ABSTRACT

Decision-making for climate-change management seldom incorporates uncertainty in the analysis that underpins the policy process:

- Uncertainty is seldom characterised fully, and attempts to reduce uncertainty – when this is possible – are rare.
- Scientists are ill-equipped to communicate about uncertainty with policy-makers, and policy-makers most often favour pretended certainty over nuance and detail.
- The uncertainty analysis that may have been conducted most often fails to actually influence policy in a significant manner.

The case is made for (i) characterising and, to the extent possible, reducing uncertainty, (ii) communicating uncertainty, and (iii) reflecting uncertainty in the design of policy initiatives for climate change management. Possible elements for a research agenda on each of these areas are proposed.

MANUSCRIPT

Policy-making for climate change management is riddled with uncertainties. Therefore, incorporating uncertainty in the policy-making process is a pre-condition for designing and implementing efficient and effective climate change-management policies (Morgan 2009). In a stylised representation of the concept, 'incorporating uncertainty' could encompass three steps: (i) characterising and, to the extent possible, reducing uncertainty; (ii) communicating the remaining uncertainty to policy-makers, in a manner that is adapted to their needs; and (iii) reflecting uncertainty in the design of policy initiatives for climate change management.[1]

Over the past fifteen years, uncertainty characterisation and reduction (the first step above) has been the subject of extensive research with regard to global estimates of warming levels and the costs arising from the impacts associated with such warming (Heal 2002; Dessai *et al*. 2007). In recent years, research on uncertainty characterisation and reduction has also focused on national-level estimates of future emission volumes

[1] Guidance exists for dealing with uncertainty in the area of climate change management. Yet, this guidance is insufficient in most cases, and under-used at best. In light of this, the article (i) makes the case for using this guidance to incorporate uncertainty in the analysis that underpins the policy process, and (ii) proposes possible elements for a research agenda in this area.

(Rogelj *et al*. 2017; Puig *et al*. 2017; Benveniste *et al*. 2018).[2] However, the latter has not influenced national-level processes for setting emission-reduction targets, as evidenced by the types of targets presented in the Nationally Determined Contributions put forward by parties to the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC 2016).

Uncertainty communication (the second step above) is an under-researched topic (Fischhoff 2012). The handful of studies available focus on the general public – not government – as the target audience, and the media – not scientists – as the communicator (Broomell and Kane 2017). A 2014 protocol for uncertainty communication provides practicable guidance that can be used in a context where scientists communicate with governments (Fischhoff and Davis 2014). This protocol appears to never have been used for policy-making in the area of climate change management, as evidenced by the complete lack of literature documenting such use.

Determining the extent to which uncertainty is reflected in the design of policy initiatives for climate change management (the third step above) is challenging. In her assessment of Swedish climate change policies, Knaggård (2014) finds that "scientific uncertainty played a very marginal role in the development of Swedish climate politics". No other comparable assessments appear to have been conducted, in Sweden or elsewhere. Knaggårds results, and the paucity of literature in this area, suggest that climate change decision-makers fail to reflect uncertainty customarily in the policies they design and implement.[3]

Against this background, it seems justified to claim that, in the context of climate change management, policy-making fails to incorporate uncertainty in a comprehensive and systematic manner. In addition to institutional inertia, two reasons account for this failure. Firstly, the appeal that (pretended) certainty has for senior decision-

[2] This interest stems from the critical role that the individual emission reduction commitments by parties to the United Nations Framework Convention on Climate Change (UNFCCC) play in the Paris Agreement.

[3] In most countries, policy-making for climate change management is informed by the results of consultations with key stakeholders. This refers to all stages in the policy process, from identifying priorities and setting objectives, to defining and implementing potential actions, to monitoring progress with implementation. In so far as these consultations help identify uncertainties, the consultations contribute to reflecting uncertainties in the policy-making process. Similarly, it is now customary for modelling results to benefit from sensitivity analyses, which help evaluate the extent to which projections of a variable of interest may change, depending on which assumption is used, across the full range of plausible future values for an uncertain variable. Whilst these, and other similar practices, constitute relevant efforts to reflect uncertainty in climate change-management policies, they are far from comprehensive, given the much broader set of uncertainties that reasonably could be considered (Walker *et al.* 2013).

makers, as described in the post-normal science literature (Funtowicz and Ravetz 1993; Mathijssen *et al*. 2008). Secondly, and far more prosaic, the resources that are required to incorporate uncertainty in the decision-making process, which are challenging to mobilise, especially in low-income countries (UNFCCC 2016).

Reversing this situation is difficult, even in countries that have the resources and the political determination to do so (Petersen *et al*. 2011). Notwithstanding, the case for incorporating uncertainty in the policy-making process is strong on at least two accounts. Firstly, it is the duty of governments to ensure that policy is based on the best available evidence (Gluckman 2016). In the context of climate-change management, fulfilling this duty is tantamount to incorporating uncertainty in the policy-making process, among other considerations.[4] Secondly, in as much as uncertainty is inextricably linked to the analysis that underpins national-level processes for setting emission-reduction targets, and because such targets are at the heart of the Paris agreement under the UNFCCC, disregarding uncertainty undermines the robustness of the Paris Agreement.[5] Given the stakes, UNFCCC-sponsored guidance on this issue appears warranted (Puig *et al*. 2017).

