1. Introduction

The significance of anthropogenic climate change in shaping and threatening the future of humankind, and the need for urgent political action is beyond scientific doubt—a fact that is supported by thousands of scholars worldwide and a large share of the policy-making community. Yet, the issue of uncertainty has been pervasive in the climate change discourse from the start (Dessai et al. 2007).

Workman et al. (2020) have in a recent work critically analyzed climate policy decision-making and what they denote as the philosophy underlying the use of integrated assessment modeling to inform climate policy. They criticize current climate policy-making processes for being naïve with respect to how they view model outputs as objective facts and use the outputs directly to program policies. From this observation, they conclude that there is a need for an alternative approach on how to inform climate policy makers about climate change uncertainties. They refer to the robust-decision-making framework as a good starting point for doing so and state the need for “an alternative approach that explicitly embraces uncertainty, multiple values and diversity among stakeholders and viewpoints, and in which modelling exists in an iterative exchange with policy development rather than separate from it” (Workman et al. 2020, p. 77).

This article will address the position of the policy maker and give advice on how to better address uncertainties involved in climate change adaptation decision-making. The article aims at providing ways to avoid the situation of policy makers becoming paralyzed by the seemingly overwhelming uncertainties embedded in climate change adaptation. We will address the local level of policy making. This is the level of governance with the least institutional capacity to conduct, or even just understand climate change uncertainty analysis, and at the same time the level of governance that in many cases must do the final climate policy decisions and implement climate change adaptation policies (Aall et al. 2012).

The article rests on three inputs: 1) a literature review on uncertainty management in the context of climate policy making, with a focus on critical reviews of the way uncertainty is treated in the works of the Intergovernmental Panel on Climate Change (IPCC); 2) presentation of a road map for how local governments can handle the issue of uncertainty in local climate policy making; and 3) demonstration of the applicability of the proposed road map with four local cases from Norway.
2. Where does the climate uncertainty debate stand today?

Manifold critiques have been raised concerning how uncertainties are handled in the climate debate. A good way to capture these critiques is to investigate the discussions relating to the works of the IPCC.

Moss (2007, p. 5) points out that in both the first and second IPCC assessments “little attention was given to systematizing the process of reaching collective judgments about uncertainties and levels of confidence, or standardizing the terms used to convey uncertainties and levels of confidence to decision-maker audience.” Response to these critiques resulted in the development of a chapter on uncertainties in the general guidance note prior to the third assessment report (IPCC 2005), and after that a separate guidance note on uncertainty prior to the fourth assessment report (IPCC 2005). Considering both initiatives, Moss (2007) argues that uncertainty analyses should be more decision focused, instead of being presented in what he denotes as a decision-making vacuum. Similar critiques of the way IPCC has treated climate uncertainties have been raised by several authors. Ha-Duong et al. (2007) make a case for a multidimensional approach to uncertainty communication, whereas Lempert et al. (2004) and Dessai and Hulme (2004) criticize the extensive use of probability-based estimates of risks, and advocate putting more effort in presenting approaches to decision-making under conditions of uncertainty. Van der Sluijs et al. (2010) find the IPCC consensus strategy underexposes scientific uncertainties and dissent, making the chosen policy vulnerable to scientific error and limiting the political playing field. Ekwurzel et al. (2011, p. 791) argue that the IPPC should “more effectively characterize and communicate the role of uncertainty in human actions as distinct from other sources of uncertainty across the range of possible climate futures.” As a response to these critiques, a separate guidance note on consistent treatment of uncertainties was develop for lead authors of the fifth assessment report (Mastrandrea et al. 2010).

The work on the sixth assessment report still relies, at least partly, on the 10-year-old guidance note, also referred to in the annexes of the IPCC special report Global Warming of 1.5°C (Matthews 2018). However, a recent shift in the conceptualization of “risks” that took place between the Fourth (AR4) and Fifth (AR5) Assessment Reports also has consequences for the conceptualization of uncertainty. This shift is basically about putting risk instead of vulnerability in the end of the cause and effect chain, which in both cases starts with the input signal from climate change (termed “exposure” in the AR4 terminology and “hazard” in the AR5 terminology). In the AR5 terminology the climate inputs interact with “exposure” and “vulnerability” and thereby create a risk. This shift was first applied by the IPCC in their special report on extreme climate events (IPCC 2012).

