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Assessing Uncertainties in Climate Change Adaptation and Land Management

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Abstract: The entire cascade of scenario generation, global and regional climate modeling, as well as concrete measures towards climate adaptation are subject to uncertainties. An exact prediction of how the climate will change in the coming years, and how it will affect land use, is not possible. There is thus a perceived need to identify ways via which uncertainties can be addressed. Based on the need to address the research gap in this area, this paper reports the findings of a study on uncertainty in a climate change adaptation context, and how it is perceived. It consists of a multi-stakeholder survey among climate change professionals, including academic staff at universities, representatives from international agencies, members of NGOs, policymakers, and representatives of industry from 50 countries, including a balanced representation of industrialized and developing nations. The results obtained suggest that uncertainties are often a hindrance to engagement in climate change adaptation efforts, and to land management. Furthermore, there is a range of tools to reduce climate change adaptation uncertainties, whose deployment may help to address them. The paper concludes by providing a list of lessons learned and suggestions as to how uncertainty can be better communicated, and by doing so, how a reduction in the levels of climate change vulnerability may be achieved, and how land management may be fostered.

Keywords: climate change; land management; climate change risks; vulnerability; uncertainty

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1. Introduction

The generalized definition of uncertainty refers to not knowing or having a doubt about a particular situation. In more specific terms, it refers to epistemic situations with limited knowledge that thus make it impossible to full ascertain current or future outcomes [1]. It further prevents one from knowing whether there are one or more possible outcomes for a situation. Uncertainties may arise in different fields of study, including statistics, finance, economics, medicine, science, and engineering, also including land management issues [1]. These are fields that are partially observable or have hypothetical situations.

Uncertainty can be broken down or characterized into two main categories, namely: irreducible uncertainty and imprecision. Irreducible uncertainty [2] arises from random processes, and accounts for the knowledge gap that occurs between certainty and precise information. Imprecision [3], however, refers to the gap that exists between the present state of information and precise information. It is often referred to as reducible uncertainty or epistemic uncertainty [4].

The concept of uncertainty plays an important role in environmental changes as a whole, and specificity to climate change and its resulting impacts. Whereas researchers are usually rather well-informed, most of the public are not only uncertain about the impacts of climate change, but also about how events of the past and present have contributed to the current climate crisis [5].

It is a fact that climate change is expected to create many changes at the local, national, and global levels. However, with these variations, many uncertainties are expected to rise. This includes, for instance, uncertainty about rainfall patterns, about short- and long-term temperature changes, and the frequency of extreme climate events, such as floods, droughts, and cyclones, among others. All of these influence land management and use. More specifically, this uncertainty also poses a major problem for decision makers, who are often unsure about which policies to follow or action to take, due to existing uncertainties. Some measures to create new models to assess and fill in the gaps posed by uncertainties have been implemented. However, much work is still needed in the shift from reducing uncertainty to understanding and finding ways to manage it [6]. Table 1 presents various types of uncertainties, classified according to different sectors and disciplines.

Table 1. Some types of uncertainties.

Type	Related Literature
Economic	An economic analysis of adaptation to climate change under uncertainty [7]; Climate Impacts on Economic Growth as Drivers of Uncertainty in the Social Cost of Carbon [8]; On the Uncertainty About the Total Economic Impact of Climate Change [9] Nature of the uncertainty: lack of clarity on costs
Agricultural	Uncertainty in simulating wheat yields under climate change [10]; Towards probabilistic projections of climate change impacts on global crop yields [11]; Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan [12] Nature of the uncertainty: lack of accurate data to guide decisions and investments
Social	Scepticism and uncertainty about climate change: Dimensions, determinants, and change over time [13]; Uncertainty, scepticism, and attitudes towards climate change: biased assimilation and attitude polarization [14]; Climate change in the media: reporting risk and uncertainty [15] Nature of the uncertainty: lack of trust in the phenomenon of climate change
Natural	Uncertainty in climate change projections: the role of internal variability [16]; Regional surface chlorophyll trends and uncertainties in the global ocean [17] Nature of the uncertainty: lack of confidence in climate data
Scientific	Public representations of scientific uncertainty about global climate change [18]; Climate negotiations under scientific uncertainty [19]; Uncertainty and unabated emissions [20]; Uncertainty and climate treaties: Does ignorance pay? [21]; How Do Texture and Color Communicate Uncertainty in Climate Change Map Displays? [22]; Uncertainty in science and its role in climate policy [23] Nature of the uncertainty: doubts regarding the scientific basis of climate change

