regional estimates and to unpick the effects of anthropogenic influences on climate from natural influences, such as changes in solar output and internal variations in the climate system (the El Niño/Southern Oscillation, for example). But one strength of their approach is that global aggregation of data potentially allows for a more robust estimate of the effects of warming on extreme events overall, which may be less affected by modelling uncertainties than some of the studies applied to individual events.

Global risk assessments are needed to inform mitigation and adaptation decisions. Risk does not just arise from hazard, the meteorological extremes that Fischer and Knutti[4] examine, it also comes from the degree of exposure to that hazard and the vulnerability of citizens and societies. Maps showing the probability of exceeding extreme meteorological thresholds can be combined with maps of vulnerability and exposure to examine where climate risks are greatest. Fischer and Knutti point to the tropics and many island states where internal variability is relatively low[12] and vulnerability can be high. Such work highlights a greater point about climate change research. While human influence on the climate system is clear, much more work is needed across interdisciplinary boundaries to understand how people of the world will be affected, and how best to avoid the worst outcomes. ❐

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References
1. *WMO Statement on the State of the Global Climate of 2014* (WMO, 2015).
2. IPCC *Climate Change 2013: The Physical Science Basis* (eds Stocker, T. F. *et al.*) (Cambridge Univ. Press, 2013).
3. Herring, S. C., Hoerling, M. P., Peterson, T. C. & Stott, P. A. (eds) *Bull. Am. Meteorol. Soc.* **95,** S1–S96 (2014).
4. Fischer, E. M. & Knutti, R. *Nature Clim. Change* http://dx.doi.org/10.1038/nclimate2617 (2015).
5. Blunden, J. & Arndt, D. S. (eds) *Bull. Am. Meteorol. Soc.* **95,** S1–S257 (2014).
6. Zwiers, F. W., Zhang, X. & Feng, Y. *J. Clim.* **24,** 881–892 (2011).
7. Min, S-K., Zhang, X., Zwiers, F. W. & Hegerl, G. C. *Nature* **470,** 378–381 (2011).
8. Allen, M. R. *Nature* **421,** 891–892 (2003).
9. Stott, P. A., Stone, D. A. & Allen, M. R. *Nature* **432,** 610–614 (2004).
10. Pall, P. *et al. Nature* **470,** 382–385 (2011).
11. Taylor, K. E., Stouffer, R. J. & Meehl, G. A. *Bull. Am. Meteorol. Soc.* **93,** 485–498 (2012).
12. Mahlstein, I., Knutti, R., Solomon, S. & Portmann, R. W. *Environ. Res. Lett.* **6,** 034009 (2011).

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CLIMATE POLITICS

Designing energy policy under uncertainty

Countries need to cut greenhouse-gas emissions from the energy sector if the world is to avoid the worst impacts of climate change. But no one is sure of the best path. New research highlights the key uncertainties driving energy policy debate in the UK.

Catherine Mitchell

Policymakers are divided over how best to decarbonize the global energy system. Many studies focus on what we know about current technologies' ability to meet emissions reduction targets. But understanding the impact of future uncertainties around governance, business models, economics, and public attitudes is equally important.

Such uncertainties perpetuate debates about the best policies to transform countries' energy systems. In an article in *Energy Policy,* Jim Watson and colleagues[1] suggest that more time and better data is unlikely to resolve these conflicts, and that decisions must inevitably be based on imperfect knowledge.

They map 14 significant sources of uncertainty, and set out potential actions to mitigate such conditions. In doing so, they give a good impression of the complexity decision-makers face when designing energy policy.

A major debate in the UK's parliament prior to the last election was whether the Conservative-led government would loosen the country's mid-term emissions reduction target, known as the fourth carbon budget. Watson and colleagues carry out an assessment of the feasibility of the budget (covering the years 2023 to 2027), and the implications that sticking to it could have for policymakers and other stakeholders.

Eight instrumental factors that introduce uncertainty into decision-making are highlighted: the availability of finance for low-carbon power generation, commercialization of low-carbon power generation technologies, diversity of heat decarbonization pathways, heat pump performance, district heating investment and business models, energy efficiency improvements and demand reduction, diversity of transport decarbonization pathways, and adoption of electric vehicles. They also identify six systemic uncertainties: fossil fuel availability and price, bioenergy availability and price, material scarcity, ecosystem service impacts, public attitudes to energy system change, and political commitment to a low-carbon transition.

They point out the unexpectedness of change, showing that actual developments often lie outside the range of imagined futures. So, how helpful is this in terms of meeting the fourth carbon budget?

Decision-makers need to understand the complexities of available climate and energy policy choices. The main contribution of Watson and colleagues is to identify a useful framework to assess this.

They set out some basic rules for making decisions in a time of uncertainty: policymakers need to set about 'opening up' the process to get the public involved and connected, need flexibility and diversity of options within energy policy, need to learn from best practice, and need to set about ensuring their country, region or locality uses as little energy as possible.

But while they give a good overview of energy policy uncertainties and what the most rational processes are to deal with this situation, they do not reference cases where rapid change has already occurred. If they had done this, they might have concluded that some decision-making variables are more important than others when trying to reduce emissions.

