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Climate change adaptation strategies: Water management options under high uncertainty - A Danish example

Jens Christian Refsgaard[1], Karsten Arnbjerg-Nielsen[2], Martin Drews[3], Kirsten Halsnæs[4], Erik Jeppesen[5], Henrik Madsen[6], Anil Markandya[7], Jørgen E. Olesen[8], John R. Porter[9], Jens Hesselbjerg Christensen[3]

This study takes a multidisciplinary approach for assessing the role of uncertainty in climate change impact assessment and adaptation analysis, applying generic frameworks for characterising uncertainty and adaptation options and using Danish adaptation measures as examples. Uncertainty is characterised according to three dimensions: level, source and nature, while adaptation options are characterised with respect to five dimensions: intent, action, temporal scope, spatial scope and structural/non-structural measures. With respect to uncertainty we observe that the dominating sources of uncertainty differ greatly among the various problems, that most uncertainties on impacts are epistemic (reducible) by nature, and that the uncertainties on adaptation measures are complex, with ambiguity often being added on top of the impact uncertainties. For adaptation characteristics we find great differences between types of adaptation measures in sectors dealing with urban and rural infrastructures and sectors dealing with agriculture and freshwater ecology. The strategies to deal with uncertainty in climate change adaptation should reflect the nature of the uncertainty sources and how they impact the risk assessment and decision making: (i) epistemic uncertainties can be reduced by gaining more knowledge; (ii) uncertainties related to ambiguity can be reduced by dialogue and knowledge sharing between the different stakeholders to obtain a common perception of the problem at hand; and (iii) ontological uncertainty is by nature non-reducible, and we have to live with it. The uncertainty cascade includes many sources of uncertainty and their propagation through technical and socio-economic models may add to substantial prediction uncertainties. Nevertheless, even large uncertainties may in some contexts imply small consequences for decision making, because there is often sufficient knowledge to justify action in climate change adaptation.

1: Geological Survey of Denmark and Greenland (GEUS)
2: Dept. of Environmental Engineering, Technical University of Denmark
3: Danish Meteorological Institute (DMI)
4: DTU Climate Centre, Technical University of Denmark
5: Aarhus University
6: DHI
7: BC3 Basque Centre for Climate Change
8: Department of Agroecology, Aarhus University
9: Faculty of Life Sciences, University of Copenhagen

Development of Decision Support Matrices for Climate Change Adaptation Planning

Jay S. Gregg, Malene Kauffmann Hansen, Kirsten Halsnæs
DTU Climate Centre, Technical University of Denmark

When deciding amongst a suite of various climate change adaptation options, decision makers have to balance uncertainties in potential physical impacts, economic judgements, and political priorities. A decision support matrix is a tool to aid in decision making, by clarifying the decision making process, highlighting key uncertainties, and identifying critical assumptions. Using a decision matrix allows decision makers to examine how different a priori stakeholder values can impact the adaptation decision. We begin with a simple hypothetical decision matrix and build more complexity by adding multiple adaptation options, multiple risks, and multiple impact variables. The goal is to show where complexities enter into the decision tool, and then present ideas on how best to address these complexities under the context of adaptation planning.

Uncertainties in assessing climate change impacts and adaptation in agriculture

Jørgen E. Olesen
Department of Agroecology, Aarhus University

Agriculture is a managed ecosystem, which is essence in the result of interlinkages between genotype (G), environment (E) and management (M), often referred to as the G×E×M interactions. In practice both management and genotypes are adapted to local environmental conditions (both average and variability of the physical, chemical and biological environment). Assessments of impacts and adaptation of climate change must therefore take into consideration how climate change affect other environmental conditions and how these through interactions with genotypes and management impacts on crop productivity and the other services that agriculture contributes to. This in itself is a complex task; however, in addition agriculture is influenced by socioeconomic drivers and by local and governmental regulations related to issues such as food safety and environmental sustainability.

