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# Energy transitioning: why bother with uncertainty and why does risk tolerance really matter?

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COMMENT

# Energy transitioning: why bother with uncertainty and why does risk tolerance really matter?

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**ABSTRACT**

The target article 'Risk analysis, uncertainty and innovation: what does this mean for the Dutch energy transition?' sets out some broad factors (e.g. uncertainty, risk tolerance) that should inform public policy making on energy transition, and in particular the Dutch Ministry for Economic Affairs and Climate Policy. This commentary further clarifies and expands on them by answering: (1) Why is the concept of uncertainty of value in risk analysis? (2) What benefit is there to integrating risk tolerance in risk management and policy decisions?

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## Goldilocks: finding the right trade-off

The overall objective of the target article 'Risk analysis, uncertainty and innovation: what does this mean for the Dutch energy transition?' (Bouder & Lofstedt, in press) is to essential solve the problem of how risk management handles unknown risks (costs in general) against benefits. Being overly cautious through the invocation of the precautionary principle means successfully mitigating risk but at the same time stifling innovation with huge potential economic benefits. Being too gun hoe, 'no risk, no fun', means exploiting an economically beneficial groundbreaking technology, but also inviting multiple unruly risks, some with dire consequences. The target article's answer to solving the trade-off is a better understanding of uncertainty and integrating a process of measuring risk tolerance. This commentary adds a little more meat on the bone, by pointing out where the issues of clarification are needed to say why understanding uncertainty is of importance to risk management, and policy decisions more broadly. Once addressing uncertainty, the remainder of the commentary discusses risk tolerance and elucidates the way in which uncertainty is associated with it, which is implicit in the target article but not fully explored. To help make the points clear here, a toy example is used.

### *Toy example: nuclear energy in Newfilandia*

In the country of Newfilandia the proposed policy to reduce dependency on imports of natural gas, and the national coal supply, is to increase nuclear energy capabilities. The target is to go from 5%, which is the current total contribution to the electricity supply, to 30% by 2060. The benefits are clean and cheap energy, along with a boost to the national economy through a new skilled labour force, with career prospects for the next generation of Newfilandians.

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Newfilandia currently has a single, and old nuclear reactor which will involve a major overhaul to extend its lifespan, along with it, two new reactors will be built. The policy is in place, but there is a chance of revoking it, and instead work towards increasing solar and wind power capabilities. Safety concerns exist, most notably because of historical examples of disasters associated with nuclear power plants that cost many lives and impacted the public purse. Therefore, new types of mitigation strategies are being pursued that involve digital twinning technologies. Digital twins are a means of simulating real world complex systems to improve operational efficiency of a system, as well as better management and optimisation for scheduling to handle fluctuations in energy demand. With all these news technologies at Newfilandia's disposal, the prospects look bright, but the path to implementing the policy is rocky.

## Uncertainty, what is it good for?

In Bouder and Lofstedt's (in press) target article they propose that uncertainty is in need of conceptual clarity, which might be so in the domain of risk analysis, but not else where. Economics, cognitive science, computer science, and decision science have done fairly well in conceptualising uncertainty. There are of course many ways to think about uncertainty (see Figure 1) and how to depict it (for discussion see Bradley and Drechsler 2014), but there are commonalities that persist across the aforementioned disciplines.

Risk analysis ***is actually*** uncertainty analysis depending on which expert you ask. If risk analysis means handling precise bounded conditions (i.e. the outcomes are known along with their probabilities) then it only applies to dice rolls or coin tosses.[1] Given that the real world isn't based on coin tosses and dice rolls, because the outcomes aren't always known (See Figure 1(C)), precise probability estimates of known outcomes is hard to achieve, and for both, things change over time (see Figure 1(B)), then we are always having to contend with uncertainty. By the same token, this means that everything in the territory of risk analysis (assessment, management, prioritisation, communication) is actually dealing with uncertainties, not risks.

