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Different levels of uncertainty in Carbon Capture and Storage technologies: Challenges for risk communication

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Abstract

There are several different risks associated with Carbon Capture and Storage that influence perceptions of the technology. In this paper we argue that being clear about the object of the uncertainty helps researchers and risk communicators chart a clearer map of the public reactions to the potential risks of CCS. We will use a new, post-normal, classification of uncertainty by Spiegelhalter and Riesch to analyse the different types of uncertainty that affect CCS. We will argue that while all types of uncertainty are present, they are not all equally relevant in every situation or for stakeholders with different background knowledge and holding different attitudes and assumptions. Risk communication strategies may need to pay attention to these different levels and the resulting different interpretations of the involved risks.
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1. Introduction

One of the problems of characterising and communicating the risks of new technologies is that risk means many different things to different people. In their influential account of "post-normal" science, Funtowicz and Ravetz (1993) argue that there are always multiple and legitimate perspectives over the risks of new science and technologies which can therefore rarely point towards clear policy decisions. On a more simplistic level there is the realisation that there are calculable and quantifiable uncertainties associated with the risks, as well as more intangible uncertainties which are more difficult to grasp and therefore to communicate. In this paper we aim to present a classification of risks developed by Spiegelhalter and Riesch (in preparation) and apply it to Carbon Capture and Storage (CCS). We will then point to the deficiencies with respect to public expectations and how our risk framework can address them.

Risk is often understood in two contrary ways, which does not help talking clearly about the topic. On the one hand, the traditional understanding of risk is that it is a combination of our uncertainty of an event happening and the severity of the outcome of the event. To avoid possible confusion, we will use this conception of risk below.

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Another use of the term, made popular in the seminal book by Frank Knight (ref) is to think of it depicting a quantifiable uncertainty. Although we won't be using his terminology, Knight's distinction is useful as a first attempt to separate calculable uncertainties from deeper uncertainties.

If we conceive of risk as a measure of outcome times uncertainty, realising that the uncertainty part of risk can either be thought of as quantifiable and therefore more or less unproblematic, and unquantifiable and therefore problematic, we can also conceptualise the outcome to be either problematic or unproblematic. Stirling (ref) uses this to construct a 2 by 2 matrix in his classification of risks: Risks can either be unproblematic both in uncertainty and outcome, or they can be problematic in both or just problematic in one of the two areas. A different way of characterising risks was presented by Wynne (ref), who divided them into four categories, starting conceptually with the distinction made by Knight: “Risks” are unproblematic in both probability and outcome, “uncertainties” are present when we know the system parameters but not the probability distributions, “ignorance” is based on the simplifications science has to make and “indeterminacy” questions the assumptions on the causal chains and networks.

Risk has also become an integral part of contemporary social theory as argued famously by sociologists Beck (ref) and Giddens (ref). In their conception of risk the quantifiable part plays only a very small role, as they are interested in the effects that risk awareness has on the functioning and self-awareness of late modern society. Thus they argue that with the increasing reliance on technology in late modern life coupled with an increased scientific and public awareness of potential risks of the technologies, we have now evolved into a risk society that is much more concerned with risks and unintended consequences than previously. The risk that are most in the back of our minds are what Beck calls the “unintended consequences of modernity”, which implies that we are not so much worried about having proper risk assessments but with the nagging worry that something, somewhere will go horribly wrong – large scale technological disasters that were not properly foreseeable such as the Chernobyl explosion dominate the public attitude to new technologies.

That there are similar considerations in the communication of uncertainty associated with CCS is demonstrated by an article in the Dutch popular science magazine NWT on the proposed CCS project in the town of Barendrecht (Japsers 2009). Jaspers argued that while the risk assessments made and communicated by the experts and the Dutch government only took into account the outcome arrived at by the accepted models, it left out wider questions on whether the models were appropriate and whether the scientific community that made these assessments was acting in the most rational scientific manner. In Wynne's classification, the risk assessments were concerned mostly with risks and uncertainties, but left out the deeper issues of indeterminacy and ignorance.

A different way of classifying uncertainties is based on answering the question where the uncertainties come from. Literature in this area is almost as old as probability theory itself. It starts from the idea that probability can be interpreted either as a measure of uncertainty inherent in the experimental set up, or as a measure of our lack of knowledge about the world. A useful illustration here is the probability a tossed coin will show heads (which is on the face of it at least merely dependent on the experimental set up), compared with the probability that that a coin that has already been tossed, but that I can't see, is showing heads. The philosopher Ian Hacking calls these two interpretations of probability “aleatoric” and “epistemic” probabilities respectively (Hacking ???).

