Investing for net zero in the face of uncertainty: Real options and robust decision-making

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Maxine Frerk

Visiting Fellow, The Oxford Martin School Programme on Integrating Renewable Energy

Biography

Maxine Frerk is an experienced regulatory expert with experience across the private and public sectors, most recently as Senior Partner Networks at Ofgem. Earlier in her career she was Head of Strategy at BT. She now works as an independent consultant through her company Grid Edge Policy and is a visiting fellow with the Oxford Martin School Programme on Integrating Renewable Energy. She has a first from Cambridge in maths and management science.

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Oxford Martin School Programme on Integrating Renewable Energy

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Summary

One of the biggest challenges currently facing Ofgem as energy regulator is how to cope with the significant investment needed to meet net zero when the trajectory and timings are still subject to huge uncertainty.

This paper looks at the appraisal techniques that have historically been used by the industry and the regulator – conventional Cost-Benefit Analysis (CBA) together with Future Energy Scenarios (FES) and Least Worst Regret analysis – and sets out some serious limitations with these tools, in particular in the context of investment in distribution networks.

Instead, the paper argues for a toolbox of different approaches dependent on the scale and nature of the decision involved. This includes scenario analysis (but used more flexibly than the FES to prompt radical thinking about how the future might unfold); options generation (drawing on the concepts underpinning real option theory) and robust decision-making approaches that combine analysis and deliberation. Probabilistic CBAs can be used to build uncertainty into assessments for smaller scale assets and ensure that flexibility is properly valued for the options it creates. Judgment will have to play an increasingly important role.

Fundamentally the paper argues for a mindset shift. In the same way that the value in the electricity system will shift from energy to flexibility, the value in regulation will come not from squeezing the last bit of efficiency out of the system but in finding ways to drive industry to be more agile and responsive to change. Ofgem has talked about adaptive regulation which is a useful concept but for them it seems to be essentially about moving away from a 5-year price control cycle. It needs to be more than that.

Ofgem continues to worry about customers paying for assets that might ultimately not be needed, but that may well be a price that is worth paying for resilience in the face of uncertainty and to provide confidence in our ability to achieve net zero. The regulatory toolkit needs updating to value the system flexibility that Ofgem rightly recognises is crucial going forward. This same toolkit is also relevant to thinking about climate adaptation, which provides some helpful examples of how these techniques can be applied in practice.

1. Introduction

The UK is committed to achieving net zero carbon emissions by 2050 as its contribution to limiting the impacts of global climate change to 1.5 degrees of warming. The trajectory that it will follow to achieve that remains highly uncertain. The Committee on Climate Change, charged with advising government, set out in its Net Zero report a range of pathways that could be followed, looking across all the sectors involved. Its latest report on the sixth carbon budget continues to highlight the uncertainty that exists including around the extent of individual behaviour change and the level of technical innovation. However, in all scenarios it is clear that significant additional investment will be needed in the electricity infrastructure while uncertainty remains around the long-term future of the gas networks and the extent to which hydrogen could provide a solution for domestic heating.

Ofgem as sector regulator has made clear its commitment to supporting the achievement of net zero at the lowest possible cost to consumers. One challenge it faces is how to assess the demands of network companies for additional investment to support this goal, as part of the RIIO[1] price control process. Ofgem has historically been concerned about allowing investments that may not ultimately be needed, adding unnecessarily to costs for customers. In a letter to Ofgem from the Secretary of State ahead of the electricity distribution methodology decision, government emphasised the importance that it attached to strategic investment to ensure that network infrastructure does not become a barrier to achievement of net zero.

In response to these challenges Ofgem has signalled a move to what it terms "adaptive regulation", making more use of uncertainty mechanisms to adjust the revenue allowances during the price control period.