The core definition of risk is the potential for adverse consequences, and the link between risk and uncertainty relates to the word “potential,” which makes it clear that uncertainty, or more broadly, incomplete knowledge (as defined in IPCC), is a key element of the concept of risk (Kunreuther et al. 2014). It is important to note that uncertainty applies also to exposure and vulnerability, not merely to the nature, magnitude, and frequency of hazards.

An important point here is that from now on, after the introduction of the new risk concept, risk is applied to both impacts of and responses to climate change. According to Reisinger et al. (2020, p. 3), this is “a significant evolution and clarification compared with earlier assessments, which have tended to be dominated by risk related to climate change impacts.” Adverse consequences relating to responses to climate change covering both mitigation and adaptation efforts can arise from such responses failing to achieve their intended outcome or creating unintended adverse effects (Kongsager et al. 2015).

3. Mastering or managing climate change uncertainties?

Long before many of the above referred critiques of the IPCC and other policy actors, Schneider and Kunstz-Duriseti (2002) outlined two main approaches on how to relate to climate change uncertainties: Society must either reduce climate change uncertainties to a level that allows for accurate selection of policy measures or accept to implement climate policy measures even in situations with high climate change uncertainties.

The first approach is termed in the literature as “predict then act,” “impact first,” or “science first” (IPCC 2014). Climate uncertainties are described independent of other parts of the decision problem, for example, in the way that probabilistic climate projections are generated for wide application and not tied to any specific choice or policy setting. This approach has been criticized by several authors as shown in the previous section and can be summed up in two main points: Climate change involves a fuzzier decision context, and it involves a deeper uncertainty than other policy areas (Lempert 2013).

Many versions of the former approach have been put forward, and a frequently referred alternative is the robust decision-making approach, which rests on three key concepts that differentiate it from the predict-then-act approach (Lempert and Collins 2007): Multiple views of the future, a robustness criterion, and reversing the order of traditional decision analysis by conducting an iterative process based on a vulnerability-and-response option. Other related approaches are assess risk of policy (Lempert et al. 2004), context first (Ranger et al. 2010), decision scaling (Brown et al. 2011), critical threshold (Jones 2001), and, more recently, a system based on an extensive review of uncertainty management in environmental risk analysis, consisting of three dimensions and 14 accompanying subcategories of uncertainty: nature (epistemic and aleatory), location (system processes, data, model, human, language, variability, and decision), and level (determinacy, statistical, scenario, ignorance, and indeterminacy) (Skinner et al. 2014).

A commonality with these alternatives to the predict-then-act approach is that they often require that scientists spend time working closely with decision-makers to customizing the uncertainty description to their needs (Tangney...
This can be very effective but is at the same time often very time-consuming and costly (Lempert and Kalra 2011; Lempert 2013). Although many alternatives to the predict-then-act approach have been proposed, the climate community has so far not been able to agree on which is the “best” of these alternatives. Therefore, the predict-then-act approach remains the prevailing approach in both climate change science and policy making (Workman et al. 2020).

4. A proposed road map to move from “predict then act” toward “reflect then act”

The point of expanding from a predict-then-act approach to address climate uncertainties is to create a better knowledge basis for making adaptation decisions. The key messages sought to be captured in Fig. 1 are as follows: first, to illustrate the criticism of the predict-then-act approach frequently leading to adaptation inaction and therefore maintaining business as usual; second, to illustrate the need to adapt even in situations when climate uncertainties are large, and to show the wide range of adaptation options that then are available; third, to illustrate that local authorities in some cases can contribute to reduce climate uncertainties by means of providing local data, and that such actions can qualify as an intermediate adaptation option; and fourth, to lift forward the precautionary principle as an important element in local climate change adaptation decision-making.

After local climate risks have been identified, we suggest that further adaptation decision-making aims to point out which adaptation option(s) are available. This could be done by answering a sequence of questions posed in Fig. 1. Our intention is to offer a road map that contributes to raise awareness of how the scope of adaptation possibilities will be narrowed and guided by present climate change uncertainties, and by how these uncertainties are being perceived and acted upon.

The first question (Q1) asks whether low-uncertainty prediction of climate change risk is possible. This fundamental question is to sort out the cases where the adaptation solution is at hand and the accompanying uncertainty is low, and hence the adaptation option may emerge as obvious. A positive answer will frequently lead to a type of adaptation measures that we coin as effect-oriented adaptation to climate change, which is the first adaptation (A1) option shown in the road map. Note that decision-makers with poor insight in climate risk uncertainties tend to underestimate uncertainty and thereby arrive at such adaptation options. Effect-oriented measures will in most cases be of technical/physical nature, and they are generally attached to high economic costs.