Taking the idea of classifying risks by the source of uncertainty and applying this to risk assessment, van Asselt and Rotmans (2002) divide several possible sources of uncertainty as falling into epistemic and aleatoric categories. Through the recognition that the uncertainties of technological risks have different sources, van Asselt and Rotmans argue for a more considered type of risk assessment that takes into account these different uncertainties and which considers the different interpretations of the resulting risk scenarios in a more qualitative way.

2. Five levels of uncertainty

In Spiegelhalter and Riesch (in prep.) we attempt to fuse and clarify the different ideas on how risks should be classified, and in the process develop some clear distinctions with which we can clarify and comment on current approaches to communicating risks. We start first by accepting the terminology that risk is a measure of the uncertainty and severity of an outcome. Though we recognise that the outcome part of risk is itself not an unproblematic concept, we concentrate on examining what the uncertainties are and how they can be classified. In thinking about uncertainty we make a distinction between sources of uncertainty (as talked about by van Asselt and

Rotmans) and objects of uncertainty. By objects of uncertainty we mean answers to the question “what are we uncertain about?”, and by sources of uncertainty we mean answers to the question “why are we uncertain?” We propose that uncertainties about different types of objects can be arrived through various sources. Therefore our classification complements that of van Asselt and Rotmans by providing a more fine-grained distinction of uncertainties.

We distinguish between five different objects of uncertainty which we think can be reasonably ordered from unproblematic to problematic and in that sense they can be mapped onto previous schemes such as Wynne's classification, though we think it has the added bonus of clarity in the distinctions, terminology used, and finally on allowing us to conceptually combine risk literatures from Beck's and Giddens’s risk society to the risk perception literature (refs). We hope therefore to arrive at a comprehensive idea of risk which is applicable across this rather diverse literature.

The five levels of uncertainty are:

1. Uncertainty about the outcome: We have an appropriate model in our risk assessment, and we know the relevant parameters. The remaining uncertainty is that predicted by the model itself.
2. Uncertainty about the parameters: We know the model, but have still some uncertainty over the parameters. The overall uncertainty in this scenario is a combination of the uncertainty predicted by the model and the uncertainty over the parameters. This overall uncertainty can be represented for example through adding error bars on to the final assessment.
3. Uncertainty about the model: there are several possible competing models with which the risk assessment can be carried out. Here disagreement is possible among competing teams of experts. This uncertainty is the one found by Jaspers when he talks about the possible inadequacies in the modelling process for the Barendrecht risk assessment.
4. Uncertainty about our underlying assumptions: The risk modelling process is only accurate as long as the underlying science is sound. Suppose there were fundamental problems with our understanding of the behaviour of CO2 in certain circumstances and it turns out to behave differently to how our present scientific understanding says it should: In this case our models would have an additional uncertainty which is not inherent in the choice of model itself, or in our choice of the parameters. This is of course not to say that it is likely that our scientific knowledge will turn out to be wrong. However, it introduces an additional uncertainty, one which will be judged differently depending on our scientific knowledge or involvement. Public fears about new technology can often be seen to be worries about level four uncertainties: In the case of genetically modified foods for example, public anxiety centred around the question “what if the scientists are wrong?” This uncertainty is not easily answered by even the most methodical risk assessments, and it is important to stress that even though scientists involved often do not even recognise this level of uncertainty, it forms a huge part of public fears about new technologies.
5. Complete uncertainty: This last level is slightly perpendicular to the rest, because it concerns uncertainty not just about our implicit assumptions, but about assumptions we didn't even know we were making. The usual quote to demonstrate complete uncertainty is the famous assertion by Donald Rumsfeld that “there are things we don't even know we don't know”. Together levels four and five make up the kind of risk scenarios talked about by Beck and Giddens in their assessment of late modern society – these represent the risks of “unintended consequences”: people who worry about a new technology do so not because the final risk assessments tell them to worry, but because they feel there are things that have been left out, or scientific facts which we assume but have some residual uncertainty about, or lastly because even then unexpected things can conceivably always happen.

These levels of uncertainty interconnect to form an overall uncertainty of a particular risk, though different levels may be more or less pronounced than others. For example when in 2007 the World Cancer Research Foundation (WCRF) published a metastudy which claimed that our risks of colorectal cancer are increased by 20% if we eat processed meat every day (discussed in Riesch and Spiegelhalter, forthcoming), there are a number of competing uncertainties at play which colour our overall assessment of the safety of eating processed meat. On the first level, there is the uncertainty provided by the WCRF, expressed through the 20% figure. On the second level, there is the uncertainty over the parameters: As this was a metastudy collecting several papers and studies on the subject, it is vulnerable to certain limitations, such as the chance of errors in the individual studies, and the overall strength of the evidence they provide. This uncertainty is expressed by the WCRF through error bars in their final estimate of the risks, and verbally through the caveat that there is “strong” evidence for a increased risk of colorectal cancer (as opposed for example to their finding of only weak evidence of other types of cancer). On the next level there are uncertainties over the methods used in the WCRF study – meta-analyses, although an established methodology in medical research, are nonetheless not without their critics, and therefore a residual uncertainty over the validity of their findings remains. On a yet higher level, the research relies to a large extent on previous scientific research on cancer which is rather well established and therefore implicitly assumed in the report.