In all sectors (gas and electricity, transmission and distribution) Ofgem has included a number of broad re-openers to accommodate changes in government policy. In addition, Ofgem has introduced specific mechanisms for each sector reflecting the fact that the challenges vary across the different networks, which are also at different stages of the price control cycle as summarised below:

- **Electricity transmission**: business plans were centred around large reinforcement projects with Ofgem having a process for approving these in period when more information becomes available (as it does now with Strategic Wider Works projects);
- **Gas distribution**: business plans were centred around replacement of iron mains on safety / environmental grounds and ongoing maintenance. Ofgem required all projects to have a payback under 16 years given uncertainty about the future of the gas networks;
- **Electricity distribution** (running two years later): business plans are expected to include significant network reinforcement but comprising many smaller scale projects. Ofgem are expected to make more use of volume drivers to adjust allowed revenues although some larger projects will need specific justification and there is a strong emphasis on using flexibility (demand side response and smart solutions) in place of conventional reinforcement.

To inform the transmission investment decisions, National Grid ESO (the system operator) carries out a Network Options Assessment (NOA) each year looking at a national system level at the different options for managing constraints. These are informed by the Future Energy Scenarios

[1] RIIO: Revenue = Incentives for Innovation and Outputs. This is the process that Ofgem uses to set the amount of revenue that monopoly networks can earn (and the incentives for improved service etc)

developed by the ESO and relied on more widely by Ofgem, for example to inform its decisions on the RIIO plans.

At the end of 2020 Ofgem published a paper it had commissioned from independent academics (Dr Stan Zachary of Herriot-Watt University, Chris Dent of the University of Edinburgh and Simon French of Panmure Gordon) on *Decision making for future energy systems: incorporating rapid change and future uncertainties.* This looked in particular at the use made of the Future Energy Scenarios, the tools for assessing options against such scenarios in the NOA and the relationship between analysts and decision-makers. While it draws out some helpful conclusions it arguably takes a rather narrow view of what the problem is by focussing on Ofgem's role in systems planning. This paper seeks to redress that balance by looking at some of the same questions but from a broader perspective.

Specifically, this paper looks in turn at:

- The current toolkit;
- An overview of what an updated toolkit would include;
- Exploring uncertainty through scenario planning and sensitivities;
- Developing a broader set of options through real options thinking;
- Evaluating options (looking at least worst regret, regret theory, "Robust" decision making, real options value and some of the practical challenges involved);
- Conclusions for regulation, including the importance of judgment and a mindset shift.

2 The current toolkit

The central tool used in the energy sector for thinking about uncertainty is the set of Future Energy Scenarios (FES) developed by National Grid ESO. These are updated each year and are based on an extensive programme of stakeholder engagement to seek to bring in as wide a set of perspectives as possible. The scenarios look across gas and electricity, considering both the demand and supply side in the context of wider social and economic developments.

Although originally developed to help in decisions around generation capacity planning, they now form the bedrock of almost all planning and regulatory decision making. As set out below they are central to the NOA process but they are also used to inform projections in network company business plans as part of RIIO, including as the basis for Distribution FESs (DFESs) at a regional level, and are identified in Ofgem's Impact Assessment (IA) Framework as a tool to inform their own policy decisions.

Zachary et al could be read as being critical of the process of FES development which would be unfair. However, the very heavy reliance placed on the FES for a wide range of different decisions is inappropriate, for reasons discussed in section 3 below.

As noted above, the core role of the FES currently is its use to support the ESO in assessing the need for additional transmission network infrastructure to transport bulk energy across the country. Each year the ESO develops a set of FES scenarios followed by an Electricity Ten Year Statement and then a Network Options Assessment (NOA) in which it considers the various options for major infrastructure investment against the four FES scenarios.

In the NOA process the ESO uses a Least Worst Regrets (LWR) decision rule to identify which projects should proceed and which should be delayed or cancelled.

Even where a formal LWR calculation is not used (for example in RIIO) Ofgem regularly use the language of "low / no regrets" as reflecting the sorts of initiatives they wish to see brought forward.

There are a range of issues with the LWR methodology which Zachary et al highlight and which are explored in section 6 below.