Table 1. *Cont.*

Type	Related Literature
Estimational hydrological	Uncertainty of downscaling method in quantifying the impact of climate change on hydrology [24]; Overall uncertainty study of the hydrological impacts of climate change for a Canadian watershed [25]; Characterizing Uncertainty of the Hydrologic Impacts of Climate Change [26]; Uncertainty in climate change impacts on water resources [5]; Prediction and uncertainty of climate change in China during 21st century under RCPS [27]; Climate change uncertainty: building flexibility into water and flood risk infrastructure Gersonius et al. [28] Nature of the uncertainty: imprecise hydroecological impacts
Structural	Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change [29]; Structural uncertainty in projecting global fisheries catches under climate change [30] Nature of the uncertainty: doubts regarding global projections
Observational	Atmospheric circulation as a source of uncertainty in climate change projections [31] Nature of the uncertainty: lack of full accuracy of projections
Managing or knowledge	Managing uncertainty in soil carbon feedbacks to climate change [32]; Identifying water resources management strategies in adaptation to climate change under uncertainty [33]; Investment Decision Making under Deep Uncertainty—Application to Climate Change [34]; Climate change, uncertainty, and natural resource management [35]
Ecosystem	Robustness and uncertainty in terrestrial ecosystem carbon response to CMIP5 climate change projections [36]; Managing native and non-native sea lamprey (Petromyzon marinus) through anthropogenic change: A prospective assessment of key threats and uncertainties [37]; Assessing uncertainties in a second-generation dynamic vegetation model caused by ecological scale limitations [38] Nature of the uncertainty: lack of accuracy of models and economic aspects
Model projection	Sensitivity of future climate change and uncertainty over India to performance-based model weighting [39]: Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history-factors [40]; Modeling climate change impact on *Septoria tritici* blotch (STB): Accounting for climate model and disease model uncertainty [41]; Modeling Uncertainty in Climate Change: A Multi-Model Comparison [42] Nature of the uncertainty: lack of full accuracy of climate models
Species distribution	Uncertainty in ensemble forecasting of species distribution [43]; Conservation planning under climate change: Toward accounting for uncertainty in predicted species distributions to increase confidence in conservation investments in space and time [44]; Incorporating uncertainty in predictive species distribution modeling [45] Nature of the uncertainty: lack of accuracy in species' distributions
Physical	Storylines: an alternative approach to representing uncertainty in physical aspects of climate change [46]; Uncertainty of climate change and its impact on reference evapotranspiration [47] Nature of the uncertainty: lack of full accuracy regarding physical aspects
Migration out	Uncertainty of climate change impacts on out-migration of local population from affected areas (wait or leave?) [48] Nature of the uncertainty: variables influencing migration

Various researchers have described climate change uncertainties as one of the most notorious inhibitors of climate change adaptation, and this also applies to land management and use. Data have indicated that climate change is associated with the increase in extreme climatic events, but predicting when this may occur is not easy. This prevents proper adaptation measures from being created or implemented. Climate change projections are often too vast and lack fine-tuning, which complicates the development of related climate change policies. Additionally, the uncertainty regarding climate change makes decision making problematic for the social, economic, and political events related to the problem [49].

Increased flooding is one of the most common effects of climate change, and one which influences land management and use. Therefore, designing infrastructure that is resilient to extreme floods is considered an important adaptation measure. However, erratic precipitation patterns in various areas prevent the proper design of the necessary infrastructure. Bearing this in mind, more advanced approaches are needed, which may account for the uncertainty related to floods. When available, these aid in the design of infrastructure that takes into account predicted and unpredicted risks. In particular, parameters that may account for different stakeholders habits and preferences [50] would be particularly useful. Professionals working in climate change, adaptation, and mitigation sectors, such as extension workers, field scientists, environmental engineers, among others, could provide invaluable information.

For a more reliable integration of climate change adaptation and mitigation, major modifications are needed in global energy systems to reduce the amount of CO_2 emissions produced [51]. This, however, is dependent on the actual effects of climate change, which largely remain unpredictable [52].