What is a better way of thinking about the properties of events in the world that require decisions? A better way to think about events in the world is according to two types of

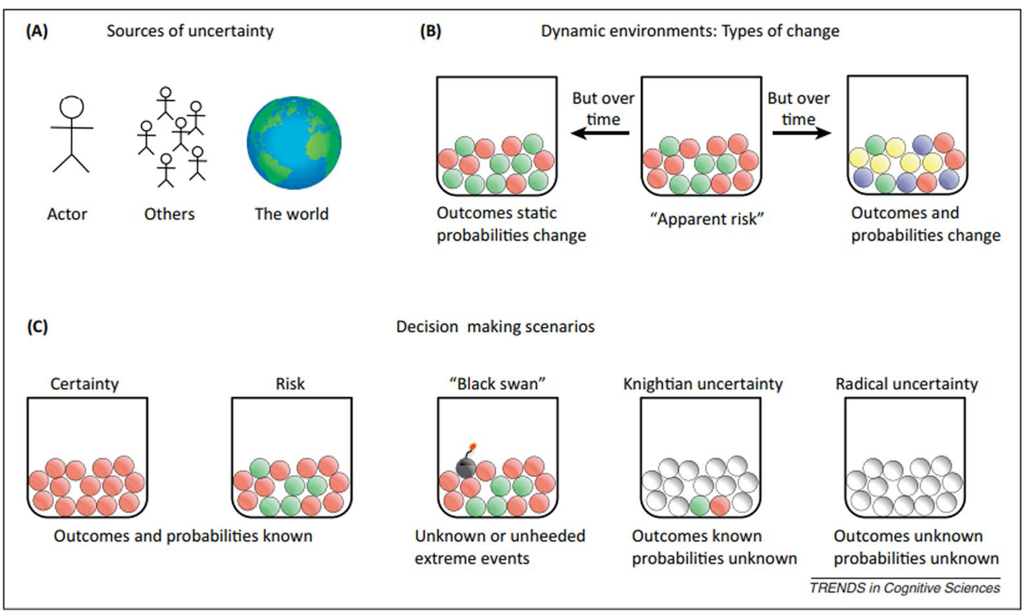


**Figure 1.** Different presentation of uncertainty relative to risk and certainty taken from Meder, Le Lec, and Osman (2013).[2]

situations. Situations where the probabilities associated with known outcomes is stochastic, referred to as aleatoric uncertainty; this can be reduced but not eliminated. Then there are situations of epistemic uncertainty, meaning that which is not known in the mind of the individual; this can be reduced or eliminated. In the latter case there are means of addressing epistemic uncertainty where only mitigation is the course of action for aleatoric uncertainty (Der Kiureghian and Ditlevsen 2009; Hüllermeier and Waegeman 2021).

To this end, continuing discussions on how to bring uncertainty into risk analysis, such as adding processes on top of what is already done (e.g. uncertainty estimates, uncertainty analyses, confidence judgments) is pointless and impractical (Osman 2021; Osman, Heath, and Löfstedt 2018). The problem isn't with uncertainty and characterising it, the problem is a lack of appreciation of what risk analysis does. Risk analysis is a means of operating in an 'as if' world, meaning the world is as if it is only made up of risks (known outcomes and their known probabilities); this is a trick that economists have been exploiting for a very long time (Savage 1954). Risk analysis (assessment, management, prioritisation, communication) is a practical way of hiding the fact that it is always dealing with the identification of and control of uncertainty (e.g. Osman 2010, 2011, 2017; Osman, Heath, and Löfstedt 2018). Where risk analysis makes a concession to uncertainty is to accept the epistemic one, either based on gathering confidence estimates around what is known at the time of a risk assessment or risk management decision. But, as mentioned, this doesn't quite cut it, when trying to make use of what is known about risks.