What we have termed as the wait-and-see approach implies the option of waiting to conduct adaptation efforts until prediction of risks is possible. Based on a traditional socioeconomic way of thinking it can be argued that this option in some cases is reasonable (Stern 2015). In a situation of large uncertainties, subsequent problems in deriving relevant adaptation measures, and the potential adaptation measures are very costly, it can be argued (and in fact will so in most cases) that it is sensible to wait to initiate measures until more knowledge about the climate risks in question are available. Still, in many cases this strategy bears high risks of postponing...
costs that must sooner or later be taken, and then at a higher price (Hallegratte 2009). Therefore, Murphy et al. (2011) argues for abandoning the wait-and-see (or business as usual) option, pointing out that often uncertainties are unlikely to be constrained or reduced in the time scale required for adaptation, and therefore argue for a paradigm shift in how to use the output from climate change risk assessments. They point out that (Murphy et al. 2011, p. 93) “a flexible and robust planning process is required where adaptation options can be re-evaluated, and pathways adjusted as new emerging information becomes available”—which is exactly what we are outlining below.

A key question that differs the predict-then-act from the wider reflect-then-act approach is to answer “yes” to the question of is it acceptable to adapt under a specified level of climate uncertainties (Q2). The point with asking Q2 is to put the assessment of "predictability" into a policy-making context, and thus also to expand from being merely a question of scientific assessment. The idea here is not to disconnect policy making from facts. On the contrary, the point is to connect political and scientific reasoning by acknowledging that the level of accepted “predictability” in the fact basis for a given decision-making process is context dependent, and to arrive at such an accept level is therefore also value based. The proposed road map does not include any predefined acceptance criteria in the meaning of which level or types of uncertainty are acceptable. Such criteria will be guided by the administrative-political context in each case, governed by factors such as national legal requirements, access to local financial resources, local support, and local political priorities.

Leaving the “prediction” part of the road map (cf. Fig. 1), the next question asks whether local authorities themselves can implement measures to reduce uncertainty to an acceptable level in any way (Q3). If the answer is yes, such measures will have to be carried out, either by the local authority itself or (more probable) by other bodies at the request of the local authority in question. In most cases, local authorities will be limited to addressing data uncertainties. The other categories of uncertainty will in most cases be depending on research work. If there is an option for local authorities to work with national authorities and/or research institutions, the scope of action can, however, be expanded. The practical examples presented in the next section will illustrate this point. After measures for reducing climate uncertainties are carried out, the path of decision-making is then turned back to the starting point of deciding whether the climate risk in question should be addressed (cf. Fig. 1).

If the answer is “no” to the question of carrying out measures to reduce climate uncertainties, the next question is about the application of the precautionary principle (Q4). In its most general sense, the principle advises that lack of certainty is not a justification for inaction in the face of possible risks, commonly termed as the weak version of the principle (Morris 2000). The strong version, however, sets up stricter criteria for when to apply it. Based on an analysis of some of the most common and influential formulations of the principle, Persson (2016, p. 140) has identified four circumstances that each justify extra precaution: 1) when we deal with important values that tend to be systematically downplayed by traditional decision methods, such as (but not necessarily exclusively) human health and the environment; 2) when we suspect that the decision might lead to irreversible and severe consequences, and where the values at stake are also irreplaceable; 3) when timing is at least as important as being right; and 4) when it is more important to avoid false negatives than false positives. Although the principle has been enshrined in many international environmental treaties as well as in national and European Union (EU) legislation, most experts agree that the precautionary principle does not call for specific measures (Bourguignon 2015). Still, a precautionary measure that is frequently referred to, especially by environmental nongovernmental organizations (NGOs), is the “reverse burden of proof” or a reverse version of the wait-and-see option. This would imply in the case of climate change adaptation that it is the development initiative in question, and not the adaptation option, that must be put on hold. The government white paper on climate change adaptation for Norway outlines a less radical course of action (Ministry of Climate and Environment 2012, p. 36): “When considering consequences of climate change, precautionary based climate change adaptation demands using high alternatives of climate scenarios.” Still, as pointed out by Persson (2016, p. 140), applying the precautionary principle may first of all be a tool for deciding under which circumstances extra considerations is justified, and leave the remaining question of what a precautionary action will entail to be dealt with by other decision methods.