In order for decarbonization pathways to be created and implemented, the impacts of climate change on carbon cycles need to be better accounted for [53]. Currently, the uncertainty surrounding future impacts to some extent hinder the design of integrated adaptation and mitigation processes. Furthermore, there are uncertainties associated with possible limitations in the effectiveness of new energy systems. More specifically, there is a lack of clarity on how to integrate the use of hydropower with solar and wind power [54] in order to maximize their synergies, as part of efforts to achieve reductions in CO_2 emissions.

Constant variations in temperature have also led to some uncertainty regarding the risks humans, animals, and plants face [43]. Whereas research has largely indicated that temperatures have been increasing, along with changes in humidity and wind intensity, in many areas, others are experiencing drops in temperature. Here, the observed uncertainty is used as a reason for not undertaking measures in anticipation of future risks. Furthermore, the vagueness of predicted annual greenhouse gas concentrations makes it difficult to ascertain, with full accuracy, how temperature will be affected in the long term. This, in turn, to some extent prevents the implementation of long-term adaptation strategies [55].

Finally, a less common uncertainty associated with climate change is in respect of its effects on conflicts. Although many scenarios exist where climate change is implicated in past and current wars and conflicts, there is a great degree of uncertainty about how climate change may cause future conflicts. In order to address this, some studies are designing models to ascertain climate–conflict linkages, and hence identify appropriate means to pursue adaptation [56].

This paper addresses the subject of perception about climate change adaptation uncertainties by addressing the following research questions: (i) how climate change practitioners perceive climate change adaptation uncertainties, and (ii) which measures may assist in reducing different types of uncertainty, and contribute towards the reduction in climate change vulnerability due to improved information dissemination.

2. Methodology

To obtain a wide range of views from different respondents and individuals working in the field of climate change and climate change adaptation, we conducted a global online survey from 8–26 October 2020 using a closed-ended questionnaire. The Google Forms tool was used for this online survey. Participation in the survey was directed towards the respective stakeholders familiar with uncertainties in climate change, climate change adaptation, and climate change management. The target group included researchers, academics, private company representatives, staff working for international agencies, government employees, NGO representatives, policymakers, as well as other climate change networks. To gather the data, the survey link was electronically disseminated to different forums, including various social media platforms as well as through bulk email distributions. The use of an online electronic platform enabled the study to maximize outreach across continents. The survey was designed to reach a highly dispersed population of professionals working in climate change, adaptation, and mitigation sectors. All study participants had in common that their professional background and their organizational activities focused on climate change, mitigation, and adaptation. The authors constantly monitored the feedback platform, and as soon as a saturation number was reached, the survey was closed.

The online survey aimed at identifying how climate change adaptation uncertainties are being perceived (Figure 1), also taking into account land management and use, and how communication may assist in reducing different types of uncertainties and, inter alia, reduce climate change vulnerability due to improved information. The authors prepared and duly pre-tested a 13-item questionnaire, and recorded responses from academics, company representatives, international agencies, members of NGOs, and policymakers (e.g., politicians, heads of government agencies) from a total of 50 countries. Respondents, which include researchers, practitioners, and representatives of development agencies and other stakeholders, have provided a dataset that can help to better understand the role of uncertainties in climate change adaptation from a practical perspective.

Figure 1. Aspects of communication and uncertainties.

The study pursued a non-probability sampling approach, i.e., convenience sampling. The online survey targeted a heterogeneous group of stakeholders and policymakers encompassing 142 respondents from a total of 50 countries, of which 22 were industrialized and 28 were developing countries. The demographic information (gender, age, level of education, and country of residence) of the participants was also gathered to assess possible relationships between these indicators and perceived uncertainties. The countries of origin of these respondents include South Africa ($n = 19$), Ethiopia ($n = 14$), Brazil ($n = 10$), USA ($n = 9$), UK ($n = 7$), India ($n = 6$), Australia, Germany, Nigeria, Portugal (each with $n = 5$), Ghana, Kenya (each with $n = 4$), Canada, Greece, Tanzania (each with $n = 3$), Argentina, Austria, Italy, Lithuania, Spain (each with $n = 2$), Bangladesh, Belarus, Botswana, Egypt, Fiji, Guatemala, Indonesia, Iran, Israel, Mexico, Mozambique, Nepal, Norway, New Zealand, Pakistan, Philippines, Poland, Taiwan (ROC), Senegal, Serbia, Singapore, Solomon Islands, Sudan, Sweden, Switzerland, the Netherlands, Turkey, Uruguay, Zambia, and Zimbabwe (each with $n = 1$).