The way people respond to the various levels of risk present in that example depends on a variety of factors and personal viewpoints. While the cancer researchers on the study will not take the higher levels of uncertainty to be predominant because they are of course unlikely to doubt their own methodologies and the science they take for granted, others may take a different view. Scientific detractors to the study for example may cast doubt on the methodology used, or the validity of the individual studies that made up the meta-analysis and the selection criteria used by the authors. People who reject a large chunk of insights from modern medicine, such as alternative health practitioners, will be more likely to judge level four uncertainties to predominate. All these various voices and interpretations of the study and the overall risk of eating processed meat were indeed heard in the public debate surrounding the study.

3. Levels of uncertainty and CCS

This section will apply the above framework to the risks involved in carbon capture and storage, and try to tease out what an awareness of different levels of uncertainty can add to current communication strategies. The first level of uncertainty is important in situations where there is largely an agreement on which model to use, and how its main parameters are assigned. This would be the final uncertainty predicted by the model when a risk assessment of CCS is performed, and the basis on which politicians like ???? would claim that experts think the risks are negligible. The second level is important in situations where there is large agreement over the model, but there is uncertainty over the parameters. The first two levels of uncertainty are evident in much of the statistical work for example on the costs of CCS (McCoy and Rubin, in press). Uncertainty over the parameters usually reflects our lack of knowledge over the precise nature of the local conditions, and therefore often represent an empirical lack of knowledge as the *source* of our uncertainty. The third level concerns our uncertainty over the model: We can have different models to chose from to describe the scenario, but we don't know which one (if any) will reflect the reality of the situation. Once the model is chosen, its parameters may still need to be ascertained, to predict an outcome with a particular probability. In the case of many studies on CCS for example, there are still debates to be had about how much models developed for and by the oil and gas industries apply to the storages of CO2 (Raza 2009). There may be additional uncertainties over what statistical methods are used, and their applicability. This is the level at which (*NWT author*) detected some uncertainty, because he felt that the model used in the initial assessment was not applicable to this more complicated situation. Whatever the merits of those criticisms, they highlight that there is an additional uncertainty which cannot be reduced through better measurements or calculations. How to deal quantitatively with this uncertainty is also an open question – while we can make qualitative estimates about which model is better than others, a precise ordering is often impossible. In the case of CCS, this presents a challenge for effective communication of the risks involved because it requires expert knowledge to be able to even qualitatively tell the merits of different models.

The fourth level is the uncertainty over our implicit assumptions: When choosing a model we also need to make judgements over the reliability of the modelling processes, the trustworthiness of the modellers and of the scientific assumptions they are using. This level, more so than the previous, is of importance to the more ideologically opposed critics of CCS. One of the most important implicit assumptions is whether we can fully trust the people who make the risk assessment (trustworthiness is one of the different sources of uncertainty discussed by van Asselt and Rotmans). CCS is a technology championed, or at least seemingly championed predominantly by fossil fuel and energy companies as well as national governments, and levels of trust among environmental groups towards these actors are low (*refs* this is for various reasons not related directly to CCS). Since levels of trust are low, pronouncements on risk assessments are treated with caution, because from the opponents' perspective there is a very real and relatively high probability that the risk assessment was not done properly, that relevant information was suppressed or that the experts are ideologically influenced to produce risk estimates that are lower than they really should be.

Another source of uncertainty which casts doubt on our implicit assumptions is that of the uncertainty in the underlying science. Though this doubt will be low in experts' assessments of the situation, the same cannot be said of the general public which will not know the science involved intimately enough and will therefore not be in the position to properly assess where our knowledge is secure enough to take it as given. This we should stress is not an argument about how the public is not scientifically literate enough, because a proper assessment of the scientific background to such complicated topics as CCS requires more than degree level knowledge. In the absence of such knowledge we are left to trust the experts involved that the underlying science is sound. This is essentially the situation in which we the authors find ourselves, since as social scientists we do not have the tools to properly assess the situation, and however much we ourselves trust the experts in this regard, we recognise that disagreeing with us is a perfectly rational position to take especially when we have prior suspicion of the motives of the experts as outlined above. Therefore unless we are experts ourselves, doubt over the underlying science often resolves to the issues of trust discussed above.