In situations where the precautionary principle does not apply according to the above cited circumstances, the proposed “reflection” part of the road map sets up three nonexclusive options: To adapt to current climate variability (A5), to increase institutional capacity for climate change adaptation (A6), and to conduct cause-oriented climate change adaptation measures (A6). These options may follow, or may be excluded, by answering Q5–7 in the road map.

The Norwegian government green paper on climate change adaptation (Ministry of Climate and Environment 2010, p. 19) identified maintenance deficit, that is, the need to catch up with an increasing backlog in maintaining physical infrastructure relating to current climatic variability, as a main approach to adapt also to anticipated effects of future climate variability (cf. the alternative A5). This being true in many cases, such a strategy will obviously not be able to reduce genuinely “new” climate risks. In some cases, adapting to current climate variability can even be counterproductive if climate change creates opposite effects when compared with current climatic conditions. An assessment conducted in 2018 of recent climate change adaptation research and development projects aimed at agriculture in Norway revealed an exclusive attention toward climate risks caused by an expected increase in precipitation, whereas risks relating to drought—a situation that appeared in 2018—had been ignored (Aall et al. 2019). Apparently, the warning presented in the official climate projections for Norway that agriculture might experience the “new” situation for Norwegian agriculture of more severe
early summer drought periods due to climate change had not been picked up by the agriculture sector (Hanssen-Bauer et al. 2017).

Several studies have identified lack of institutional capacity as an important barrier for climate change adaptation (Amundsen et al. 2010; Eisenack et al. 2014). Thus, as identified in A6, increasing the institutional capacity for local climate change adaptation in many cases will be a relevant option that can serve as preparation for moving farther into concrete climate change adaptation.

The last option illustrated in Fig. 1 (A7) we have termed as cause-oriented climate change adaptation, an option that is set up to resonate with the one to the mere left in the figure: the effect-oriented option (A1). Smit et al. (1999, p. 208) have presented a run through of prevailing climate change adaptation distinctions and typologies, which refers to either the processes or forms of adaptation. The frequently used dichotomy proactive versus reactive relates for instance to the timing of adaptation, whereas other typologies relate to, for example, scope (temporal, spatial) or form (e.g., autonomous versus planned). In the context of the special collection that this article contributes to—on investigating the scope and content of sustainable climate change adaptation—we have found it relevant to choose a distinction presented by the United Nations (UN) World Commission on Environment and Development (WCED) in its report Our Common Future from 1987 (WCED 1987). The UN commission identifies two main approaches to environmental policy: the effect- and the cause-oriented approach. The report emphasizes that it is the former that has prevailed, whereas it is the latter that must be included in any serious policy attempt aimed at promoting a sustainable development. This distinction resembles the proactive and reactive dichotomy in the sense that it relates to the issue of timing. However, whereas the proactive and reactive dichotomy relates to the timing of when the adaptation effort is implemented (respectively before or after an incident—e.g., a natural hazard event), the cause-versus-effect-oriented approach relates to the timing of a cause-and-effect chain of the issue at hand. The driver–pressure–state–impact–response (DPSIR) framework, emerging from an early stress-response framework developed by Statistics Canada in 1979, was initially developed to provide a structure within which to present environment and sustainability indicators (Garcia et al. 2014). This system can also be used to illustrate the difference between the cause-and-effect approach, in which the former will address the left half whereas the latter will add the right half of the continuum driver–pressure–state–impact, and the response part being the adaptation effort itself.

The endpoint of the reflect-then-act extension of the road map illustrated in Fig. 1 covers the situation in which none of the actions under high uncertainty (A3–A7) are judged as relevant or acceptable. Then the last option is to go back to A2 wait and see. What Fig. 1 illustrates is the big difference between selecting wait and see as a first option when facing large climate uncertainties, versus going the long way, through a serious of reflection points, and then leaving wait and see as the last adaptation option.