The gathered data were cleaned and analyzed further using descriptive statistical analysis in SPSS and Microsoft Excel to yield the mean and standard deviations. Moreover, the frequency of percentage response for the demographic data was also measured. For the mean, matrix rating scale results were scored on a Likert scale from 1 to 5 (e.g., least important = 1; slightly important = 2; moderately important = 3; important = 4; very important = 5). The percentage of respondents who selected each response in the matrix scale was also included in our results. Similarly, the effectiveness of tools to reduce uncertainty was measured by rating (e.g., not effective = 1, low = 2, medium = 3, high = 4, very high = 5), and the percentage of respondents were calculated accordingly. Supplementary Materials includes the detailed questionnaire.

The evidence of uncertainty about facts, numbers and scientific information should also be analyzed. The data from each case study will be presented individually, in a summarized manner, and subsequently amassed in different tables and graphics, where they may be benchmarked against one another. Ultimately, the dataset will allow an overview of how uncertainty is communicated and how trends may be improved, so that advice to guide future efforts made by the various stakeholders in this important area may be provided.

This paper has some limitations. The first one is the fact that it did not cover all countries, so it cannot be regarded as fully comprehensive. In addition, the fact that the study was performed online and in English means that only persons with internet access and fluent in English could take part in it. However, despite these constraints, the paper provides a welcome contribution to the literature on climate change uncertainties, and provides insights into how they are perceived across a set of geographical regions.

3. Results

In environments of high uncertainty, climate change adaptation in practice and decision making is challenging, and requires new interdisciplinary approaches [1]. An improved understanding and communication of climate change adaptation uncertainties are fundamental for making the right decisions towards reducing climate change risks and vulnerability [57]. This study assessed perceived determinants of uncertainty on climate change adaptation and tools currently applied by various stakeholders to reduce distinctive types and degrees of uncertainty.

3.1. Description of Respondents' Characteristics

Assessing the perceptions of researchers, practitioners, development agencies, and at-risk segments of the community can help to better understand the role of uncertainties in climate change adaptation from a practical perspective. Figure 2 highlights the global distribution of respondents.

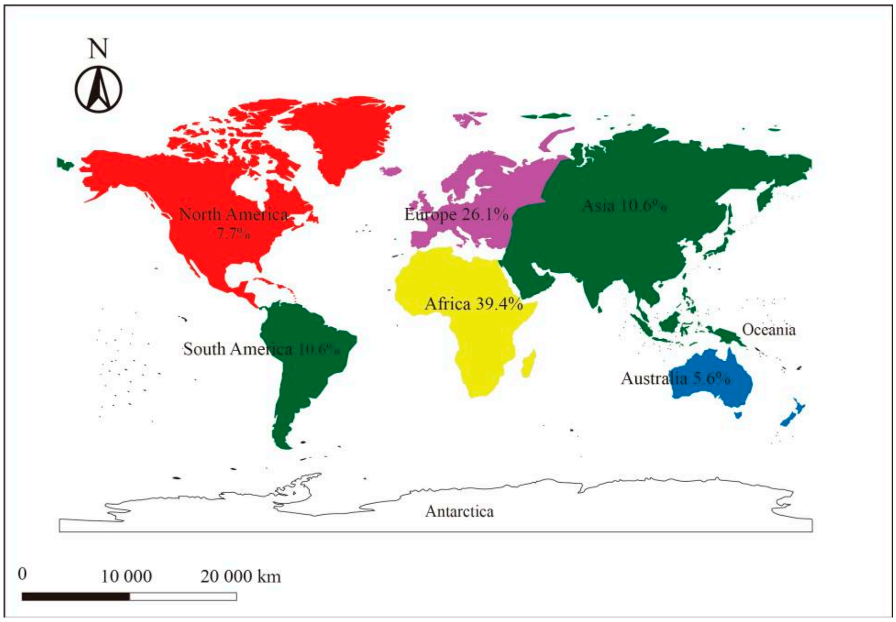

Figure 2. Continental percentage distribution of online survey respondents.