The other tool that Ofgem uses itself and expects companies to use in justifying individual investments is conventional Cost-Benefit Analysis (CBA) using discounted cash-flows to calculate the Net Present Value (NPV). This is typically based on a central forecast, sometimes with sensitivity analysis to test the effect of varying assumptions. Ofgem's IA Framework for its own policy decisions reflects this CBA approach but the section that discusses risk and uncertainty is quite undeveloped and generic. The Framework includes a resources section at the end which includes a 2012 Ofgem consultation on real options assessment for gas interruptible contracts. However, that paper is not mentioned in the body of the document and there is no discussion of the real options concept.

In their latest Business Plan Guidance for the RIIO ED2 Price Control Ofgem have identified eight sets of assumptions (based on FES and the Climate Change Committee pathways to net zero) that it expects companies to test their plans against. In that Guidance Ofgem has started to use the language of investment proposals that are "robust" across the range of scenarios. As discussed below, this is the language that Zachary et al used and is a concept that is more aligned with the approach advocated in this paper than a focus on minimising regret. However, it is still not fully clear what level of analysis Ofgem expects the companies to produce as part of this assessment (and whether this number of scenarios is helpful or practical).

2. An updated toolkit - overview

In reflecting on what one would hope to see in an updated toolkit to deal with an uncertain net zero future, it is important to unpack the different stages in the decision-making process. This point was made by Zachary et al who positioned the (non-linear) stages as being sense-making and modelling, analysing and exploring, interpreting and implementing. This paper focusses similarly on three broad steps, which should be seen as part of an iterative process:

- **Exploring the uncertainty**. This is the role of scenario planning. However as set out below this has become formulaic rather than a creative process aimed at identifying risks to the proposed plan, which is how scenario planning began.

- **Developing options**. Although government and regulatory guidance always acknowledges its importance, this aspect is not often discussed in the literature where the focus is on the methodologies for choosing between options. Real option theory presents a way of thinking about options and in particular seeks to move away from a single decision to a sequence of choices. Adaptive pathways is a similar concept that is used around climate adaptation.

- **Evaluating options**. The aim here is to identify the preferred option given the range of potential futures. This is where the Least Worst Regret rule comes in currently in the NOA but where a broader concept of looking for "robust" decisions would arguably be more appropriate. In simpler cases a probabilistic CBA approach can be used. In all cases it is crucial that the methodology used takes account of the added value that comes from flexible options, as highlighted by real options theory, even if putting a precise number on that value is not practical.

As Zachary et al highlight, the role of judgment is crucially important to help in navigating through uncertainty which means that the models and process need to be transparent.

This is also important in terms of iterating through the steps to get to a better solution. If a particular option proves to be sub-optimal under a particular scenario, the question should be asked - is there anything that could be done to refine it to make it more workable (ie creating a new variant option)? If a particular option comes out well ahead one can ask what would need to happen for that option not to be such a good idea (ie testing for any additional scenarios that should be considered).

The question is then who is doing this analysis (between Ofgem and the company) and whether one needs to go through that process for all decisions (given the effort involved). While the regulator will need to be satisfied around the process to be followed it has to be for the companies to work through the risks and options. The challenge for the regulator is to ensure its own frameworks do not act as a barrier (eg by working on the basis of decisions being 'all or nothing' or by relying on CBA techniques that do not take account of uncertainty).

For decisions at distribution network level, which will typically involve a large number of small investments, working through all the steps for an example case may help in highlighting what really matters and allow a much simpler framework to be adopted for other similar decisions. In the words of Kay and King, in their book Radical Uncertainty, the key in managing uncertainty is to get a sense of "what's going on here". Ideally that should be a shared understanding between the regulator and the companies.

For complex whole system decisions such as those currently driven by the NOA it is accepted that there is a need for a sophisticated computational model to capture all the different elements. The University of Melbourne which carried out a review of NOA for the ESO looking at international experience concluded the NOA process was at the forefront of good practice both in terms of the extensive validation of different options and combinations of options that are tested for viability ahead of the LWR analysis and in terms of the LWR approach itself. However, they acknowledge that the process is "risk averse" in terms of investment which they argue is appropriate – but may be questionable in the face of net zero. They also acknowledge that the NOA methodology does not take into account the real option value of flexibility which they will consider further in a subsequent paper.