The fifth level, “Rumsfeldian” uncertainty, is somewhat perpendicular to the others. These are the things we are not even aware that we don't know and can affect our risk assessment at any point, which is why we portrayed it in figure 1 as hovering menacingly in the background. It is of course difficult to give a concrete example here for the case of CCS, because as soon as we draw attention to what may go wrong it ceases to be something we don't know we don't know. However, intuitively it is easy to see why people would be concerned about unexpected consequences, because this concerns unknown risks which may have a hugely severe impact, and therefore even though the probabilities of them occurring are low, the overall risk can still be very high. This is illustrated in Taleb's (ref) concept of “black swan events” in finance: these are unimagined events that are unforeseen and therefore considered to be vanishingly unlikely, but due to their potential high impacts when they do happen they have a tendency to completely alter the playing field.

As we've argued above, the last two levels of uncertainty are an important factor when considering non-experts' responses to CCS, since they need to factor in their own assessments over the reliability of the risk estimates they have just heard given background concerns that are not evident or assumed as given in the technical literature. The fact that despite all the reassuring risk modelling something almost always goes wrong due to unforeseen circumstances if the project is rolled out on a large enough scale (as in the airline industry where accidents still happen despite efforts to reduce the risks to zero), suggests the deep rationality behind the quite stringent public demands for “zero leakage” outlined by Ha-Duong and Loisel (2009).Yet CCS literature aimed at the public does not routinely address such concerns, which is understandable from the expert's point of view since it would be unnatural to cast doubt on your own trustworthiness or expertise. However it is here that the public will have the most need for proper understanding if it is to make an informed assessment of the overall risks involved.

4. Conclusions: How to deal with communicating uncertainties

The framework we present here of differentiating different levels of uncertainty involved in technological risks will be helpful in devising strategies to help communicating risks. We suggest that the different types of uncertainties will require different approaches in presenting the technology, and will moreover require a framework with which the overall risk can be presented.

By accommodating communication strategies to the very different natures of the uncertainties present, we may hopefully end up in a situation where the experts' own feelings and assessments of risks are communicated effectively and the public is in the position to make a well-informed and rational decision over whether to accept or reject the risks. The lower levels will not require much change, because they are already well represented in the current risk communication literature. However, we would suggest that even here it may help being clearer about what the uncertainty is: it needs to be distinguished that the outcome uncertainty is different from the uncertainties we get from incomplete knowledge of the parameters and local conditions. To take up the example on processed meat from above, if we were to make a decision based on the WCRF report on whether to continue eating sausages we would have to take into account both the final risk estimate as well as the estimate on the strength of the evidence. There is a qualitative difference between a high risk for which there is some but not much evidence and a moderate risk for which there is strong evidence. Similarly if I needed to make a decision on whether to accept a

CCS project in my backyard, I'd feel there would be a qualitative difference between say a moderate risk based on rather incomplete knowledge of the local conditions and a higher risk based on more precise measurements, even if the overall risk were the same. To address this, these uncertainties need to be presented separately, as was done (though by no means properly highlighted) in the cancer study.

Level three may present a different challenge, depending on the confidence we have in the modelling. Unlike level two uncertainty, uncertainty over the model is not easily or systematically assessable through a probability distribution, and presentations of this level of uncertainty often need to resort to lists of the different scenarios together with verbal descriptions of our assessments of them. We may for example model a best case scenario and present it together with a worst case scenario in order to give an indication of the range of the different outcomes, as well as present an estimate on how likely we judge each scenario to be. Level three also however presents a rather different challenge because it needs to take into account evaluations of the situation which differ from our own judgements and preferred models – this is understandably something which experts are loath to do, but even worse it will mean that the estimates on how likely each scenario is will differ between the competing experts and there will therefore rarely be a completely agreed upon evaluation with which to present the different models. Yet these differing expert judgements need to be addressed, and should not be swept under the carpet simply because the person writing the communication effort strongly disagrees with other experts. This will require some judgement however, since not all experts are of course equally able and we may feel that they are either not fully competent to deal with the assessment, or are in some way untrustworthy. Probably the best way to deal with such difficulties is to be candid about what the writer feels are the strengths and weaknesses of other approaches and try to make the reader see the situation from their point of view.

Worries about trustworthiness and competence lead to level four uncertainties. Here the communicator faces another difficult challenge because this uncertainty is about their own trustworthiness. The other source of uncertainty, about the underlying science is similarly problematic, because as I've argued above, communicating it essentially boils down to trust as well. Here communication strategies will need to pay detailed attention to explaining the science and needs to keep in mind that no matter how settled these issues may seem to the expert, there are still very rational worries and uncertainties left among those unfamiliar with the science, or even those familiar with it but with a different perspective. There will probably be no magic solution to communicating these uncertainties effectively, therefore the best suggestion would be to present the information dispassionately and persuasively. Most important however is to acknowledge that this level of uncertainty exists and is not swept under the carpet under the excuse that the public is too illiterate to understand them. Worries over uncertainties on this level exist and even if they are not informed by the best of current scientific knowledge they are nonetheless perfectly valid and rational concerns to have. Failing to address them will only make suspicions worse.