In total, 142 respondents from 50 countries spread across 6 continents took part in the survey, with Africa contributing 39.4%, Europe 26.1%, South America 10.6%, Asia, 10.6%, North America 7.7%, and Australia 5.6%. Among the 50 countries, hereof about 1/3 developed and 2/3 developing countries, South Africa recorded the highest number of responses, constituting 13.38% of the total participants, followed by Ethiopia (9.86%) and Brazil (7.04%). Table 1 highlights the age structure, as well as the professional and gender profiles of the respondents.

In terms of age (Table 2), the topical informants ranged from 60 years and above (20%); 41–60 years old (54%); 26–40 years (25%), and the youngest age group, 18–25 years old (1%). From the survey, a total of 69.7% of respondents were PhD degree holders, while 23.9% had achieved an MSc/MA degree, and with 2.8% being holders of Bachelor's and professional degrees, respectively. Only one respondent indicated technical/vocational training. The self-categorization of respondents underscores the heterogeneous target group the study sought to reach: There was a cross-section of respondents ranging from academics, companies, consultants, farmers, NGOs, government agencies, and international organizations who theoretically and practically were assumed to have been exposed to uncertainties in climate change adaptation. Slightly more than 2/3 (68.3%) of respondents were male and about 1/3 (31.7%) female. The lower number of female online survey respondents might reflect gender disparity, i.e., fewer female experts engaged or represented in climate change adaptation interventions and research, as observed by Rao et al. [58] in semi-arid regions of Africa and Asia.

Table 2. Professional and gender profiles of respondents.

Item		Frequency	Percentual (%)
Gender	Female	45	31.69
	Male	97	68.30
Age	18–25	2	1.4
	26–40	36	25.4
	41–60	76	53.5
	>60	28	19.7
Education level	Ph.D.	99	69.7
	MSc/MA	34	13.9
	Bachelor's	4	2.8
	Professional degree	4	2.8
	Technical/vocational	1	0.7

3.2. Perceived Determining Factors of Uncertainty

The process of implementation of climate change adaptation measures requires an adequate understanding of the dynamic nature of climate extremes and non-climate factors [59]. The stakeholders' climate change adaptation measures could be stimulated or constrained by environmental, socioeconomic, and political factors. The nature and sources of uncertainty in dealing with climate change adaptation and land management could vary across sectors, based on the degree of climate risk exposure, and the local adaptive capacity. Accordingly, Table 3 summarizes the perceived uncertainties of climate change adaptation to multiple reinforcing factors. The results suggest a solid knowledge level of uncertainties, i.e., 91.4% of the respondents were aware of the concept and determinant factors of climate change uncertainties and climate adaptation. To complement the more exploratory analysis supported by Dessai and de Sluijs [60] and qualitative statements [57], a quantitative analysis was conducted by computing some basic measures of correlation between the rating of uncertainty factors and the perception of respondents.

Table 3. Relevance of selected uncertainty factors.

Rating of Uncertainty Factors	Percentage of Respondents					Mean	Standard Deviation
	Least Important	Slightly Important	Moderately Important	Important	Very Important		
Environmental	2.14	6.43	10.71	20.71	60.00	4.3	0.36
Social	0	6.47	15.11	35.25	43.17	4.15	0.35
Economic	2.92	3.65	17.52	40.15	35.76	4.02	0.34
Technical	1.44	12.95	29.50	34.53	21.58	3.62	0.31
Political	1.44	8.57	18.57	30.71	40.71	4.01	0.34
Ethical	5.07	16.67	24.64	26.81	26.81	3.54	0.30
Health	1.45	8.70	21.01	25.36	43.48	4.01	0.34

Note: scale from 1 (least important) to 5 (very important).

Table 3 shows the matrix rating of the perception of respondents towards environmental, social, economic, technical, ethical, political, and health uncertainty factors. It indicates that environmental factors were regarded as the most important factor influencing uncertainty regarding issues of climate change and adaptation. Furthermore, 60% of the respondents regarded environmental factors as very important in uncertainty, followed by health (43.48%), social (43.17%), and political (40.71%) factors. Technical and ethical issues were rated the least important at 21.58% and 26.81%, respectively.