5. Applying the proposed uncertainty road map: The case of the 2014 October flood incident in western Norway

During 26–29 October 2014 heavy rain combined with snow melting in the mountains, led to the largest flooding in parts of western Norway in modern times. The most severe incidents of the so-called October flood occurred in the municipalities of Voss, Odda, Aurland, and Lærdal (Langsholt et al. 2015; Dannevig et al. 2016). Four local cases will be used to illustrate how the suggested procedure for uncertainty profile analysis could serve as basis for climate adaptation decisions in realistic land-use planning settings. It should be noted that none of the studied municipalities were given access to the suggested planning framework, so that the demonstrated use of the uncertainty profile and adaptation decision-making road map has only been applied by us in retrospect.

The four cases are (i) the flooding of the lake Vangsvatnet in Voss, with the subsequent inundation of the Voss cultural center; (ii) riverbank erosion of the river Opo in Odda, where five dwelling houses were destroyed; (iii) flood in the river Flåmselvi in Flåm, Aurland municipality, causing erosion and damage of 13 dwelling houses and public infrastructure; and (iv) erosion and mass transportation in tributaries of the river Lærdalselvi in Lærdal, with damage of farmland, roads, and bridges.

Data for this study were gathered in a project commissioned by the Norwegian Water Resources and Energy Directorate (NVE) aimed to draw lessons from flood incidents in the four municipalities with highest damage loss caused by the 2014 October flooding (Fig. 2). This was done by mapping the land-use planning, execution of land-use plans, risk perception, and risk communication that took place in the areas in question ahead of the flood damage (Dannevig et al. 2016). Thus, all the data presented below are from this study.

a. Voss

The town Vossevangen is the administrative center of Voss municipality, situated 100 km northeast of Bergen city by the shore of the lake Vangsvatnet. In 2014 the town had 6164 inhabitants (Statistics Norway 2021a). In historical times, Vossevangen was frequently flood stricken, but after the outlet of the lake was widened in 1991, severe flooding events ceased for nearly one-quarter of a century, until October 2014. No personal injury occurred but considerable material damage was caused by erosion along rivers in the Vosso catchment area, and by inundation of many buildings, particularly the new cultural center that was raised close to the shore of Vangsvatnet and inaugurated in 2011.

The building site chosen for the cultural center was then covered by a zoning plan from 1987 that contained no judgement of flood risk or provisions about flood protection. However, in 2006 Voss municipality adopted a provision that set a limit for building within the flood hazard zone established in the flood maps issued by NVE that year. The municipal provision quotes: “For larger public buildings, commercial buildings, industrial areas and critical infrastructure, the culmination value
of a 200-year flood [50.32 (meters above sea level)], with an addition of 0.3 meters, will be applied. This equals to the 50.62 contour line.”

The 30-cm addition to the estimated elevation for a flood with a return period of 200 years was a security margin that, among other factors, took consideration of climate change. This security margin was in line with recommendations from NVE, and exceeded the legal requirements laid down in the governmental Technical Regulations (TEK10) in force at the time. Below the 50.62 contour line, building permits would only be given for constructions that could endure inundation (garages etc.), unless flood control measures were carried out. Throughout the planning of the cultural center, the municipality decided to push this limit to the maximum, by placing the basement floor exactly at the 50.62 contour line. This was due to the limited available space between the main road and the lake, as well as competing land-use interests with a neighboring hotel. The municipal administrative leadership has rightly claimed that they in the building application process followed national recommendations on risk planning and uncertainty management (Dannevig et al. 2016). Hence, the uncertainty profile had been analyzed, not by the municipality itself, but by the national flood authority—namely, NVE. Given the fact that the 2014 flood surpassed NVE’s security margin with 50 cm, could the local planning authorities have faced the climate risk in a way that would have prevented the flood damage in this case?

Following the road map in Fig. 1, it is evident that constructing the cultural center close to a flood exposed watercourse did not give room for low-uncertainty prediction of climate change risk. This is illustrated by the fact that the building was pushed as close to the lake as possible within the limitation of the building permit zone recommended by the national flood authorities. When the municipality complied with NVE’s guidelines, they were in good faith adapting to climate change. Therefore, from the perspective of the local planning authority, it could be argued that they chose a cause-oriented adaptation to climate change (A7). To build the cultural center in a site beyond the reach of a 200-yr flood—plus a 30-cm climate change safety margin—was seen as a “viable and acceptable option of concrete climate change adaptation measure” as formulated in Q7. Construction parts below the 50.62 contour line were sealed to prevent water from penetrating into the basement.