Any assessment of climate change impacts and adaptation in agriculture must therefore not only consider the direct effects of climate change on crops and livestock, but also the effects on adaptation at field, farm and regional scales (Olesen et al., 2011) and the effects of other drivers within society, such as the need for bioenergy (Dalgaard et al., 2011) and the technological changes affecting agricultural productivity (Ewert at al., 2005). This means that scenario uncertainty adds to uncertainties associated with quantifying impacts and adaptation.

Since agroecosystems involve complex interactions between physical, chemical and biological processes as well as human interventions, dynamic crop-climate models that incorporate these processes have often been used to simulate the impacts of climate change, and they have also been used to address some adaptation options. However, most of these models have not been revised recently and do not necessarily represent current knowledge (Rötter et al., 2011). Also different models may provide different answers, and use of multi-model approaches may be a better option

(Palosuo et al., 2011) that will also allow quantification of some of the model uncertainty. However, there are also other approaches for quantifying impacts of climate change on agroecosystems, such as development of empirical models based on mining of large datasets (Kristensen et al., 2011) or the use of space for time analogues (Olesen et al., 2011). Future studies in this area should apply a range of different approaches and compare these with the aim of better understanding uncertainties as well as opportunities for adaptation that will minimise costs of climate change for both farmers and the society.

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Uncertainties in Agriculture Impact Studies under Climate Change

Manuel Montesino
Faculty of Life Sciences, University of Copenhagen

Addressing uncertainty is extremely important due to its practical application; it can be used for decision support and cost calculations of impacts and adaptation measurements to climate change. As the relevance of uncertainty permeates scientific community, (1) the uncertainty magnitude will increase as a result of the quantification of new sources. (2) Secondly, the bridges connecting source-nature-behaviour will be described. Once this degree of knowledge is reached, (3) proper modelling will efficiently manage uncertainty reducing its presence in impact prediction by avoiding unnecessary ones.

Regarding the first point, currently it is not possible to measure uncertainty in all its magnitude. The ultimate cases of uncertainty inaccuracies are the assumptions and simplifications necessary to reduce complexity and computational demands. Therefore this thesis in a first sub-project (Probabilities in wheat yield for 2020 and 2050 in Denmark) aims to come up with a framework to study the different sources of uncertainty separately and translate them to probability measurements. Apart from climate uncertainties, impact predictions in agriculture are overshadowed by model inadequacy, parameter uncertainty and measurement error (in order of importance) (Refsgaard et al., 2011). Future yield in terms of probability has been already solved theoretically, but there seems to be a barrier for its practical use. This theoretical framework does not completely connect with current methodologies of uncertainty analysis such as Bayesian Calibration or Bayesian Model Comparison (BMC) techniques.

The thesis also aims to introduce the second point within two further sub-projects: "Variations of uncertainties with scale" and "Model inadequacy development with time". This point (bridges connecting source-nature-behaviour) has to do with the variation of uncertainty from one study to another. Uncertainty is related to model complexity. Model complexity is in turn related to scale (Challinor and Wheeler, 2008; Tubellio and Ewert 2002; Challinor et al., 2009). Simple models seem to be prepared for bigger scales and more complex models for lower ones. More complex models need more data to avoid over-parameterization phenomena. This shows that there is a triangle of interactions between model complexity-scale-data that should be studied in order to find the optimum in given study (Challinor et al., 2009). This optimum can be defined as the point in which uncertainty efficiency is at its maximum.

Apart from the evolution of uncertainty with scale, it is also worth to consider the uncertainty development with time. For a given scale and data set, the uncertainty in complex models can be larger compared to simple models. On the one hand, the parameter uncertainty is supposed to be larger and uncertainty propagates faster through the equitation system of the complex models. On the other hand, as models in climate change impact studies are pushed to their limits; complex model may remain more stable. In other words, in complex models uncertainty evolves slower with time (as climate changes). This can lead to the hypothesis that in some point, for long term studies, more complex models are required independently of the scale.

The first sub-project is linked to the future climate. Time and scale variations of uncertainty point to uncertainty behaviour working with current climate data. Analysing this behaviour can help to build up the basis for improving uncertainty efficiency.