Heightened research efforts will be required to progress toward incorporating uncertainty in national-level climate change-mitigation policy. Key among these are the following (Table 1):

- A conceptual framework exists that supports the characterisation of uncertainty in the context of model-based analyses (Kwakkel et al. 2010). However, climate change-mitigation policy cannot always rely on modelling, because modelling tools are underdeveloped (such as is the case for land-use planning), or because the country has limited tradition (and thus expertise) with modelling.[6] In these situations, a

[4] When the resources needed to obtain 'the best available evidence' are not on hand, it is the government's duty of care to explicitly acknowledge this, while adopting a no-regrets approach to policy-making. In this setting, a 'no-regrets approach' to policy-making refers to adopting measures that meet two requirements: they are consistent with the information about which there is a high degree of certainty, and they preclude as few future courses of action as possible (Kwakkel *et al*. 2016). Ideally, this approach to policy-making should be complemented with regular evaluations of performance against the policy's intended objective.

[5] In the Paris Agreement, the accounting of future emission levels relies on UNFCCC parties' deterministic estimates of future emission-reduction volumes by the individual parties. If those estimates turn out to be overly optimistic (or pessimistic), a key pillar of the negotiations is compromised. In light of this, it has been suggested that national-level emission reduction targets should be attached to scenarios, and expressed in probabilistic terms (Puig *et al*. 2017).

[6] Model refers to a computer-based representation of reality, simple as it may be, as opposed to a less explicit or tangible alternative.

broader framework to guide the characterisation of uncertainty is needed, possibly structured around qualitative scenarios (Enserink *et al*. 2013). Such broader conceptual framework is missing.

- A handful of reviews has been published, documenting techniques that can be used to quantify uncertainty. However, they are sub-optimal with regard to designing national-level climate change-mitigation policies: some of these reviews are mainly relevant in the context of regional integrated assessment modelling (Katz 2002; Unwin *et al*. 2011), whereas those that lend themselves better to application in a national-level planning context, arguably lack detail (IPCC 2006; Morgan 2009). Additional research is needed, to shed light on what the best techniques might be for quantifying uncertainty at the level of a specific sector (such as electricity generation) or decision-support tool (such as cost-benefit analysis).

- National-level policy-planning for climate-change mitigation is rarely confronted with irreducible uncertainties, such as those that are common in climatology. For the most, this type of policy planning faces two kinds of uncertainties: those that can be reduced only through years' worth of additional research (for example, the impact on fuel demand attributable to fossil fuel taxation), and those that can be reduced reasonably easily (for example, the choice of options available to pursue a given objective). A protocol exists to reduce uncertainties in applications of multi-criteria decision analysis (Montibeller and von Winterfeldt 2015). Additional research is needed to develop similar protocols for other types of decision-support tools, notably for cost-benefit analysis (Puig and Bakhtiari 2017).

- As mentioned above, a protocol for uncertainty communication has been developed, which attempts to promote communication between scientists and policy makers (Fischhoff and Davis 2014). There is no documented use of the protocol in the area of national-level policy-planning for climate change mitigation. Application of the protocol across different types of policy-planning processes for climate-change mitigation would contribute to building a body of knowledge in this area, ultimately helping improve communication between scientists and policy makers.[7]

[7] It is worth noting that uncertainty reduction may, in some instances, hamper uncertainty communication (Supplementary Information Note 1). This observation only strengthens the case for developing uncertainty reduction protocols, and gaining experience with uncertainty communication (for example, by applying the Fischhoff and Davis protocol referred to above).

- A review of Swedish policy-making appears to be the only study of the extent to which uncertainty is being reflected in the design of national-level policy measures for climate change mitigation (Knaggård 2014). Additional research in this area is needed to gain the insights needed to improve the methodological frameworks used to conduct this kind of evaluations, and understand the barriers to increased uptake of uncertainty evidence in national-level policy-planning for climate-change mitigation.

Table 1: Research gaps for incorporating uncertainty in national-level mitigation policy

Topic	**State of research today**	**Potential research priorities**
Characterising uncertainty	Conceptual framework for use in computer-based models (Kwakkel *et al*. 2010)	Broader framework, catering to both computer-based and other types of models
Quantifying uncertainty	Descriptions of generic techniques (Morgan 2009)	Adaptations of the generic techniques, to suit the specificies of key sectors (for example, transport) or decision-support tools (for example, cost-benefit analysis)
Reducing uncertainty	Protocol suitable for multi-criteria decision analysis (Montibeller and von Winterfeldt 2015)	Protocols for other types of decision-support tools
Communicating uncertainty	Protocol for uncertainty communication (Fischhoff and Davis 2014)	Application of the protocol to different types of policy-planning processes, to build a body of knowledge in this area
Reflecting uncertainty in the design of policies	Review of the extent to which Swedish climate change policies reflect uncertainty (Knaggård 2014)	Additional reviews, to improve methodologies and foster the integration of uncertainty in policy designs

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