Ideally, the uncertainty framework presented in this paper could have encouraged the municipality to reflect on the Q3 question whether the local authority can reduce climate change uncertainties. A thorough evaluation could have led to the conclusion that uncertainties at stake were too large to give a building permit based on such limited adaptation measures and urge a new round of seeking measures to reduce climate change uncertainties, guiding decision-makers back to Q1. One possible outcome is that available historical flood records would be utilized to improve the flood frequency analysis and design.
flood estimates that form the basis for the flood hazard zone around Vangsvatnet. That was also what happened after the flood experience, when NVE supplemented the official flood record time series with five historical records dating back to 1604 from parish books and engraved flood water level at the church wall (Engeland et al. 2018). With these local available data, combined with records from the 2014 flood, hydrologists were able to adjust design flood estimates that led to profound changes in local planning regulations, such as an extended flood hazard zone, and redefinition of the possible use of building parts placed below that limit (e.g., basement only usable for storage and parking).

b. Odda

Odda, a small industrial town 125 km southeast of Bergen, had 5090 inhabitants in 2014 (Statistics Norway 2021a). The lower parts of the steep river Opo that flows through the municipal center Odda had up to 2014 not been considered a flood river, given that the water-conveying capacity is high because of the riverbed profile. However, during the October flood high water velocity caused erosion of the riverbank and destroyed five private houses—four of which were taken by the river—by digging away the ground under the buildings. In addition, a bridge and other public infrastructure worth more than USD 12.5 million were swept away.

The flood damage was a big surprise to the local authorities and inhabitants of Odda. Even though the discharge flow during the incident was the highest recorded in the river Opo during 106 years of hydrometric measurements, it only reached three-quarters of the estimated level of a 200-yr flood, and the water level itself never posed a threat to the buildings along the river. However, extensive mass transportation changed the course of the river, leading the stream to excavate glacifluvial deposits at the eastern riverbank, eventually eroding the ground under one dwelling house. This, in turn, changed the topography of the river so that the stream was bent westward and hit the opposite riverbank, destroying four more houses.

Being a community set in a dramatic landscape and surrounded by numerous climate risks, it is striking that Odda municipality prior to the October flood had no superior planning documents that mentioned natural hazard or vulnerability to climate change. Evidently, the municipal management did not at that time possess the impetus to carry out proactive climate adaptation planning. Moreover, as no one realized the risk of riverbank erosion, it is less likely that the uncertainty framework would have been applied in such a context, should climate adaptation have been put on the agenda.

Disregard the abovementioned reservations, if we assume that considering the second step in the road map resulted in “identification of climate risks that should be addressed,” a thorough assessment of the vulnerability should have led to a negative answer to Q1 and a positive answer to Q2. Then, confronted with Q3—“can the local authority reduce climate change uncertainties?”—further options under A3 would be blocked because of lack of competence. Then A6 would become the only viable option, in terms of increasing institutional capacity for adaptation, for example, by involving external expertise. This is what Odda municipality has attempted after 2014, urging NVE to carry out flood mapping of Opo. That request has been rejected on the grounds that the climate risk in this case is linked to soil conditions that would be too resource demanding to map. Then, given the large values at stake, the situation should call for precautionary action (A4).

c. Flåm

Whereas Vossevangen and Odda are small towns, the flood incidents in Flåm and Lærdal took place in sparsely populated rural areas. The river Flåmselvi in Aurland municipality runs 14 km with 760-m difference in altitude from the mountain area in the south, north to the village Flåm by the fjord. The October flood was particularly damaging because of the high water velocity, causing rapid riverbank erosion along a stretch of 1 300 m from Flåm church, some 3 km from the river mouth, and northward. Some 260 of the 350 inhabitants of the valley were evacuated during the flood, and, according to a municipal officer, it was “sheer luck” that nobody was killed (Amundsen and Dannevig 2021). Thirteen dwelling houses were taken by the river or destroyed, and so were 3 km of local roads, 10 bridges, and other infrastructure.

The dwelling houses in Flåm that were hit by the flood were raised between the 1930s and 1950s without any zoning planning or considerations to flood risk, at a time when the building legislation only applied to urban areas. Between 1999 and 2013, four of the houses that were flood stricken in 2014 were expanded. In three cases, building permits were given without mentioning of flood risk. In the fourth case the local building authorities declared that flood prevention rules applied, yet the builder was exempted from carrying out statutory flood control measures such as elevation of building ground. Some of the damages Flåm experienced in 2014 could have been avoided if the area had been developed in accordance with today’s planning regulations, and in that respect the case illustrates the challenge of climate hazard protection of existing infrastructure. However, the main lesson that can be drawn from this incident is that there will always be irreducible climate uncertainty that cannot be dealt with in terms of climate change adaptation.

