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Comparing the social and scientific values of national climate projections in the Netherlands, Switzerland and the UK

Maurice Skelton; James J. Porter; Suraje Dessai;
David N. Bresch; Reto Knutti

December 2016

Sustainability Research Institute

Paper No. 101

ICAD Paper No. 11

SRI PAPERS

SRI Papers (Online) ISSN 1753-1330

First published in 2016 by the Sustainability Research Institute (SRI)
Sustainability Research Institute (SRI), School of Earth and Environment,
The University of Leeds, Leeds, LS2 9JT, United Kingdom

Tel: +44 (0)113 3436461
Fax: +44 (0)113 3436716

Email: SRI-papers@see.leeds.ac.uk
Web-site: http://www.see.leeds.ac.uk/sri

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Abstract

National climate projections are used to inform adaptation planning and decision-making in many countries. This paper seeks to understand why such climate information is produced differently from place-to-place. We examine and compare the social and scientific values of three national climate projections in the Netherlands, Switzerland and the UK. To do this, we performed a comparative analysis of documents and expert interviews linked to the projections. Our findings reveal a new typology of use-inspired research in climate science for decision-making: (i) innovators – where the advancement of science is the main objective; (ii) consolidators – where knowledge exchanges and networks are prioritized; and (iii) collaborators – where the needs of users are put first and foremost. These values of 'good' science are mirrored in the way users were involved in the production process: (i) elicitation – where scientists have privileged decision-making power; (ii) representation – where multiple organisations mediate on behalf of individual users; and (iii) participation – where a multitude of users interact with scientists in an equal partnership. These differences help explain why climate science gains credibility and legitimacy differently while the information itself might not be judged as salient and usable. The push for deliberate co-production of knowledge needs to be sensitive to the socio-cultural and institutional-political conditions that inform the work of scientists if lessons from other countries are to be learned.

Keywords: Climate projections, climate scenarios, adaptation, decision-making, understanding and use of science, co-production of knowledge

Submission date: 28-11-2016;   Publication date: 05-12-2016

About the Authors

Maurice Skelton is a PhD student and scientific assistant at ETH Zurich, Switzerland. During his masters at ETH Zurich, he undertook a 6-month exchange research project with the Climate Change Adaptation Group at the University of Leeds. His past and current research interests concern both the supply and demand of climate information. E-mail: maurice.skelton@usys.ethz.ch

James Porter is a research fellow at the Institute of Work Pyschology, University of Sheffield, UK. His research focuses on the science-policy interface, management of institutional risks, and decision-making, particularly in the context of flood risk modelling and climate change modelling. E-mail. james.porter@sheffield.ac.uk

Suraje Dessai is Professor of Climate Change Adaptation in the School of Earth and Environment at the University of Leeds. His research focuses on the management of climate change uncertainties, perception of climate risks and the science-policy interface in climate change impacts, adaptation and vulnerability. He is the recipient of a European Research Council Starting Grant and was a lead author of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Working Group II - Impacts, Adaptation, and Vulnerability. E-mail: S.Dessai@leeds.ac.uk

David N. Bresch is professor for Weather and Climate Risks at ETH Zurich and MeteoSwiss, Switzerland. His research focuses on the impacts of weather and climate on socio-economic systems. Combining numerical (open-source) modelling of weather and climate risks with the engagement of decision makers and end-users, his research aims to explore ways to strengthen their resilience and create a shared understanding of their weather and climate susceptibility. Such an integrated view along the chain of impacts also opens new perspectives and approaches to the treatment of uncertainty in decision-making. He has conducted many case studies across the globe, applying a worldwide consistent, yet locally specific methodology to strengthen climate resilience while integrating adaptation with economic development and sustainable growth. E-mail: dbresch@ethz.ch

Reto Knutti is professor for climate physics at ETH Zurich, Switzerland. His research focuses on physical changes in the global climate system. He uses numerical models of different complexity, from energy balance to global and regional three-dimensional coupled climate models to provide national to global climate change projections. He further develops methods to constrain uncertainties and important feedback processes in the climate system by comparing observations with model results. Besides that, he collaborates with statisticians, economists, philosophers and social scientists on a variety of topics, including climate impacts, scenarios, climate services, uncertainty, climate policy, and communication and perception of climate change. E-mail: reto.knutti@env.ethz.ch

1 Introduction

Extreme weather events are already causing damage, disruption and loss of life across the world. As our climate changes, extreme events like floods and heatwaves are likely to become more frequent and intense (IPCC 2014). To adapt, we need to better understand how our climate might change and the associated risks. Climate information, such as national climate projections, show how temperature, rainfall and other climate variables may change over the next century. National climate projections are a set of government approved descriptions of future climates in a specific geographical area covering one whole nation. They are plausible, coherent and internally consistent characterisations of future climate, contingent on predefined greenhouse emission pathways (Hulme and Dessai 2008)[1]. National climate projections have become influential tools for informing adaptation planning and decision-making in the United Kingdom (Jenkins et al. 2009), Switzerland (CH2011 2011), Germany (DWD 2012), South Africa (DEA 2013), Ireland (Gleeson et al. 2013), the Netherlands (KNMI 2014a), the US (Melillo et al. 2014), Australia (CSIRO and Bureau of Meteorology 2015), and other countries.

Yet climate information is left unused because it’s judged as too complex, irrelevant, or not usable. To narrow this ‘usability gap’ (Lemos et al. 2012), scholars have turned their attention to bring scientists and users together to deliberately co-produce climate information (Meadow et al. 2015; Dilling and Lemos 2011). If scientists understand what climate information is needed, and in turn, if users understand what scientists can provide, then delivering relevant and usable science faces less practical difficulties (Lemos and Rood 2010). How this should be done is unclear, however. For instance, Tangney and Howes (2016) have shown that the climate information’s credibility, legitimacy, and saliency is seen differently from one country to another. Indeed, different political cultures and scientific norms affect how climate information is produced and the extent to which users are involved (Hanger et al. 2013; Beck 2012; Jasanoff 2005; Shackley 2001). This is because the ways in which science is publicly acknowledged, circulated and legitimised in each country comes with their own ‘civic epistemologies’ (Jasanoff 2005). That is, the process by which countries ‘assess the rationality and robustness of claims that seek to order their lives’ (Jasanoff 2005). As a result, while greater scientist-user interactions should be encouraged, those advocating co-production need to be aware of the existing social and political dimensions they are intervening in. If not handled sensitively, co-production could exacerbate existing problems, or even create new ones (Castree et al. 2014).