Table 4 highlights that 56 respondents were influenced by uncertainties on climate change to some extent, 45 respondents to a great extent, 11 respondents to a small extent, and 1 not at all. This finding implies that all respondents face uncertainties in one way or another in the execution of tasks in their organizations. Moreover, the influence of uncertainties due to climate change on various sectors may emerge from errors, such as the design of models, the parameters that are included, and the treatment, simplifications, or assumptions concerning the interactions of these parameters [61]. As shown in Table 4, most participants indicated that the task they play in their organizations may be closely linked to adaptation to natural variability, for example, atmospheric, oceanic variability, socioeconomic, demographic, and technological changes [6]. Finally, 87.23% of respondents indicated to a great extent that climate change should be tackled, which reflects a rather high awareness and knowledge regarding the phenomenon of climate change.

Table 4. Influence of uncertainties on climate change adaptation.

Influence of Uncertainties on Climate Change	Frequency
To some extent	56
To a great extent	45
Moderately	27
To a small extent	11
Not at all	1
TTL number of responses	140

3.3. Importance of Tools Used to Reduce Uncertainty in Climate Decision Making

This section presents the tools that respondents commonly rely on to reduce climate change adaptation uncertainties.

As highlighted in Table 5, most participants confirmed that they depend on long-term studies (50%) as tools to tackle and deal with uncertainties when making decisions, and that they find these tools to be very effective instruments. Other respondents cited UN documents (41.27%), expert opinion (36.92%) studies commissioned by the government (21.36%), and official forecasts (20.75%). Meanwhile, the least dependable tool was movies, at an estimated 8.99%. Furthermore, 0.85% felt that long-term studies are not effective at all when dealing with uncertainties. The UN produced documents that were also regarded as dependable tools for decision making when dealing with climate-change-related uncertainties. In the following section, the results for several ways to reduce and deal with climate change uncertainties are highlighted. Communicating uncertainties is of fundamental importance, but such information is not always successfully transmitted to the decision makers who most need it. Traditionally, this has taken a linear communication approach, where scientists identify sources of uncertainty and propose findings to policymakers that are often codified in nature [62].

Table 5. Importance of tools used to reduce uncertainty in climate change decision making.

Tools Applied	Effectiveness of the Tool(s) (% of Respondents)				
	Not Effective	**Low**	**Medium**	**High**	**Very High**
Expert opinion	1.54	1.54	16.92	43.08	36.92
Long-term studies	0.85	1.69	14.41	33.05	50.00
Official prognosis/forecasts	0.94	6.60	25.47	46.23	20.75
Informal forecast/ Indigenous knowledge	3.96	26.73	31.68	26.73	10.89
UN documents	2.38	1.59	19.84	34.92	41.27
Studies commissioned by government	3.88	7.77	33.01	33.98	21.36
Wide information and communication strategies	4.90	10.78	42.16	32.35	9.80
Fact-based broadcasting	5.00	13.00	30.00	37.00	15.00
Movies	31.46	22.47	22.47	14.61	8.99
Others	27.27	3.03	18.18	33.33	18.18

3.4. Ways to Reduce/Manage Uncertainties on Climate Change and Adaptation and Land Management

This section presents the suggested ways to avoid or reduce uncertainties on climate change adaptation as per respondents' views, bearing in mind land management and use. Prominently, respondents suggested the development of guidelines at different levels to assist practitioners to manage climate-change-related uncertainties.

Table 6 highlights that most participants felt that it is rather important to develop global and continental guidelines (28.20%). In addition, 16.9% of the respondents felt that to reduce the impact of uncertainties on climate change there is a need to develop global, continental, regional, and country guidelines. The lowest percentage of respondents felt that we should accept uncertainties as an attribute of the system and stop trying to control it, and instead work with it (1.4%), while the same 1.4% also felt that the development of global, regional, and continental guidelines can assist in reducing climate change uncertainties. These views concur with findings from Pindyck [63], who ascertained that uncertainty in climate change has been increasing over the years as a result of how a better understanding of physical mechanisms can help to address uncertainty.

It was not the intention to breakdown the results of each individual stakeholder. Doing so would produce a rather fragmented, and hence unviable, set of results, since some groups were better represented in the survey than others. Rather, the approach used hereof is to report on the overall views on uncertainties among these actors. It is the focus on uncertainties, and how they influence the behavior of the stakeholders, that is at the core of the paper.

Table 6. Percentage responses on ways to reduce uncertainties in climate change and adaptation.