If we imagine how the proposed framework could have influenced uncertainty management in the Flåm case, simultaneous outcomes are rendered possible. The building authorities’ reluctance to demand flood control measures within the danger zone for 200-yr flood, is clearly an example of business as usual (A2). Flood risk was not thematized in land-use planning context by Aurland municipality before the 2008 municipal master plan introduced zone planning and natural hazard mapping as mandatory measures for all development projects. In 2009 a flood hazard map for Flåmselvi was issued, and the same year the municipality promoted a cause for the parliament—with flood protection as the main argument—to reverse an earlier decision to protect the Flåmselvi catchment area against hydropower development. Initiatives to tame the river with hydropower dams could be seen as one way to
reduce climate change uncertainties (A3), providing that the concessioner was willing to reserve some of the power basin capacity for flood control purposes, and thereby renounce parts of the profit. One could argue that this strategy would rather be effect-oriented adaptation to climate change (A1), but from an opposite angle it could be portrayed as a cause-oriented approach (A7): because damage occurs as a result of the unpredictable discharge flow, containment of the river would be to attack the cause.

d. Lærdal

Lærdal municipality is formed by a valley that crosses a mountainous area with summits at 1500–1700-m altitude, with the 50-km-long river Lærdalselvi as a main landscape feature. In 2014, the municipality had a population of 2174 (Statistics Norway 2021b), but only a few inhabitants were directly affected by the flood incident. However, flood in several of the tributaries of Lærdalselvi, especially the river Kuvelda, resulted in erosion and mass transportation. Although no dwelling houses were damaged, roads and bridges were broken, and farmers experienced considerable loss of farmland from erosion and floodplain deposits.

Flood authorities have so far paid little attention to flood hazard in remote tributaries, because these are located in less-built-up areas that could be exposed. However, such floods have the potential to threaten the denser-populated main valley, both by mass transportation and by flood waves set off when obstacles of debris and vegetation finally burst. Still, in 1992 river embankment constructions were made along 1 km of the tributary outlet of Kuvelda, with the purpose of protecting the farmland that in 2014 was flooded and buried with deposits. The magnitude of the October flood surpassed by far the capacity of the existing flood protection.

It is fair to assume that there was little will to extend the embankment upstream the existing flood barrier, indicating that the municipality and flood protection authority pursued a business-as-usual strategy, that is, adaptation option A2, which in fact means lack of adaptation. If the perceived threat had been larger, effect-oriented adaptation in the form of further embankment constructions would be a more likely outcome (option A1).

6. Discussion

Abundance of water and steep mountains are among the features that define Norway as a nation. The mountain range that stretches more than 1600 km along the western coast receives more precipitation than almost any other European region. This has been both a curse and a blessing: flood disasters have haunted the people for as long as the Scandinavian peninsula has been inhabited, and some of the earliest engineering achievements in Norway were linked to flood protection, an effort that was institutionalized by the establishment of the Canal Director in 1847, the predecessor of NVE. Nevertheless, Norway’s transformation from a poor and underdeveloped country in both a European and global context to a prosperous welfare society during the twentieth century was largely initiated and fueled by taming of rivers as sources for hydroelectric power. Hence, disciplines such as hydrology and hydrotechnics were developed to the highest international level to reap the benefits of the water resources. As a testament to this, we find the longest daily hydrological record back to 1892, from the outlet of Vangsvatnet in Voss. Furthermore, Norway has taken a prominent global position in developing knowledge about climate change and how this can affect not least precipitation. One such prominent knowledge provider is the Bjerknes Centre for Climate Research, located in Bergen and named in honor of the visionary scientists V. Bjerknes (1862–1951), who laid the foundations of modern meteorology and weather forecasting through the Bergen School of Meteorology, and his son J. Bjerknes (1897–1975), who carried out pioneering research on climate change and the role of the ocean in the climate system. On top of this, river flooding is among the most damaging natural hazard events in Norway as well as globally, and flood risks are expected to increase as a result of both climate change and changes in land use (Jurárez et al. 2021).