National differences in institutional-political setups can be quite profound. In the UK, for instance, scientific expertise and political authority are separated to deliver ‘objective’ and ‘rational’ knowledge to support evidence-based policymaking (Tangney

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[1] Terminologies for climate risk assessments vary from ‘climate change projections’ ‘climate change scenarios’ to ‘national climate assessments’. For clarity, henceforth we use ‘climate projections’ to encompass these terms.

2016; Jasanoff 2005). Yet in many instances this same expertise is funded by UK government departments with their own agendas and priorities (Tangney 2016; Steynor et al. 2012). To counter the decline of expert credibility, the British public are increasingly encouraged to participate in science (Chilvers and Kearnes 2016). Other countries are very different, by contrast. For example, neither Switzerland nor the Netherlands have majority governments. Decisions have to be consensual, otherwise nothing proceeds. Inclusion of the political, scientific, public and private minorities are common. Highly confidential and seldom transparent, this process is essential to enable compromises (Hermann et al. 2016; Andeweg and Irwin 2005). Differences between the two exist, though. A more participatory process is practiced in the Netherlands to include everyone from political actors and interest group representatives (Andeweg and Irwin 2005). In Switzerland, on the other hand, different representatives from politics, public administrations and interest groups mediate between themselves, with the Swiss electorate asked to decide issues in referendums if no consensus is reached (Hermann et al. 2016).

In this paper, we seek to understand why climate information is produced differently from place-to-place by examining the social and scientific values of climate information. To do this, we performed a comparative analysis of three countries – the Netherlands, Switzerland and the UK – who share a number of similarities in modelling capacities yet chose to design their climate projections in very different ways. After explaining our methods and data, we compare the modelling approaches, institutional arrangements and climate information provided in each country. We then investigate the different motivations for producing a climate projection, before we turn to the different scientist–user interactions. To close, we develop a typology to explain the differences in how and why the climate projections took a particular shape.

2 Data and methods

To understand how climate projections are produced, and importantly why they differ from one country to another, we adopted a case-study approach to examine the recent efforts of climate scientists in the Netherlands, Switzerland and the UK. We chose these case studies because they share a number of similarities and differences. Each country has a history of developing climate projections, enjoys well-funded climate programmes, and makes use of state-of-the-art computing facilities and expertise, yet each differs in the modelling approaches taken and the degree to which users were involved.

To examine these case studies in greater depth, we brought together the findings from two methods. First, we conducted a desk-based search to identify documents (e.g. briefing reports, technical summaries, guidance notes) relating to the release of each set of climate projections. These documents provide a public record as to why modelling decisions were taken, how users participated in the process, and the reasoning behind different presentational styles in each country. A total of 37 documents were imported to MAXQDA – a qualitative coding software – and analysed (n=12 KNMI’14, n=13 CH2011; n=12 UKCP09). We then manually coded the documents to identify emergent themes on a range of topics from the treatment of uncertainty, involvement of users, and lessons learnt.

Second, we conducted semi-structured interviews (n=10) with advisors of, and climate scientists responsible for, delivering the Dutch and Swiss climate projections during winter 2015/16. We supplemented this data with five interviews performed with actors involved in the UK’s climate projections in mid-2013 (Porter and Dessai in Review). Whenever possible, interviews were held face-to-face in participants’ offices or held via Skype. We adopted a conversational approach, which allowed people to express their views and experiences on aspects of the production process not covered in the official documentation we analysed. To that end, we asked: Why is a climate change projection needed? Who was involved in the production process, and what role did they play? And to what extent were users involved, and what did they contribute? All the interviews were audio-recorded (with consent) and transcribed using an intelligent verbatim transcription approach – omitting filler words or hesitations (Hadley 2015). Once the transcripts were imported into MAXQDA, we manually coded the responses to identify emergent themes including modelling decisions, user engagement and institutional relationships.

To introduce greater rigour to our findings, we triangulated the codes from both datasets to understand where the greatest agreement, or disagreements, existed.

3 Context: How do the British, Dutch and Swiss climate projections compare?

Despite only a few years separating the release of the British, Dutch and Swiss climate projections, they differ in a number of ways (see Table 1). Briefly introducing each of the scenarios below, we highlight how these differences are not only concerned with the way climate change was assessed, or the actors involved, but also how each country presents climate information.

3.1 UK’s climate projections: UKCP09

After seven years’ work, the UK Met Office released the world’s first set of probabilistic climate projections: UKCP09, in 2009. Funded by the UK Government, the projections serve as an ‘input to the difficult choices that planners and other decision-makers will need to make, in sectors such as transport, healthcare, water resources, and coastal defences’ by giving users the freedom to choose the scale, time period, and thresholds corresponding to their risk tolerance and appetite (Jenkins et al. 2009).

A major focus for UKCP09’s land projections was its effort to account for the inevitable uncertainty around future climate change. Probability distributions are provided to indicate the plausible range of climate change under a particular emission scenario – with a qualitative expression of how strongly different outcomes are supported by

Table 1 – A broad comparison of British, Dutch and Swiss climate projections, 2009-2014