The sections below consider each of these steps in the process in turn, reflecting on both the approach to complex system choices such as the NOA but also the approach to wider decision making under uncertainty adopted by Ofgem in its own policy decisions and, importantly, in RIIO.

3. Exploring the uncertainty - Scenario Planning and sensitivities

In terms of capturing the range of uncertainties that need to be considered in reaching a decision, scenario planning is the obvious tool. However, the way that it is carried out can vary significantly and in the energy sector it is often taken as being synonymous with FES.

The way that the FES have developed – as a comprehensive and consistent set of "core" scenarios which can be used for modelling to support the NOA – takes them some way from the original concept of scenario planning as envisaged by RAND and Shell which was as a way to challenge conventional thinking.

Particular features of the FES are that:

- The scenarios are internally consistent and developed in considerable detail to allow the quantified modelling to be carried out;

- the detail behind the scenarios and the extensive analysis required to identify energy flows across all the boundary points over time means that it is only realistic to do this against a small number of scenarios. Melbourne University note that internationally for transmission planning no more than 5 scenarios are used because of the analytical effort involved;
- the detail focuses on the issues that matter to the modelling for electricity transmission (with eg less detail historically on gas demand);
- for the 2020 FES three of the four scenarios achieve net zero in 2050. While this reflects the imperative of meeting net zero it is not clear that this represents the full range of possible futures;
- however, the nature of the LWR mechanism means that the results are heavily influenced by any extreme scenarios and hence the FES scenarios adopted have to be plausible "core" scenarios. As an illustration, in 2016 Ofgem were critical of the impacts of including what they perceived then as an unduly optimistic scenario around de-carbonisation ("Gone Green") which led to what they described as spurious network investment being recommended.

The CCC scenarios are similar in that they paint an aggregate national picture but with detail by sector (looking beyond just energy) in order to allow calculation of the climate impacts. They are badged as pathways to net zero so again assume net zero by 2050.

In contrast, Wilkinson and Luber describe the Shell scenario planning process as looking more widely: "As unthreatening stories, scenarios enable Shell executives to open their minds to previously inconceivable or imperceptible developments."

To overcome some of these issues Zachary et al advocate having a number of core scenarios but then a set of wider, less fully developed more extreme scenarios against which to consider other risks.

Broadening this out to look at a wider set of decisions suggests the following principles around scenario planning:

a) Need to consider a wider range of risks

To properly understand the risks associated with particular strategies requires a wider set of scenarios to be developed at least in outline. Zachary et al's idea of testing more extreme uncertainties through high level sensitivity analysis (rather than full modelling runs) would seem a proportionate approach. The instructive part is the insight that the exercise provides.

The University of Melbourne suggest using weighted LWR for the NOA which would allow more extreme scenarios to be included with a low probability attached - but the analytical effort in considering a larger number of scenarios is still likely to be an issue.

For development of full RIIO business plans the analytical challenges of dealing with a wide number of scenarios will similarly be an issue. The idea of a limited number of modelling runs around core scenarios but with stress testing against more extreme scenarios would again seem to make sense.

For individual CBAs where the analytical constraints may not be so significant it should be easier to consider a wider range of risks and reliance on the FES scenarios in those cases feels unduly restrictive.

b) Scenarios need to be focussed on the question at hand

Building on the FES, the DNOs have developed Distribution FESs (DFESs) which look at the FES scenarios at a local level taking on board local stakeholder input. As noted above, Ofgem have asked for RIIO business plans to be developed against a set of assumptions drawn from the FES and the CCC pathways.

However, the uncertainties that matter most when thinking about national level power flows are not necessarily the same as those that determine the need for investment in the LV (low voltage) network.

Looking at FES 2020, for example, all four scenarios end up with around the same total number of EVs in the early 2040s – the difference is just one of pace in getting there. In terms of local network planning, one could therefore conclude that the risk of asset stranding is low – the reinforcement will be needed it is just a question of when.