We can think about how to apply uncertainties usefully in the toy example of Nuclear Energy in Newfilandia. The policy makers have conducted a risk assessment and have alerted risk managers to six areas that they are willing to concede are unknowns. Half the risk managers are proposing that a precautionary principle be invoked, meaning delays in implementing the policy or even stymying it. The remaining camp are proposing that any harmful outcomes can be mitigated, and that the overall benefits (e.g. economy, job creation, clean energy) to the country outweigh the associated costs (e.g. maximum credible consequence[3] – loss of lives, and financial costs in addressing it).

Here are the six areas that are flagged as unknowns:

1. The efficacy of new nuclear safety protocols based on implementation of technological advances (e.g. Burgherr and Hirschberg 2008);
2. The range of vulnerabilities that digital technologies will expose that pose national security threats (e.g. Mondal, Martinez, and Jain 2024);
3. Viability of a frictionless integration of new nuclear reactors into the current national power grid (e.g. Bragg-Sitton et al. 2020);
4. The effectiveness of new technologies for improving nuclear waste management (e.g. Mondal, Martinez, and Jain 2024);
5. Public appetite for increasing reliance on nuclear energy (e.g. Bisconti 2018; Gupta et al. 2019; Ho et al. 2019);
6. News media presentation of the policy (e.g. Bohdanowicz et al. 2023; Rothman and Lichter 1987).

What is the practical value of adding to these unknowns some more uncertainty analysis in the form of confidence estimates in risk assessment and management decisions? Aside from the fact that there isn't any good way to carry out meaningful uncertainty analyses anyway (Osman, Heath, and Löfstedt 2018), even if there were, where would be the cut off on confidence judgments that would be acceptable for a management or policy decisions to be made? Bouder and Lofstedt (in press) would say that this is where risk tolerance comes in, because experts (i.e. risk managers, policy makers) can settle on a position on the proposed Tolerability of Risk model to then decide what to do. This in turn is where the implicit connection between uncertainties and risk tolerance are made, and which is covered in more detail in the next section. Suspending a discussion on risk tolerance for now, if we go back to the simple categorical distinction between aleatory uncertainty and epistemic uncertainty, a useful way to address the 6 areas flagged as unknowns is to classify them into one or other type of uncertainty. The reason for doing this is that it can pinpoint what areas can be addressed where uncertainty can actually be significantly reduced, and where inevitable uncertainties will remain though can be accepted so long as sensible mitgation is in place in the event that problems arise.

One could argue that the last three unknowns are examples of epistemic uncertainty, and that it could be reduced simply by new data gathering efforts (e.g. 4, 5) or reviewing past literature of comparable situations (e.g. 5, 6). In turn this can help with planning responses, so policy teams can carrying cost benefit analysis for which waste management systems should be built into the new reactors. In turn, understanding what factors inform changes over time in public appetite for nuclear energy is of use to for public consultation that is needed if and when the new policy takes effect. The interplay between public opinion and news media is also one which is difficult to pilot, but again a wealth of evidence can be drawn upon to help set out clear communication of the costs of the policy, and how they will be practically addressed within the policy.

This leaves the first three unknowns, which could be classified as aleatory uncertainty as well as epistemic uncertainty. With regards to the first one and third, there may be examples of new reactors that have been built where best practice, albeit recent, can be imported to the new construction of reactors in Newfilandia. But there is always going to be some features of the problem that will mean the dynamics are different and unique which also means a response that considers best possible alternatives, as well as crisis management. Random safety breaches will occur, but even if their probability isn't know, in the event that they do occur, then a mitigation strategy needs to be in place. For the second of the list of identified unknowns, it is clear that there will be little to draw from to make any good estimates of the likelihood of national security breaches, but enough to anticipate where the likely vulnerabilities will occur. Along with this there are several innovations in data science to help simulate threats to help with preparedness in the event that breaches will occur (e.g. cyber defence exercises, gamification, hackathons) (Brilingaitė, Bukauskas, and Juozapavičius 2020; Chatfield and Reddick 2017; Workman 2021).