	UK – UKCP09 land projections	**Switzerland – CH2011**	**Netherlands – KNMI'14**
Previous Scenarios	CCIRG91; CCIRG96; UKCIP98; UKCIP02	CH2007	Buishand & Tank 1996; WB21; KNMI'06; 2009 Supplements to KNMI'06
Scientific Bodies	Met Office Hadley Centre (MOHC)	Federal Office of Meteorology and Climatology MeteoSwiss; Swiss Federal Institute of Technology Zurich (ETH), Center for Climate Systems Modeling (C2SM)	Royal Netherlands Meteorological Institute (KNMI)
Boundary Organisations	UK Climate Impacts Programme UKCIP	ProClim Forum for Climate and Global Change	None
Funders	Department for Environment, Food & Rural Affairs (Defra); Department for Energy & Climate Change (DECC)	ETH and MeteoSwiss through in-kind contributions; smaller financial contributions by the Swiss Federal Office of Energy (SFOE); Federal Office for the Environment (FOEN); and through C2SM by Empa, Agroscope Reckenholz-Tänikon, ETH Zurich foundation	Ministry of Infrastructure and the Environment
Advisory Bodies	Steering Group (strategic: MOHC & Defra); Project Management Group (operational: MOHC); User Panel (consultative: UKCIP)	Coordination Group (strategic & advisory)	International Advisory Board (8 scientific members from other European climate research institutions).
Review Process	Method reviewed by International Review Group with 6 members from the UK, USA and Canada (UKCP09 Review Group 2009), reports reviewed by User Panel members	Report reviewed by climate scientists (11 named + anonymous). Methods and models had already been published or were in press with academic journals (Buser et al. 2009; Fischer et al. 2011)	Internal review from the Advisory Board with the methods published in an academic journal (Lenderink et al. 2014), summary report reviewed by selected users.
Scenarios Used	3 emission scenarios (A1F1; A1B; B1)	3 emission scenarios (A1B; A2; RCP3PD)	4 (Two driving variables: global temp and air circulation; Two conditions: high or low)
Ensemble	Perturbed Physics Ensemble (PPE); Multi-Model Ensemble (MME)	MME	Initial state perturbation for 8 EC-Earth integrations; MME
Data Source	280 Global Climate Model (GCM) runs with HadSM3; 13 GCM HadCM3 runs; 11 Regional Climate Model (RCM) HadRM3 variants	8 GCMs; RCMs from ENSEMBLES: n=20 up to 2050; n=14 up to 2100; n=10 for the daily data for meteorological stations up to 2100	Downscaling of 8 EC-Earth GCM runs with RACMO2 RCM; 250 GCM calculations of Coupled Model Intercomparison Project CMIP5
Regional Differentiation	25km^2 grid cells (=434 selectable land grid squares); 23 river-basin regions; 16 administrative regions	Averaged over 3 regions (without the Alpine region)	None. Apart from a qualitative differentiation for temperature.

	UK – UKCP09 land projections	Switzerland – CH2011	Netherlands – KNMI'14
Time Horizons	2020s, 2050s, 2080s available as monthly, seasonal and annual 30-year means/ probabilities (daily and hourly via the weather generator)	2020-2049; 2045-2074; 2070-2099 available as seasonal ranges (daily via raw data)	2030's (combining all four scenarios), 2050's and 2080's available at seasonal and annual ranges, daily via raw data
Climate Variables	25 (e.g. temperature, precipitation, sea-level rise; cloudiness; solar radiation)	10 (n=2 quantitative: temperature and precipitation; n=8 qualitative: summer heat waves, intense rainfall, droughts, etc.)	12 (e.g. temperature, precipitation, sea-level rise, fog) stated as 22 indicators (e.g. mean, daily maximum, number of days ≥ 20 mm)
Electronic Resources	User-interface website with a visualizer; product reports (e.g. marine, land, observations, weather generator, n=518 pages)	Website to download projections reports (e.g. summary and scientific, n=94 pages), raw data and subsequently provided extensions (no user-interface)	Website to download scenario reports (e.g. brochure and scientific, n=156 pages), and raw data with all indicators at station-scale (no user-interface)

different lines of evidence (e.g. climate science, observations, and expert judgement) (see Figure 1; Jenkins et al. (2009)). For instance, users can assess the likelihood that temperatures will increase by more than 3ºC in London in the 2080s relative to the 1961–1990 base period. A large number of climate simulations were run to capture model uncertainties, accounting for different climate models' ability to replicate key aspects of current and future climate change. To do this, a perturbed physics ensemble was combined with a multi-model ensemble through a novel and sophisticated, yet contentious, approach that used a Bayesian statistical emulator (see Frigg et al. 2015; Parker 2010).

The projections are given at a resolution of 25km^2 over land, or as averages for administrative regions and river-basins. Confidence varies within the data, however. It is highest at the continental scale and lowest at the local scale, which most interests users (Porter and Dessai 2016). Users can choose from seven time periods, with overlapping 30-year windows spanning 2010 to 2099. Users, in turn, are also encouraged to work with all three emission scenarios: high, medium and low; to learn the full extent of possible changes (Jenkins et al. 2009). The projections are available free-of-charge via three formats: (1) key findings – headline messages, maps, and graphs; (2) published materials – reports, guidance and case studies for various sectors; and (3) customisable outputs – raw data via the user interface website (Steynor et al. 2012).