Viewed against this background, one should think that hardly any nation would be better equipped to deal with flood risk and climate change. Still, the national flood protection authorities, as well as the local planning authorities, have difficulties in handling uncertainties related to how climate change influences flood risk. Some of these uncertainties become visible when we apply the proposed uncertainty framework (Fig. 1) on the four case municipalities hit by the October flood taking place in western Norway in 2014, an incident that—at least in some locations—manifested itself as a new sort of flood hazard because of its unprecedented intensity.

Even though flood projections, flood hazard mapping, and flood management have been developed and refined for more than a century, confronted with climate change uncertainties we rarely find ourselves in a situation of predict then act. Much of the flood protection work is still done by using traditional flood protection measures, such as levees and dredging of the river channel, activities that threaten floodplains and river ecosystems (Jurárez et al. 2021). Also, the main hazard prevention policy measure—land-use planning in accordance with the Planning and Building Act—is an instrument formed within the tradition of predict then act. The planning system as of today relies on scientifically calculated risk levels. The provision of very precise numbers (down to 1 cm for flood levels) indicates a level of certainty that is far from reality. The case from Voss shows how the provision and successive application of such precise numbers in planning decision may lead to successive failure in the face of a flood that trespasses the estimated return periods.

Aven (2020) picks up on the new risk approach taken up by the IPCC and points at what he denotes as two main problems with the current approach: 1) the risk concept is too much associated with a statistic definition of values and 2) the applied characterization of climate risk fails to integrate probabilities and judgments of the strength of knowledge supporting the values used. To address these weaknesses, Aven argues that it is essential to conduct professional characterizations
of climate risks and uncertainties in such a way that risk and uncertainty perception scope is made more accurate, and its interpretation is simplified. Skinner et al. (2014, p. 196) have reviewed the content and use of 30 typologies of uncertainties, and stress that “uncertainties cannot be managed if they are not identified, and they may not be identified if the potential types of uncertainty are not understood.” Tangney (2019) criticizes both the previous and the newly adopted IPPC risk-based approach for perpetuating the ideals of objective risk as well as probability calculations, and he cautions against prescriptions for the rational application of objective risk assessment to policy making. It is therefore a need to transform current planning systems to become more flexible and reflexive, thus pushing them toward a more reflect-then-act way of functioning.

A study on local and central authorities in Norway finds that the understanding of climate uncertainties and climate risks is in general poor, most so at the local level and somewhat better at the state level (Orderud and Naustdalslid 2018). Thus, it seems obvious that there is a need for new approaches of addressing climate uncertainties in policy making—in particular, local policy making.

The proposed uncertainty framework is a possible way out of some of the problems and pitfalls described above. Even if the demonstration of the proposed system is done in Norway, being a high income and liberal democratic country with a very clear division of responsibility among the national, regional, and local levels of government, the proposed framework should work in other contexts. It can easily be applied for decision-making at regional as well as national levels of government, as well as, in principle, the supranational policy level.

7. Conclusions

Our study indicates that, in a situation of lack of low-uncertainty prediction of climate change flood risks, a shift toward a broad approach to risk management is needed. This shift should include three elements: First, we need to accept that in many cases we will not be able to reduce climate change uncertainties to a level that fits with the notion of predict then act. Second, we need to diversify the way in which we describe climate change uncertainties, moving from a one-dimensional technical perspective to a multidimensional perspective that applies uncertainties to social and political processes and systems. Third, we need to change the way we address climate change uncertainties by moving from a predict-then-act approach to a reflect-then-act approach. This implies that we must become better at adapting to climate change under high and varied forms of climate uncertainties. Embedded in this last point is to accept that in many cases of climate change adaptation, unlike those of climate change mitigation, the precautionary principle will apply.

Acknowledgments. We thank Halvor Dannevig at Western Norway Research Institute for his contribution to the case study of the 2014 October flood. Thanks also are given to two anonymous reviewers for valuable comments. The article is funded by grants from the Norwegian Research Center on Sustainable Climate Change Adaptation (Noradapt); and the project “Unpacking climate impact CHAINs. A new generation of action—And user-oriented climate change risk assessments” (UNCHAIN) funded through ERA-NET Cofund “Assessment of cross(X)-sectoral climate impacts and pathways for sustainable transformation,” Grant Agreement 776608, and funding scheme H2020-SC5-2016-2017.

Data availability statement. The interview data are stored electronically in accordance with requirements from the Norwegian Centre for Research Data. All other referenced data are available by contacting the corresponding author.

REFERENCES