Response	%
Develop global guidelines and develop regional guidelines	28.20
Develop global guidelines, develop regional guidelines, develop continental guidelines, and develop country guidelines.	16.90
Develop regional guidelines, develop country guidelines, and integrate forecasting.	16.2
Develop country guidelines	11.4
Develop global guidelines, develop regional guidelines, develop continental guidelines, and develop action plans at a municipal level.	6.3
Develop regional guidelines	4.9
Recognize the value of uncertainties in terms of increasing robustness of the decision making process and work with uncertainties	4.2
Develop global guidelines	3.5
Develop global guidelines, develop continental guidelines, and develop country guidelines.	2.1
Develop regional guidelines, country guidelines, develop continental guidelines, and develop action plans at a municipal level.	2.1
Accept uncertainty as an attribute of the system, stop trying to control it, and instead, work with it.	1.40
Develop global guidelines, develop regional guidelines, develop continental guidelines, develop country guidelines.	1.4
Develop global guidelines, develop regional guidelines, develop continental guidelines, develop country guidelines, maintain the status quo, and integrate indigenous knowledge.	1.4
Total	100

4. Discussion

The current study focused on evaluating the perceptions and views of various stakeholders, and how to deal with uncertainties in climate change adaptation in practice. Findings from the study suggest that climate change uncertainties, also in respect of land management and use, remain an integral component in improving climate change adaptation capacity and policy formulation, though it remains an elusive subject for both research scientist, practitioners, and policymakers alike. Even though technology and scientific knowledge capabilities, i.e., the ability to project future trajectories, have improved over the years, gaps remain in our understanding of uncertainties in climate change adaptation.

These blind spots emanate from data processing tools as sources of uncertainty. As evidenced in our current study, different tools are applied in practice to identify uncertainties in climate change adaptation and improve measuring climate risks. Our study observes that there is a range of tools that policymakers, practitioners, and academics make use of to reduce uncertainties in climate change adaptation, e.g., 50% indicated that they make use of long-term studies, while UN documents were used by 41.27%, with 36.92% indicating that they use expert opinions and 21.36% indicating that they make use of government-commissioned studies. This suggests that stakeholders involved in climate change adaptation apply a set of tools to spread the risk in an endeavor to avoid making improper decisions. The identified tools range from evidence-based inputs and insights drawing on official UN statistics, to current expert knowledge and national-level investigations to aid policy making and facilitate a truly sustainable transformation.

In an attempt to reduce climate anomalies and enhance the accuracy of predictions, stakeholders usually resort to the use of models, including climate models that also take into account land management and use. However, these resemble sources of inherent uncertainty by themselves as tools used to estimate expected seasonal rainfall based on satellite data are sometimes not consistent [64,65]. Using models is further complicated by the fact that there is not a known the best climate model [66], therefore, uncertainty remains an indispensable element of modeling [67]. Furthermore, model uncertainty has also been found to increase with increases in slopes, particularly for precipitation and runoff [68].

This is further expounded by Ju et al. (2021) [69], who established uncertainties in respect of emissions, climate models, and hydrological models. This therefore negatively weighs heavily on crafting climate adaptation policies and interventions based on models only, hence the need for a multi-sectoral approach. To overcome uncertainties associated with the use of climate models, Ribes et al. [70] proposes a new climate model ensemble that uses improved surface observations as well as a new statistical approach.

On a global scale, three overarching sources of uncertainties are grounded in climate predictions, namely, the internal variability of the climate system that emanates from the absence of radiative forcing of the planet, model uncertainty that comes from the differences in climate models simulating different outcomes, while the third source of uncertainty comes from future greenhouse gas emissions, i.e., scenario uncertainty [71]. Such uncertainties also extend to what extend the global warming phenomena will stretch and, to some extent, this might actually be unknowable [64]. Such variabilities create uncertainties in decision making at different stakeholder levels, including policymaking [72]. Uncertainties due to climate change may also influence the tasks played by respondents in organizations based on incomplete temporal/spatial data coverage.

The other source of climate change uncertainty stems from how different stakeholders process uncertainty data and come to conclusions that warrant taking certain paths in decision making, particularly those concerned with land management and use. Traditionally, the scientific community applies a systematic way of building knowledge; non-scientific communities use other ways and means to build knowledge [73]. Underscoring the growing importance of indigenous knowledge (IK), Petzold et al. [74] provide evidence of IK on adaptation across regions.