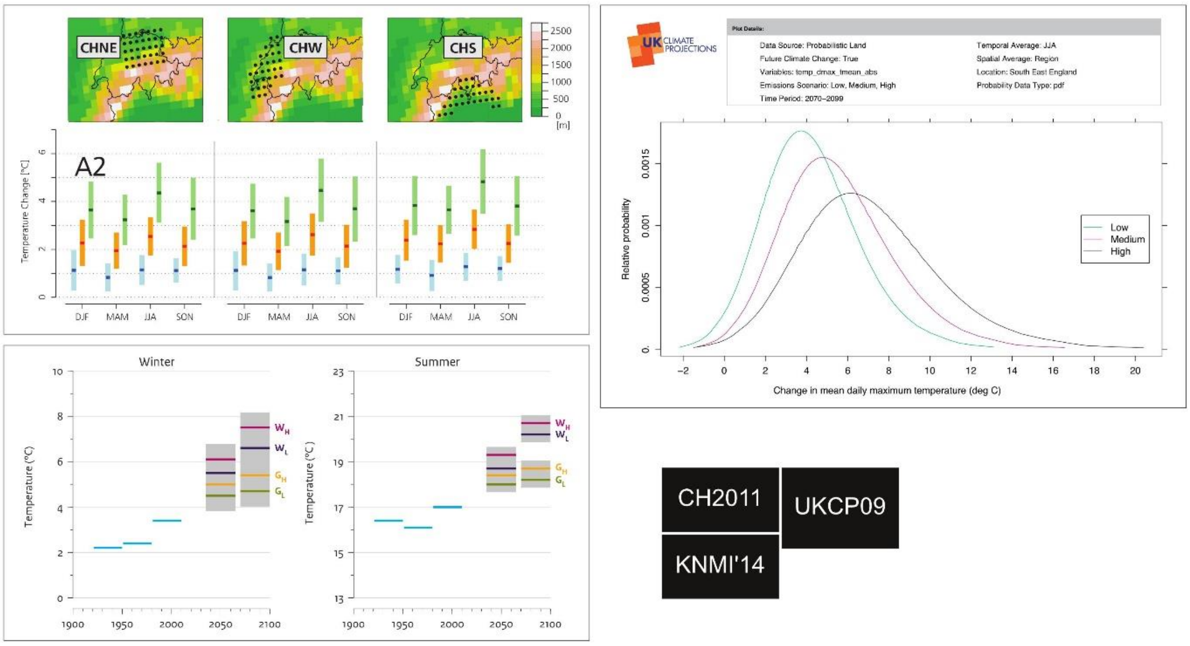

Figure 1 – Comparison of the British, Swiss and Dutch climate projections visuals, 2009 – 2014. *Top left:* CH2011 divides Switzerland into three climatic areas with corresponding seasonal ranges for three future time periods. The example shows temperature changes under emission scenario A2. *Bottom left:* KNMI’14 only visualises winter and summer temperature and precipitation changes to increase legibility, combining all four scenarios with three historical averages. Data for autumn, spring, and the natural variability are available only through a table. *Top right:* UKCP09 visualises likely changes as probability density functions for each of the three emission scenarios. This graph holds no temporal information – for each of the climate variables, time periods, grid points, and regions such a graph is available online. The example indicates changes in summer-mean daily maximum temperature in South East England for the 2080s. Sources: CH2011 2011; KNMI 2014a; Jenkins et al. 2009.

3.2 Switzerland’s climate projections: CH2011

Released in 2011, the Swiss climate projections CH2011 marked the completion of a joint science-led initiative by the Institute for Atmospheric and Climate Science at the Swiss Federal Institute of Technology Zurich (ETH) and the Federal Office for Meteorology and Climatology MeteoSwiss, with contributions from the Center for Climate Systems Modeling (C2SM, a research collaboration housed at ETH), the National Centre of Competence in Research Climate (NCCR Climate, a major Swiss research grant housed at the University of Berne), and the Swiss Advisory Body on Climate Change (OcCC, housed at the civil society organisation ProClim). CH2011 provides a new assessment detailing how Switzerland’s climate may change over the next century. Delivered without a mandate but officially sanctioned once completed, the projections provide a ‘coherent’ basis to develop ‘climate change impact studies…

addressing ecologic, economic, and social' consequences to inform 'climate adaptation and mitigation strategies' (CH2011 2011).

CH2011 projections are 'based on a new generation of global and European-scale regional climate models' (CH2011 2011). Switzerland does not have its own global climate model but ETH contributed to the regional climate modelling COSMO-CLM community project. This means CH2011's 'model data have been provided by several international projects' instead (CH2011 2011). Climate simulations from the ENSEMBLES project (van der Linden and Mitchell 2009), as well as studies and assessments from the Intergovernmental Panel on Climate Change (IPCC) were used. New, but importantly peer-reviewed, statistical methods were used to generate multi-model ensemble estimates of changes and associated uncertainties. Probability statements as in IPCC (i.e., "likely" indicating at least a two in three chance of the value falling in the given range), but no probability density functions, are assigned to temperature and precipitation only, under three emission scenarios (two non-intervention and one climate stabilisation) to give users an indication of the likely direction of change (e.g. summer rainfall "likely" to decrease by 6-23% for 2060 in the western part of Switzerland in the A2 scenario) (CH2011 2011).

The projections were aggregated spatially into three broad regions with much of the Alps excluded, as its topographical complexity raised concerns over how to reliably interpret the model results (CH2011 2011). Projected changes over the 21st century are broken into three time periods (2020-2049; 2045-2074; 2070-2099), and are available as seasonal and daily ranges. The CH2011 projections can be accessed freely for research, education and commercial purposes, by visiting the website and downloading the individual datasets (e.g. regional scenarios at daily resolution) or by requesting the published reports for the main findings.

3.3 Netherlands' climate projections: KNMI'14

The Royal Netherlands Meteorological Institute (KNMI) issued the country's most recent climate projections in 2014: KNMI'14. Funded by the state, the projections 'will be used [by decision makers] to map the impacts of climate change… [and] evaluate the importance and the urgency of climate adaptation measures' for building coastal defences, healthcare, city planning, and nature conservation (KNMI 2014b: 1).

A defining feature of KNMI'14 is the use of four scenarios to visualise how future climate may change around 2050 and 2085 (see Figure 1). Each scenario differs in terms of the amount of global warming (moderate or warm) and possible changes in air circulation (low or high). Around 2085 (2071-2100), under the G_L scenario (low air circulation change, low global temperature rise) annual mean temperature is projected to be 1.3°C warmer than the reference period (1981-2010) whereas under the W_H scenario (high air circulation change, high global temperature rise) it could be 3.7°C warmer. To obtain a range (e.g., for summer daily maximum extremes) KNMI'14 provides the currently observed natural variability which users can superimpose on to the future climate change signal to derive future upper and lower bounds. These scenarios show a single spatial scale: the whole of the Netherlands. This is because ‘any attempt to make climate predictions at a relatively small spatial scale such as the Netherlands or even Western Europe for multiple decades ahead cannot be expected to lead to skilful results’ (KNMI 2014b).

Eight initial-state perturbed climate simulations with the community global climate model EC-Earth (co-supported by the Dutch) and their own regional climate model RACMO2 were performed. These were then supplemented with a multi-model ensemble from the Coupled Model Intercomparison Project Phase 5, CMIP5 (WCRP 2010). Users are able to access the KNMI’14 projections free-of-charge by downloading the published reports or requesting the dataset directly from KNMI.

