them. Interestingly, when given the choice, the established Bioeconomy Strategy was least selected by the expert panel, in contrast to the newer proposals of the European Green Deal or the Circular Economy, which represented broader portfolios of solutions, that allow for a more comprehensive consideration of various impactful issues. However, none of these proposed policy initiatives was deemed by expert panelists to be sufficient in themselves, revealing a wide misalignment between the current intent of EU policies, as defined in their policy instruments and initiatives, and the preferred future imaginaries that were envisaged in the Delphi [43]. This type of assumption and misalignment underscores the potential capacity for analysing imaginaries to reveal potential underlying overlooked areas. These represent clear discontinuities from established future directions. These planned-for and assumed futures are suddenly challenged by competing underlying aspirations by the public through new imaginaries. The study also identified sets of imaginaries that directly respond to the pandemic crisis, that are characterised as "business as usual" and "moderated degrowth", and the outlier being the highly uncertain "degrowth", that would need further clarification and definition of how it could manifest [43].

Reflecting on the method used in this case, the respondents were brought through the qualitative Delphi process by exploring their assumptions, referring to the imaginary based on collective views about what 'should happen in the post-Covid era', and in the second round to see how current proposals indeed match up to actually defined strategies. Finally, they were asked to create newspaper headlines for the future where they could design a new transformative policy mix, to align better with their interpretation of viable imaginaries. These point to relevance, for example as Holmgren *et al.* [44] pose, when crises serve as catalysts for transformation, the question arises: which imaginaries point us toward novel directions and paradigms? They depict biofuture imaginaries as difficult to pin down because of different ontologies and schools of thought. This point seems relevant for biofutures, with sub-sectors like forestry being constantly repositioned to find the optimal biofuture package. Holmgren *et al.* suggest that for imaginaries concerning biofutures, little attention is paid to imaginaries that deal with existing inequalities and how they may be addressed [44]. In this way, we can see that established imaginaries inform decisions, but they can also obscure other valid possibilities at the same time, where the possibility for new future imaginaries to emerge can function to inform society toward new directions. Imaginaries often exist because of collectively perceived uncertainty (e.g., pandemic, climate change, war). We cannot know how future imaginaries will inform future decisions in society, and similarly as imaginaries

themselves are hard to pin down, it can be seen that we do not fully understand how they are affecting current decision making. Minkkinen [45] for example suggests the value of imaginaries, where "effective imaginaries skillfully combine existing discourses and stretch the limits of plausibility to promote novel social practices" and he surmises that the negotiation of plausibility in imaginaries is an important potential topic to develop.

The second related framing approach I want to reflect upon, is where the critical uncertainty considers future generations (in this case, how well they are considered in governance). Future generations as the subject is a strongly developing area internationally, adopted throughout many disciplines and sectors. It was the topic of a recent Finnish government sponsored study by Airos *et al.* [46,47], that I was involved with, that formed a basis for the wider "Finnish governmental report on the future 2023" on the same theme [48]. The research was significant, as for the first time in Finland it collected and identified best practices and capabilities to better consider future generations in decision making, foresight, legislation and law-making [49]. Its aim was to identify what types of formal systems and entities have been established, or indirectly, to consider future generations. It utilised an online questionnaire as the method as well as a literature review, in part to explore the foresight related topics, with a balanced representation of international experts involved in related fields. The findings suggested that it is crucial to establish institutions and practices that prioritise the interests and rights of future generations. However, there are various uncertainties and challenges associated with representing them. These challenges include difficulties in defining what actually future generations are in relation to our own time, defining what are the present-day obligations towards future generations, the lack of future-oriented institutions in society, and the problem of excessive dependence on short-term political and economic theories [49]. Overcoming these challenges can be seen as an important perspective for biofutures to develop, that considers the interests and needs of future generations more clearly, and considers short term economic theories, while establishing institutions and systems that deal with long term mechanisms [49].

Considering the wider interpretations and definitions of future generations (not only human focused) that directly connect natural resources to future generations, often it is the legislative and legal pioneering actions involved in maintaining natural environments that are important. For example, lakes gaining legal rights. Here future generations can be clearly linked with issues of biodiversity and natural infrastructure. The question of who we refer to as future generations is ambiguous itself. In the research [46,47,49], many interpreted meanings were explored by Knudsen *et al.* regarding: our children or those about to be born? Or those who will live after our current generation? Or those generations affected by our actions today? And furthermore, can we consider non-human living beings to be included as future generations? A more mature definition leans toward observing the actions we take today. However, we might be wary that this may place our generation's interests over others, closing their futures to open ours or vice versa. It might be interesting to consider then what roles we set for future generations both formally and unintentionally, if our role is toward establishing a sustainable life, others might be toward avoiding other risks. As sustainable development inherently bears the responsibility of safeguarding future generations, however,

its focus is primarily centred on the well-being of humans. Then when issues of planetary biodiversity and ecological boundaries come to the fore, a broader perspective that includes non-human living beings emerges. In this context, the critical uncertainty surrounding future generations and our capacity to address their needs and rights significantly pertains to both current and future resource allocation. The concept of intergenerational responsibility introduces various roles that we may call upon future generations to undertake as much as we take consideration of them, opening up new areas of focus that warrant further consideration. Unintended consequences could be covered by a principle to do no significant harm to future generations, where current strategies are weighed against future needs, as Gupta *et al.* have defined [50]. The scope of the case study takes a first meaningful step [46,47], connecting current established relevant practices concerning future generations, so that the uncertainties here identified represent near future implications and foundations. If we consider a genuine uncertainty approach, we encounter a specific gap where we cannot know a priori who future generations are or what they will want. We must in this way plan and speculate for the emergence of something quite unknowable, a challenge that suits a futures inquiry. Future generations can be understood to be currently underrepresented in decision-making, representing a huge set of unknowns.