Watson and colleagues show most energy policy choices can be made to seem uncertain. But what they fail to illuminate is that a technology pathway way to meet the UK's carbon targets will require a very different energy system with different practices. Different technologies will be necessary, but markets, business models, system operation and customer involvement will also have to change. Each of these has the potential to alter the system in different ways. Such uncertainty leads to contradictory information flowing from stakeholders anxious that their preferred pathway is chosen.

Policymakers' energy choices depend on the governance of each specific country. This in turn depends on the very practical realities of governance and policy design, such as laws, technical realities, economic incentives, and social and cultural preferences. These are known as the 'enabling environment', which makes doing something possible and economic. The third important factor is someone or something taking action. How these three things come together is less well understood.

Moreover, uncertainty is a double-edged sword. For any country that does not really want to implement an effective energy or climate policy, uncertainty can always be a reason to undertake more research. As the article concludes "efforts to overcome uncertainties have resulted in complex solutions or a tendency to inertia or inaction". On the other hand, if a country wants to put policies in place to meet a carbon budget or any other goal, 'uncertainty' about the future does not stop it from doing so.

Apart from the technical and design aspects of policy effectiveness, what stops a policy from working is, ultimately, public connection and reaction. Andy Stirling has likened this to 'murmurations' or 'emancipatory transformations'[2]. When a concept such as reducing emissions becomes more about enabling unruly collective action than responsible policy, Stirling argues, change can happen very rapidly.

Globally, investment in renewable energy technologies rose from US$39.5 billion at the beginning 2004, to US$214.4 billion by the end of 2013,

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excluding hydropower installations larger than 50 MW. Net investment in renewable energy capacity was greater than net fossil-fuel investment (US$192 billion versus US$102 billion) for the fourth year in 2013[3].

At a technology-specific level, lessons can be learned from the rapid growth in the use of solar photovoltaic units (PV). Around the globe, 2.6 GW of solar PV had been deployed at the start of 2004[4]. By the end of 2009, this had jumped to 23 GW, with 139 GW installed by the end of 2013. In Great Britain, use of solar PV increased rapidly as a result of the introduction of the small-scale feed-in tariff. There was almost no solar PV capacity in Britain at the start of 2010 (despite 20 years of renewable energy policy) but two years later at the start of 2012, there was about 1 GW — and as of the end February 2015, there was 5,229 MW across 668,714 installations[5].

At a national level, Germany[6] and Denmark[7] are often used as examples of rapid change. These countries act as beacons — and as pilot studies for voluntary research, development, demonstration and dissemination — that push prices down, increase operational knowledge and best practice, and eventually act as drivers elsewhere in the world. For example, in Germany, in 1991, 3% of electricity was from renewable sources, now 23% is[8]. Of that portion, only 5% is owned by the so-called big four energy companies. This has transformed the face of the energy market: there were 66 energy co-ops in 2001, now there are 888.

This suggests that Germany's conventional utilities have more or less lost their retail market in the last decade. This is leading to existential change in the German electricity system, meaning that its operation and market prices are being directly impacted by renewable energy sources. For example two or the big four, Eon and RWE are losing profits, experiencing falling share prices and restructuring as a consequence. It has also led to an avalanche of financial analysts prophesying the end of the conventional utility model.

Watson and colleagues thoroughly review the uncertainties surrounding technology pathways to meet the fourth carbon budget. But the fact remains that some countries embrace change and opportunities, while others don't. 'Just Do It'[9] might seem like a glib slogan, but a country that keeps to the basic policy lessons of Watson and colleagues' research, takes note of what the public are doing, keeps an eye on real-world experience, learns from action, and 'just does it', has the best chance of meeting its targets. ❐

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References

1. Watson, J., Gross, R., Ketsopoulou I & Winskel, M. Energy Policy http://dx.doi.org/10.1016/j.enpol.2015.02.030 (2015).
2. Stirling, A. *Alternative Energy Pathways — Making Democractic Choices* (SPRU & STEP Centre, University of Sussex, 2014); http://go.nature.com/OQrUKK
3. Randall, T. Fossil fuels just lost the race against renewables. *Bloomberg* (14 April 2015); http://go.nature.com/Xt5j7q
4. *Renewables 2014 Global Status Report: 2014 Key Findings* (REN21, 2014); http://go.nature.com/ctYC8z
5. *Solar Photovoltatics Deployment* (Department of Energy and Climate Change, 2014); http://go.nature.com/8RYnfb
6. Burger, C & Weinmann, J. *The Decentralized Energy Revolution: Business Strategies for a New Paradigm* (Palgrave Macmillan, 2012).
7. *The Danish Energy Model:Innovative, Efficient and Sustainable* (Danish Energy Agency, 2015); http://go.nature.com/4KQ1P3
8. Burger, C. *Germany's Decentralised Energy Revolution* (European School of Management and Technology, , 2014); http://go.nature.com/iHFsur
9. Mitchell, C. *The Political Economy of Sustainable Energy* (Palgrave Macmillan, 2007).