3.4 Key differences between the British, Swiss and Dutch climate projections

We found four key differences in how the British, Dutch and Swiss scientists approached the production and dissemination of their climate projections. Simply put, this can be described as differences in (i) modelling capacities, (ii) treatment of uncertainty, (iii) the actors involved, and (iv) access to the underlying data.

First, whereas the British and Dutch have their own climate models, the Swiss are more reliant on utilising modelling efforts of others. In turn, the British climate projections took a more computationally demanding and complex modelling approach than its counterparts. Second, this gave rise to the British communicating uncertainty through probability density functions. The Swiss, however, combined Bayesian statistics with expert judgment, while the Dutch assessed and communicated their uncertainty through four scenarios. Third, the Dutch kept the entire modelling and user engagement within a single organisation: KNMI, whilst the British and Swiss included institutionally distinct and physically distant actors responsible for different parts of the project. For instance, the CH2011 community comprised multiple institutions, with some scientists asked to represent the views of multiple actors (and users) simultaneously. Lastly, although the British provide users with all the output data and guidance on potential limitations, the Dutch and Swiss were more specific in what users received. The Swiss withheld parts of the data relating to the Alps due its topographical complexity and the Dutch aggregated the data into two driving variables, air circulation change and temperature. These different epistemological preferences, and social assumptions, effect the reasoning behind how a climate projection is done in the first place.

4 What is the purpose of a climate projection?

Two main reasons were cited by all three sets of scientists as to why they felt it was important to produce and disseminate climate projections. First, in order to take well-informed adaptation and mitigation decisions, a single coherent body of locally relevant scientific evidence is needed. Second, such exercises can help advance scientific understanding through the development of new methods, computing power, and working relationships. Although the three case studies share these two objectives, our research suggests that they were prioritised, understood and acted upon differently.

4.1 Informing adaptation and mitigation decision-making

All interviewed climate scientists agreed that their country needed its own set of climate projections because decision-makers are primarily ‘interested in their local patch’ (UKCP09 Scientist 5) and because weather patterns are different from one place to another (KNMI’14 Scientist 1). The IPCC assessment reports and its regional projections chapter (Christensen et al. 2007) are simply ‘too coarse’ to inform local or sector-based adaptation decision-making (CH2011 Scientist 2).

A growing user base, with evolving requirements, has also led to ‘many requests for additional information and guidance’ such as the inclusion of more climate variables, extreme weather events, and regional details that larger-scale projections cannot provide (KNMI 2014b). Servicing the informational needs of these users is a major purpose of climate projections. All the scientists shared this conviction and went to great lengths to stress how they wanted their work not only to be ‘useful’ to decision-makers but also importantly ‘used’ by them (CH2011 Scientist 4).

National policies added further support for use-inspired science. All three countries have enacted legislation requiring climate projections to inform national-scale policymaking as well as local-scale decision-making in public and private organisations. Only in Switzerland have climate projections emerged without a governmental mandate (only to be officially approved prior to publication) (CH2011 Scientist 2). Yet in each case, scientists retained the power over ‘what these scenarios should look like’ or ‘when to provide these scenarios’ (KNMI’14 Advisor 1).

Another key purpose of climate projections for KNMI scientists was to initiate a ‘paradigm shift’ in how users think (KNMI 2014b). Moving away from responses based on experiences of ‘past climatic events’, users should instead anticipate ‘possible future conditions’ for decisions today (ibid). UKCP09 scientists also felt that climate projections helped reaffirm the different roles and responsibilities of those involved in adaptation decision-making:

> ‘It’s not the climate scientist’s responsibility to provide a golden number [for users] and accept that risk [for it]. Because [scientists] can only provide what is the best science at the time, and make all the uncertainties available before saying “Okay, this is our best estimate, so take from that what you can”. And then it’s over to users as to how they use it’ (UKCP09 Advisor 1).

In other words, climate projections should help users build the capacity needed to assess their vulnerabilities, and determine how to manage future risks themselves, rather than ‘rely on a definite answer being provided for them’ (UKCP09 Advisor 1). By contrast, KNMI’14 scientists felt one of the main purposes of a climate projection was to engage as many people, from different backgrounds with different interests, as possible so as to actively avoid giving users multiple, perhaps conflicting, outputs (KNMI’14 Scientist 2). Instead of a range of outputs, KNMI’14 gave users single figures (averages) for each of the four scenarios, as this was less likely to be misinterpreted or cause confusion (KNMI 2014b).

4.2 Advancing scientific knowledge

One, if not the main, driver for developing each climate projection was the opportunity to advance scientific knowledge. However, the three groups of scientists interpreted their intellectual contribution differently. For instance, KNMI’14 and CH2011 aimed to improve and consolidate the ‘evidence base’ in their respective countries (CH2011 Scientist 4), whereas the UKCP09 projections wanted to develop a ‘new method for quantifying uncertainty’ with international reach too (UKCP09 Scientist 2).

Newly developed methods, improved computing power, and recently released model runs (e.g. CMIP5) alongside the availability of new observation datasets, were all cited as reasons for producing a climate projection. For KNMI’14 scientists, advances in climate modelling opened up a new dialogue with users over ‘what could or couldn’t be done’, prioritising the scientific work together with users (KNMI’14 Scientist 2). It also allowed KNMI’14 scientists to test if the predecessor, KNMI’06, underestimated the impact of air circulation patterns on temperature rise (KNMI 2014b). Interestingly, KNMI’14 scientists were ‘a little disappointed with the final result [due to] the similarity of the outcomes’ between KNMI’06 and KNMI’14 (KNMI’14 Scientist 1). Whilst KNMI’14 scientists reiterated their primary goal to improve the usability and use of the projections, the satisfaction derived from being the first to discover some scientific novelty is still important.

For CH2011 scientists, the need to advance scientific understanding via a new set of climate projections was expressed differently. Already serving as IPCC lead authors but lacking the modelling resources enjoyed by other countries (Brönnimann et al. 2014), the CH2011 projections strengthened old and encouraged new collaborations between Swiss research institutions (CH2011 Advisor 1). It brought researchers and (scientific) users ‘to one table’ where everyone could discuss how the modelling should be done (CH2011 Scientist 4). ‘There wasn’t always a consensus within the group’ because the complex topography of the Swiss Alps presents challenges for modelling. But by ‘bringing together the different institutions’ the Swiss climate science community was able to speak with ‘one voice’ for the first time and created the momentum for funded future projections, as well as political support to establish the Swiss National Centre for Climate Services (CH2011 Scientist 4).