The take home here is that, in broad agreement with Bouder and Lofstedt (in press) those in the risk analysis community, and those practitioners that live and breath risk, will benefit from a better appreciation of the concept of uncertainty. A reframing of risk analysis into pure uncertainty analysis is too radical. Even if this would be of benefit in the long run, it won't happen. So, given this, at the very least, risk managers should think about decision problems in terms of different types of uncertainty (aleatory, epistemic) so as to identify those that will remain (albeit reduced in form) and those that can be eliminated. For the former, best- and worst-case scenarios need to be described, and cost-benefit analyses for each need to be developed to find the optimal mitigation response. Thinking about uncertainty in this way is less complicated and more practical than embedding yet further processes (e.g. confidence intervals) to an already complex set of procedures for risk assessment and management.

## What is risk tolerance, and whose matters?

There is a large body of work in the domain of risk perceptions that has pointed to the fact that it should be treated separate from risk tolerance (Anderson et al. 2023; Bouder, Slavin, and Löfstedt 2007; Hunte et al. 2024; Jenkins, Harris, and Osman 2021, Jenkins, Lachlan, and Osman 2024). The main reason for drawing the distinction is the 'risk perceptions paradox' (Wachinger et al. 2013) – perceptions of risk do not in turn reliably predict behavioural responses to those risks.

Risk perceptions are derived from one of the most important methodologies to come out of risk research, the psychometric paradigm (Fischhoff et al. 1978). The methodology in effect determines peoples' 'personality of hazards' based on their rating of hazards on a series of characteristics thought to influence perception of risks, for instance, familiarity, level of personal/scientific knowledge and severity (Slovic 2010). The way the public respond or adapt to risks corresponds more accurately to how they consider the overall benefits (e.g. convenience, efficiency, and safety) weighted up against overall concerns (e.g. harmful, hazardous, unfamiliar) (e.g. Hunte et al. 2024; Jenkins, Lachlan, and Osman 2024). The same is no less true for domain experts when asked to provide their judgments of risk tolerance (Bouder, Slavin, and Löfstedt 2007; Bouder 2018).

Thus, people weigh the benefits (e.g. utility of the product/service in terms of benefits through its function, frequency of use) against dread (e.g. harms caused, types of hazards, lack of understanding/limited experience), to determine their overall tolerance of the risks. We all can forgo the risks associated with something because it has high utility, and because it is useful we absorb the responsibilities through our own mitigation of the harms. Seen in this way, it makes sense that risk tolerance corresponds to actual behaviour, and offers a way of resolving the risk perceptions paradox.

Predicting behaviour at scale is obviously useful when it comes to risk management, because public responses to interventions designed to mitigate risks needs to be anticipated – such as the adoption of recommendations presented in public campaigns. Not only this, even when risk assessments suggest that the risks are high, even if public perceptions of risk are aligned to thi, their tolerance may not be – that is, they may well be highly tolerant of the risks because the utility is deemed high (e.g. high costs, high rewards). Again, the predictive value of risk tolerance is going to be useful because it is more informative than risk perceptions alone.

Bouder and Lofstedt (in press) make the case for a framework that builds in 'Tolerance of Risk' as a way to support risk management, and which generalises to policy decision-making in the main. The point that needs to be emphasised is that there won't always be convergence across public risk tolerance and expert risk tolerance for any given matter. Public risk tolerance is informative because it gives some idea to risk managers of what people are prepared to accept given their current understanding of the costs and benefits. Risk managers, in turn need to recognise that their own decision-making is informed by personal appraisals of the utility given the costs, and their own risk tolerance will not be aligned with other risk managers, let alone other stakeholders, or the public.