8. Conclusion

This has been a sensemaking exercise to reflect on what is involved in engaging with the concept of Critical Uncertainties, its different interpretations and how new frames might be helpful. I have taken a reflective (interpretivist/subjectivist) approach to meaning-making and conceptualising uncertainty as an intersubjective construct, meaning that I observe the wide approaches to uncertainty and how they relate to each other. Engaging in critical uncertainty, especially as part of a participatory process is an opportunity to explore phenomena in new ways and attempt to broaden its definition in relation to biofutures. This type of foresight exercise represents different functions, one that represents a solution space, and another as a kind of created monster to react against, to test and explore futures in reaction to it. This has the potential to be a very useful and powerful part of a sensemaking process, to analyse and identify signals of change (weak signals and drivers of change), and to take a broader look at those ramifications and separate them into manageable domains (e.g., social, technological, cultural, economic, and environmental). With this perspective, we can see that identifying and defining a critical uncertainty in context is a vital part of the sensemaking process, employed as a framing mechanism in strategic foresight activities. However, this step itself could benefit from further reflection, and here I have only given a brief overview of types of uncertainties and two suggested interesting frames. The relevance for those in biofutures dealing with the sustainability of biomass use for energy production is clear, as Karaoglanoglou *et al.* [51] suggest that participatory approaches with a wide representation of stakeholders bears importance when considering the bioeconomy. They note that with any long-term project, especially the development of industrial bioeconomy activities, represents a sustained, complex sociotechnical process, involving many complex vectors and areas at

several levels. Balancing this high level of uncertainty means that an effective strategy should be designed as a participatory process [51].

My reflexive position here has been to suggest that uncertainty is necessarily made into a kind of monster, with the current need to engage in colossal issues like existential risks. However, there is an admitted danger in adopting this perspective—where it may hinder a more thorough engagement with the phenomena, never engaging with what is actually unknown, by defaulting to a solving mindset. By finding the first solution, do we keep the threat at a distance and only abstractly consider the ramifications without actually exploring the nature of it? Of course, it can be argued that through discovering the implications and attempting a more complete view of that world we then can better understand the 'nature of the beast'. But potentially this reflection stage is often missing where the real cascading risks may be blocked by some assumptions informed through different imaginaries. This of course may be interpreted as an overstated criticism of the use of strategic foresight. Decision-making in this wicked-complexity-context often leans toward being reactive, potentially overlooking the potential to harness critical uncertainties to discern new emerging issues. However, the extent of this shift ultimately depends on the context, balancing solutions and exploration. My contention is that as futures and foresight processes have become more established, there is a growing bias or blind spot regarding threats and risks, particularly when critical uncertainties are in a state of flux. For instance, the growing call for formal bodies, such as the UN, to earnestly incorporate existential threats into their decision-making processes, aiming to address future uncertainties that pose substantial risks to our planet. This includes the systematic consideration of global environmental uncertainties stemming from climate change, as well as the intricacies of geopolitical tensions. This is of course representing a fascinating challenge, a 'call to arms' and a source for potential emerging resource of methods, theories and interdisciplinary research toward uncharted arenas.

Considering global challenges, the established mechanisms we have already developed can be understood as key to build upon, like Sustainable Development Goals that represent a comprehensive framework for tackling many of the known challenges facing our planet. But they too will need to be reconsidered as Agenda 2030 arrives. We might speculate if we then name new Sustainable Development Goals? or offer a whole new framework that represents new uncertainties? In this context, critical uncertainties assume a greater role in both organisational and personal decision-making. Bevan [52] reminds that there is 'no one uncertainty framework to rule them all' and there is a need to review uncertainty frameworks especially for environmental change. As for next steps in utilising uncertainty, there has been much work already made in defining what methodological experiments are actually good for exploring uncertainties, but there is a need to go further, especially experiments that consider ontological uncertainty, the unknown unknowns, genuine uncertainty that are often asked for but are often missing in studies [17].

The two distinct approaches I presented offer emerging frames for both communicating and exploring critical uncertainties. They offer long-term future perspectives, moving towards more strategic orientations that potentially tap into the realm of open-unknown futures. Transformative imaginaries explore potential conceptions of pathways that emerge

from the convergence of various sectors and solutions. These pathways can be juxtaposed with existing policy instruments and the desired futures articulated during times of crisis. Imaginaries serve as attractors for broad and yet unformed future orientations rather than rigid scenarios, they are fluid, exploring them may indicate how society reacts to uncertainty, but furthermore what manifestations of future imaginaries may emerge in society is highly unknowable. Next, the theme of future generations I presented, delves into the institutions and capabilities required to support forthcoming actions, that point to unique inter-generational uncertainties that highlight emerging critical issues from both future societies and ecosystems. My suggestion is that the green transition is an opportunity to consider more radical biofutures and that task requires identifying and engaging critical uncertainties from new vantages, where imaginaries and future generations could be valuable assets of framing.

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Conflicts of interests

The author declares no conflict of interest.

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