UKCP09 scientists differ from their KNMI’14 and CH2011 counterparts in how they understand, and in turn, acted upon the need to both advance scientific knowledge and inform adaptation decision-making. For KNMI’14 and CH2011 scientists the two objectives can sometimes be incompatible whereas UKCP09 scientists felt that they go hand-in-hand. UKCP09 scientists assumed that if users want to make ‘reliable, robust, and relevant’ decisions ‘they need the best science’ available (UKCP09 Scientist 3, Interview; see also Porter and Dessai in Review). Better science, it seems, equals better decisions. To that end, and in contrast to the single figures provided in KNMI’14, UKCP09 quantifies climate variables’ ranges so that users can decide about the level of risk they want to manage. Whereas multi-model ensembles have conventionally been used to assess uncertainty, UKCP09 scientists felt this method failed to capture the full range of uncertainties (Porter and Dessai 2016). By developing their own method, not only would they make a significant intellectual contribution to quantifying model uncertainties, but they also could meet their institutional and political goals to be included in the IPCC process (UKCP09 Scientist 2).

4.3 Different understandings, different priorities

All three sets of scientists were fully committed to informing adaptation decisions and advancing scientific understandings yet interpreted these commitments differently. For CH2011 scientists, priority was given to assembling a consistent evidence base that spoke with ‘one voice’. To do this, effort was focused on improving working relationships and intellectual exchanges to advance scientific capacities. For KNMI’14 scientists, a major driver was the need to change how people think and act in relation to climate change. Advances in climate modelling certainly aided this process but were not the sole catalyst. For UKCP09 scientists, efforts to quantify uncertainty were underpinned by the assumption that users need the ‘best science’ possible. Practical or application-based considerations inevitably took a backseat to intellectual contributions and the pursuit of curiosity-driven science, as a result. These different understandings of the purpose of a climate projection affect the way users are involved in the process, and the extent to which they are listened to.

5 How involved were users in producing the climate projections?

Our research suggests that all three sets of climate projections differed considerably in the extent to which they involved users, what they expected them to contribute, and even whom they thought the user was in the first place. Together these differences have had a marked effect on the particular form taken by the British, Dutch and Swiss projections. For instance, how model uncertainty was quantified (cf. UKCP09 vs. KMNI’14) is based on a series of assumptions about the capacity of users to work through and make sense of complex information. Narrowly defined perceptions of users and their needs, however, has diluted commitment to co-produce climate science.

5.1 Scientists’ perceptions of users

Without exception, the official documents issued for all three sets of climate projections paint a very broad picture of potential users. From those interested in digging down and exploring the data to others interested only in the headline messages, and many actors somewhere in-between; the projections resist the temptation of becoming the exclusive preserve of a small group of users alone. This manifests itself differently in each country. Where the KNMI’14 and CH2011 projections aimed to inform decisions in sectors from water, healthcare, agriculture, and transport to infrastructure, UKCP09 went even further by subdividing the users within these sectors into three categories: researchers, decision-makers and communicators (Steynor et al. 2012). Simply put, all three projections should officially cater to different users, all with different needs.

Few of the scientists interviewed shared that view, however. CH2011 scientists, for instance, felt the end users would be either impact modellers or government officials (CH2011 Scientist 1). Previous experiences from the last projections, CH2007, and the government agenda to develop a national adaptation strategy, informed this view. Yet misunderstandings over what users need and what scientists think is useful (see Lemos et al. 2012) soon developed. CH2011 scientists realised they had ‘produced far more information than [government officials] could use’ or make sense of (CH2011 Scientist 1). Lacking the time and resources to work through the probability statements provided, government officials were forced to simplify the climate information they used. A ‘user bubble’ of likeminded individuals – impact modellers – consulted by the CH2011 scientists meant they had, unintentionally, overestimated the capacity of non-quantitative users (Liniger 2015). Upon reflection, CH2011 scientists told us that while it was fairly intuitive to identify which sectors might be interested in using climate projections, it remained a mystery how the projections would actually be used or what users needed from them (CH2011 Scientist 3).

UKCP09 scientists, similarly, were confident that they ‘knew what users needed’ (UKCP09 Scientist 1). Via years of experience developing climate projections, scientists had formed close working relationships with several users: impact modellers, water managers, and consultants (Porter and Dessai in Review). All of these users share certain characteristics. They are highly numerate, motivated, and knowledgeable actors. These characteristics were woven into the fabric of the new projections. That is, UKCP09 requires users to have already assessed their vulnerability to climate change themselves to be able to use probability distribution functions (Jenkins et al. 2009). A persistent criticism, though, is that potential users without the time, resources or capacity to make sense of their vulnerabilities can find themselves excluded (Frigg et al. 2015; Tang and Dessai 2012). Indeed, UKCP09 scientists were warned against defining the user too narrowly (Steynor et al. 2012). Very late in the process, the government funder, Defra, told the scientists that the projections should be opened up to ‘as many people as possible’ to avoid satisfying only a single type of user (UKCP09 Scientist 2).

KNMI’14 scientists did things differently, by contrast. They already knew water managers were the primary user of the previous climate projections, KNMI’06 (KNMI’14 Scientist 1). Unlike their CH2011 or UKCP09 counterparts, ‘the first meeting of the [KNMI’14] project team was on user requirements’ (KNMI’14 Advisor 1). To appeal to the widest audience possible, they reduced the complexity of the material presented by giving users single (averaged) figures of future temperature change instead of full probabilities (KNMI 2014b). Put differently, KNMI’14 scientists believe that limiting the volume of (undigested) information given to users, and the choices they have to make, improves the accessibility and understanding of the projections. Asking users to focus on four storylines places less demands on their time and requires only a basic level of understanding, initially at least. KNMI’14 scientists, therefore, imagined different users with different needs and capacities (KNMI’14 Scientist 2).