This view affirms the view that climate change uncertainty should be regarded as a multi-disciplinary, complex field that should be managed rather than mastered [75]. What remains of fundamental importance is the need to better understand the sources of uncertainty, so as to enable the design of appropriate climate change adaptation policies which may address them. This is further elaborated by Pastor et al. [76], who established that most global studies have evaluated parametric uncertainties, yet the same authors recommended that the world should embrace uncertainties as a way to enable better communication within the field of climate change and adaptation. Interestingly, only 1.40% of the respondents felt that it is important to accept uncertainties as an attribute of the system, which may indicate that stakeholders' perceptions are still dominated by the idea that there can be zero uncertainty.

The findings of this study thus underline the call for improved communications on the role and influences of uncertainties in climate change adaptation, and may contribute towards the awareness-raising for stakeholders in governments and international organizations involved in policy formulation, as well as NGOs and further outreach workers working in the field of climate change adaptation. This is especially relevant in respect of land management and use, whose decisions are often characterized by various uncertainties.

5. Conclusions

Uncertainties in climate change adaptation are caused by the complexity of the climate system, the necessary abstractions in the framework of the models, the natural variability of the climate, and assumptions about the future development of greenhouse gas concentrations, aerosol, and land use. They are also caused by limited access to information. A partial reduction in these uncertainties can be expected in the next few years. However, the substantial factor will remain. Nonetheless, the existing uncertainties do not reduce the need to make decisions based on the available information.

Therefore, this paper provides a welcome addition to the literature on climate change uncertainties since it reports on an effort to provide a better understanding of the processes that influence them, coupled with an overview of the levels of information and awareness among some key players in the process.

As the complexity of climate change generates trajectories influenced by uncertainty, it is challenging to choose the most appropriate adaptation strategy to address specific climate-change-related impacts. Uncertainty over climate-change-related impacts—and this includes land management and use—refers to limited knowledge about the intensity of a precise local impact within a global dynamic. Undoubtedly, our understanding of climate change and the underlying dynamic continues to increase. Even so, some uncertainties remain regarding the links between cause and impact within a specific geographic setting. This uncertainty in turn generates serious challenges when identifying the appropriate adaptation strategies for risk and impact reduction within a specific geographic setting, even when climate-change-related impacts pose a global risk for communities and societies.

The current study was conducted globally, with participants being drawn from six geographical regions, namely, North America, Europe, Africa, Asia, Australia, and South America. Participants had diverse backgrounds, ranging from academia, government departments, and international organizations, as well as NGOs. Factoring in uncertainty remains a key component in crafting climate change policies and climate change adaptation responses. However, the present study establishes that factoring in uncertainty remains a complex process. Climate change practitioners across the globe regard and treat uncertainty issues differently, resulting in differential communication strategies for various audiences. From the participants' perspectives, of which about 2/3 reside in developing countries, environmental factors were ranked as the most important factor in climate change uncertainty. An overwhelming majority, 87.23% of the respondents, felt that dealing with climate change is of paramount importance, which highlights that climate change practitioners around the world are very aware of the challenges associated with climate impacts, which may imply a high willingness to work to find solutions to sustainably adapt to climate change. Moreover, 50% of the participants felt that they rely on long-term studies as the main tool to reduce uncertainty in climate change adaptation.

To reduce the impact of uncertainties on climate change adaptation, the participants advocated the development of guidelines on all scales, e.g., global, regional, and national levels. Some practitioners even proposed local, i.e., municipality-based guidelines, since these are relevant to local land management and use. It is therefore important that policymakers acknowledge the relevance of, and the need to consider, uncertainties in crafting climate-related policies and decision making across scales, as suggested by this study.

The implications of this study are twofold. Firstly, it suggests that if one does not acknowledge the character and features of uncertainty, and if these are not reflected in how the associated evidence is used, then the chances of making more informed decisions are reduced. Secondly, if uncertainties are not duly considered, they might become less manageable, and this might hinder the ability to make coherent decisions and design effective policies. Ignoring uncertainty can also undermine effective risk management, if the risks that would result from including uncertainty are ignored and not considered in necessary actions [77,78].

Finally, not 'sufficiently' including uncertainties increases the probability that an action may be inadequate and increase vulnerability. There is an increased possibility of maladaptation when failing to sufficiently consider uncertainties in the knowledge base.

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