So, to go back to the toy problem, two of the factors (i.e. 5 and 6) are better informed by examining risk tolerance than risk perceptions or risk attitudes, because only one is a better predictor of behaviour. How to respond to findings of public risk tolerance also needs to be coordinated with the overall risk tolerance of risk managers with regards to the other factors (e.g. 2, 3 and 4). Regardless of level of technical knowledge and expertise, for new technologies in the domain of nuclear energy, some will have high risk tolerance (the overall benefits outweigh the costs) and others will have low risk tolerance (the overall costs outweigh the benefits).

Divergence in risk tolerance, such as illustrated here, as Bouder and Lofstedt (in press) suggest, needs to be acknowledge, but at the same time some practical way forward is needed to help generate consensus decisions. Here is where the link between risk tolerance and uncertainty resides, and it requires posing a question. *Will reducing your epistemic uncertainty change (in whichever direction) your risk tolerance?* In other words, is the tolerance (or not) of the risk fundamentally rooted in aleatory uncertainty, in which case there is probably no basis on which to shift it – some will simply not be prepared to tolerate the maximum credible consequences of a nuclear powerplant accident. A room with views on what to do based on only entrenched personal levels of tolerance of risks is no grounds for achieving a fair consensus decision. Therefore, some diagnosis needs to be made of what adjustments risk managers are prepared make in light of new information, hence why the question is worth posing. In other words, there is going to be epistemic uncertainty in all of the minds of the risk managers because the domain they are making a decision is a highly uncertainty one. Evidence is building which can reduce the epistemic uncertainty, and this might, for some be a basis on which to adjust their tolerance of the risks. Moreover, the same applies when address public tolerance of risks. It would be worth determining what gaps in knowledge could be reduced to usefully make a difference in changing tolerance of risks around a future that means greater dependence on nuclear energy. Of course this is goal directed. In other words, underlying all this is a need to achieve a consensus where most (i.e. public, experts, risk managers, policy makers, media) are on board with a decision to either enact a policy, or pursue an alternative to a dependence on nuclear energy. In view of no alternative, then greater efforts need to be made to examine the viability of the policy itself, and that requires reducing epistemic uncertainty because the stakes are high and it is the only option on offer. Also, epistemic uncertainty has to be reduced because the responsibiltiy for mitigating any foreseeable negative outcomes is too great, especially given that aleatory uncertainty will always remain.

The take home here is that gauging risk tolerance separate from ascertaining risk perceptions is a necessary step to predictive accuracy of behavioural responses to risk, as well as risk management decisions. The value of risk tolerance is that it can help determine where the public align with or not, with evidence provided from risk assessments, and is another tool in the armoury when making good risk management decision (as well as policy decisions). The critical reason that risk tolerance is associated with uncertainty is we may not be fully cognisant of the costs, but willing to pursue the benefits of a given high stakes situation. The trade-off can be better informed by addressing epistemic uncertainty, and putting things in place in response to aleatory uncertainty.

## Notes

1. In fact, from a theoretical (different approaches to probability theory), as well as a practical perspective (creating machines that tests out a series of coin flips over 10 times up to 1000s of times), the range of possible outcomes of a coin toss is, heads, tails and neither – since there is at least a probability that the coin will land on it's edge, so in this sense 50% head, 50% tails is not accurate, and so even here coin tosses are not an example of risk [i.e. known probabilities of outcomes].
2. (A) Uncertainty is epistemic and sits within the mind of the boundedly rational agent where the source of uncertainty can be themselves, others, and the world – which can itself reflect aleatoric uncertainty - genuine randomness in the external environment. (B) There are also more extreme forms of uncertainty that are dynamic in nature and can shift over time. (C) There are different ways in which uncertainties can manifest and so these are illustrated in their various visual forms using an urn and distributions of outcomes (e.g. the coloured balls).
3. This concept was first introduced by Dopchie, Juliens, and Vandewiele (1958) in connection to associated outcomes in the advent of an accident from a nuclear reactor. The concept is now used in risk assessment (Burgherr and Hirschberg 2008) to calculate the probability of an event (accident) occurring with the most severe consequences (human fatalities, environmental harms).

## Disclosure statement

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