5.2 Interactions between scientists and users

Despite initial reluctance from some scientists to involve the intended and therefore favoured users, by the end, a closer working relationship between the two became highly valued. Scientists concerned over lack of time or the right skills to engage with the favoured users soon realised that with a better understanding of how climate information is used, and therein what users actually need, they could make a ‘few small changes with immediate impact’ (UKCP09 Scientist 1). The only way to do this was for scientists and users to meet face-to-face. Yet all three sets of climate scientists held very different views on the interaction format and the extent to which users are listened to.

CH2011 scientists told us that users ‘weren’t involved as much as they would have liked’ (CH2011 Scientist 1). Both a lack of ‘funding’ and no official ‘mandate’ were cited as major barriers (CH2011 Scientist 2). Efforts were made to ensure the voice of users was heard, nonetheless. Although ‘we didn’t do a full user survey… [canvassing only impact modellers] we still had a good impression [of]… what users needed’ (CH2011 Scientist 4). Moreover, when a coordination group was set up to oversee the production of the projections, 2 of the 6 seats were filled by user representatives. Mirroring the political culture of Swiss collegiality, the coordination group required members to reach decisions collectively. Yet it was not always easy for user representatives to relay the ‘heterogeneous needs’ of users (CH2011 Advisor 1). As a consequence, this institutionalised the ‘user bubble’ rather than challenged it (Liniger 2015). Users were only introduced en masse until just ‘before the report was released’ where ‘talks and events’ were held so that everyone ‘who should know about [the projections] did know about them in advance’ (CH2011 Scientist 4). However, not only is awareness different from engagement, but the introduction of users at such a late stage restricts what they can, and are willing to, contribute and articulate.

KNMI'14 and UKCP09 scientists both conducted surveys with users from previous versions of their climate projections and ran workshops to understand how user needs have changed. A long 'shopping list' of requirements was identified, but was interpreted and acted upon differently. For instance, the 'explicit presentation of [model] uncertainties and assumptions behind [them], easier access [to the data], and higher temporal and spatial resolution [data]' was flagged by both projects (Steynor et al. 2012; see also Bessembinder et al. 2011). Whereas this confirmed UKCP09 scientists' need to advance science linearly (UKCP09 Scientist 1), KNMI'14 scientists felt a closer dialogue was needed to dispel the 'you ask, we deliver' paradigm in the hope that users reconsider their requests (KNMI'14 Scientist 3). Indeed, KNMI'14 scientists raised concerns about the methods to elicit user needs. For them, surveys risk closing down fruitful conversations about user needs, and therein, fail to understand how, or why, users actually use climate information:

> 'You cannot just go to users once and ask them for feedback. You need to have regular contact, continuous contact, over a long time to get really useful feedback. It's not just asking 'what do you want?' and then giving it to them… many users want to do something with climate adaptation but don't know exactly what that is or how to do it… so it's important to know how they use climate data' (KNMI'14 Advisor 2).

To encourage as much interaction as possible many face-to-face meetings between scientists and users were organised (KNMI'14 Advisor 2). Two communication experts were hired to get users more involved instead of 'just listening to talks' (KNMI'14 Scientist 2). 'Light workshops with standing tables' mixing scientists and users with 'only six people around each table… to make it easy to ask questions' were used (KNMI'14 Advisor 2). This setup helped scientists to better understand how climate information is used, and in turn, what users need. It also opened up conversations over 'the advantages and disadvantages of probability distributions and the way uncertainties are presented' and differences between what is doable and what is desirable by getting users to think more reflexively about 'their list of requests' (Bessembinder et al. 2011). 'That discussion and dialogue between users and KNMI staff really was the main contribution of the three years of work. Much more so than the analysis of the data and the climate projections' (KNMI'14 Scientist 2).

UKCP09 scientists, by contrast, were less enthusiastic about interacting with users than their KNMI'14 counterparts. That reluctance was due, in part, to different ideas about the roles and responsibilities of scientists (Porter and Dessai in Review). UKCP09 scientists' job is to do 'world-leading science' while organisations like UKCIP should engage users because they possess the 'skills and time' to do so (UKCP09 Scientist 2). Part of the British political culture of evidence-based decision-making serves to reinforce this separation of scientists and users, in order to preserve the integrity and authority of expert knowledge, on one hand, and a top-down hierarchy between the two is maintained, on the other (Tangney and Howes 2016). Practical concerns were also raised, such as the number of users involved, how regularly (or when) to consult them, and how to weigh their contributions equally. For instance, there is the risk that ‘users who [are] able to eloquently express their needs or regularly attended meetings’ gain greater attention or have ‘undue influence’ on the process (Steynor et al. 2012). That said, three years after the modelling began the UKCP09 project was reorganised with the funder, Defra, insisting a user panel was set up to bring scientists and selected users together (UKCIP 2006). Yet, user input was highly constrained. Modelling decisions had gone beyond the point of being reversed (cf. Corner et al. 2012). Users were left to comment on ‘presentation issues’ over the spatial aggregation of the outputs (e.g. 25km^2 grid cells vs. river basins) rather than discussing how to model uncertainty differently (UKCP09 Advisor 2). The new lecture-like setup with ‘talk after talk’ sold the projections to users (UKCP09 Scientist 2).

5.3 Doing things together

The motivation, intensity and format of the scientist-user interaction was different across the three countries. The ‘you ask, we deliver’ paradigm was dispelled by KNMI but used strategically in UKCP09 to support their scientific work. In addition, the timing was problematic for both the British and Swiss projections: Users engaged with UKCP09 only after the major decisions have already been taken (and the funder Defra stepped in), and in CH2011 the interaction was confined to awareness. At best, this limits what contributions users can make, and at worst, it can lead to frustration and disengagement.

This limited interaction was partly accepted because British and Swiss scientists felt they *knew* who the user was. It didn’t matter that the engagement was restricted because the scientists already constructed an image of the user, and this conception confirmed what type of climate projection the scientists wanted to produce in a self-serving way. An early and more intense user engagement might have resulted in scientists having to produce something they did not want to. For KNMI’14, however, conceptualising their target audience was only the starting point, thus questioning their preconceptions and not falling prey to such a confirmation bias.

6 Discussion

Our comparative analysis reveals that climate projections are influenced by the ‘civic epistemology’ of each country, that is, the role science plays in policy-making. The respective political cultures shape who has a say, what roles scientists and users play, and the interactions between the two. Internal disagreements and different opinions on methodological aspects, communication and target users exist but are often veiled by the prevailing science-society relations.

The role science plays in society reflects values about what makes science ‘good’ for decision-making. Three types of use-inspired research emerge here: *innovator* (UKCP09), *consolidator* (CH2011), and *collaborator* (KNMI’14). Each differs in their approach to knowledge production (see Table 2). The Swiss are more conservative emphasising the need for peer-reviewed, consensual research, whereas the British are more risk-taking pursuing novelty above else in assuming that the 'best' information is a prerequisite to successful adaptation planning. The Dutch value science which is usable and mix established methods with novel ones when culturally relevant (Enserink et al. 2013; see also Dilling and Berggren 2015). Our 'typology of use-inspired research' ties in with other work on values and assumptions shaping the atmospheric sciences. For Shackley (2001), climate modelling centres judge 'good' scientific practice differently, which is due to the different institutional-political priorities faced by each. Often a modelling hierarchy emerges in which greater modelling complexity is assumed to lead to greater realism and better decision-making (Shackley et al. 1998; Shackley and Wynne 1995). Whereas UKCP09 has gone down the modelling complexity route, CH2011 and KNMI'14 question what value is added by this.

All three climate projections also differed considerably in how users were engaged, which speak to different types of user–scientist interaction (Table 2): *elicitation* (UKCP09), *representation* (CH2011), and *participation* (KNMI'14). For example, while the Dutch KNMI involved a large number of users in the production process, the British and Swiss producers chose more limited interactions to retain power over production. Jasanoff's (2005) 'civic epistemologies' argues that the way science for policy-making is done reflects wider societal factors (e.g. consensus-building in Switzerland, inclusiveness in the Netherlands, and expert authority in the UK). Knowingly or not, science responds to these cultural differences, affecting what knowledge is produced (and, by extension, by whom and how it's used). We have found, similarly to Beck (2012), that public discourse of climate change depends on the particularities of national politics, and how climate science is embedded therein.

Our two proposed typologies help to bring a socio-political context into the 'knowledge systems' framework (Cash et al. 2003). Where the 'typology of scientific enterprise' characterises how judgements of 'good' science give rise to 'credible' information, the 'typology of user-interaction' explains how the process of producing 'legitimate' knowledge to inform decisions can unfold. Through the culturally situated production of climate information, the scientific output is expected to be 'salient' (i.e. relevant) for governmental decision-making – a key argument of the 'civic epistemologies' (Jasanoff 2005). However, relevance and usability of information are not synonyms. Lemos et al. (2012) argue that usability is high when information is tailored to needs and capacities of users; a quality achieved through co-production and scientists listening to users. Our results support this proposition: UKCP09 included sophisticated and numerate members in their user panel while KNMI'14 included a broad user base. Both essentially served the users involved in the production.

Table 2 – Comparison of characteristics of climate science and user engagement of between UKCP09, CH2011 and KNMI’14 according to the two proposed typologies: the first ‘typology of scientists’ capturing features important to (climate) science aimed at decision-making, and a corresponding ‘typology of user engagement’ on how users were involved, and listened to.

	Innovator – UKCP09 land projections	**Consolidator – CH2011**	**Collaborator – KNMI'14**
Number of institutions	Two, plus one active funder	Five or more (some producers have several affiliations)	One (funder not active)
Tasks of institutions	Distinctive – but diverging	Less clear – but with goal consensus	Distinctive
Institutions’ physical distance	High – several hours journey	Medium – all in Zurich, with one exception	Low – same building
Scientific innovation	Very important – driving motivation	Less important	Intermediate – but high if it benefits users
Scientific consensus orientation	Less important – UKCP09 needed to be ‘novel’	High – driving motivation, with emphasis on peer-reviewed, consensual findings	Intermediate – but high if it benefits users
	Elicitation – UKCP09 land projections	**Representation – CH2011**	**Participation – KNMI’14**
Number of users involved	40	2 – 5 (depends if MeteoSwiss producers are counted as users)	At least 70 users, more likely to be 100+
Scientists’ inclination to engage with users	Initially low, raising to medium	High with the representatives, low with individuals	High – driving motivation, with a particular focus on interaction with individuals
Start and duration of engagement	Formalised user elicitation began after all modelling decisions taken; met every three months over a period of three years	With representatives: from the start until the end, with lots of discussions. Individual users were notified but not engaged.	Throughout the whole process
Prior knowledge required for use	High – very numerate users	Medium – user has to be able to read and understand complex topics	Low – entry barrier for use is held as low as possible (no ranges, etc.)

We conclude, therefore, that two types of discussions need to take place to highlight and understand the social dimensions of producing climate information. First, that those advocating scientists to co-produce usable climate information need to be sensitive to, and reflect upon, the existing social and political dimensions shaping climate information. ‘Universalising’ cases into ‘best practices’ disregards the cultural context which influences uptake, success and failure to a large degree. Second, more work is needed to explore whether government-approved climate information can close the perceived adaptation implementation deficit – or exacerbate it. Indeed, we have shown that the national civic epistemology influences usability of information for less sophisticated users profoundly. Can political cultures similar to the UK produce knowledge serving a larger user base with less capacities – but still be ‘salient’ for governmental policy-making? What challenges does this present? And how do users with more modest needs judge the credibility and legitimacy of ‘salient’ knowledge, in absence of governmental approval?

7 Conclusion

Our research has helped map out how different social and scientific values shaped three sets of climate projections. Political culture, and the respective roles of science, government, non-state organisations and individuals within it, strongly influence what knowledge is produced, how scientists and users interact, and to whom information is tailored. Our research also shows that whilst government-approved science can improve the legitimacy and credibility of climate information, the same is not necessarily true for its saliency and usability.

Acknowledgements

S.D. and J.J.P. were supported by the European Research Council (ERC) under the European Union’s Seventh Framework Programme for Research (FP7/2007–2013), ERC Grant agreement 284369. We are grateful to Meaghan Daly for comments on an earlier draft and to everyone who participated in this study.

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