However, if you explore with a DNO what determines the pace of reinforcement that is needed, the uncertainties are around how far EV ownership will tend to cluster in particular streets in the early years, the balance between at home and destination charging and the use made of smart charging.

To really think through the long-term implications for the local network you need to think more about the potential role of autonomous vehicles, the likely take-up of micro transport (electric scooters etc) and active transport as well as public transport more generally.

In contrast, understanding the risks around investment in the gas networks requires serious exploration of the potential futures for those networks – the geographical areas where hydrogen is more or less likely to be used for domestic heat and whether heat pump conversion could realistically be done street by street (and then the gas network de-commissioned) or whether the gas network will still be needed until the last customer is moved off sometime in the late 2040s. What role might hybrid heat pumps play? (In contrast the level of EV growth is largely irrelevant!).

In thinking about climate adaptation and investment to improve resilience, thought needs to be given to the handling of low probability, high impact events which Meyer and Kunreuther argue present particular challenges. In particular they argue that failings in how we think about such events results in a tendency for disaster preparedness efforts to consistently fall short of what is needed.

Thus, while the FES scenarios are a helpful set of central forecasts (eg for Ofgem benchmarking of business plans), to manage investment under uncertainty requires a specific focus on the risks that will have most impact on the question at hand and the uncertainties that impact that particular decision.

c) Need for creativity in thinking about scenarios / sensitivities

To identify those uncertainties impacting a particular decision it can be helpful to think in terms of regret – are there any worlds in which this option might turn out to be a bad idea? Or what would you most like to know in order to be confident in this decision?

For example, in ED1 while companies were expected to test their plans against all the FES scenarios, none of those scenarios envisaged the level of solar PV that subsequently materialised and caused real problems for some DNOs. It is very plausible that this could that have been anticipated with a slightly more open approach to thinking about uncertainty and what would cause DNOs most problems. This sort of approach will be familiar to the DNOs in terms of operational resilience planning and could helpfully be brought into investment decision making.

Wilkinson and Luber argue that “Scenarios have the power to engage and open the minds of decision makers so that they pay attention to novel, less comfortable, and weaker signals of change and prepare for discontinuity and surprise”. Practitioners at BCG offer tools for prompting this sort of creative process which they term “what if?” thinking.

This is also a reason for a strong emphasis on stakeholder engagement as part of the RIIO process. Engaging with stakeholders from different perspectives is one way to pick up early signs of trends or developments that could be material. Strong antennae and an open mind are important to pick up these weaker signals.

d) Recognise that the scenarios are not wholly exogenous

One of the challenges in energy system planning is the chicken and egg nature of some of the decisions. For example, Ofgem turned down proposals for transmission investment to Shetland because the windfarms had not got Contracts for Difference[2] (CFDs). However, the windfarms could not get CFDs because they did not have grid connections.

Taken at an aggregate level, the amount of generation assumed in the scenarios that are used will determine the level of network investment - which will in turn affect the generation that can connect. If you plan for low levels of renewables that is what you will get[3].

Similarly, on electricity distribution, the assumed take-up of EVs determines the allowed investment which will impact the rollout of charging infrastructure which will affect the take-up of EVs.

Ensuring that the core scenarios used are consistent with net zero is therefore important or one is planning to fail. However, the fact that the scenarios are not wholly exogenous is a dynamic that decision makers need to be conscience of. At present the scenarios are often presented as independent of the course of action taken, which they are not.

5) Developing a broader set of options – using real options thinking

Ofgem guidance on RIIO and its own IA Framework stress the importance of developing a range of options for meeting an objective. However, this tends to be seen in terms of different technical solutions. Thinking as well about the timing and sequencing of decisions and the benefits in keeping options open is an important dimension that is encapsulated in the idea of “real options”.

Real options thinking draws on the theory behind the valuation of financial (put and call) options, and in particular the fact that options have more value the greater the market volatility and the longer the duration of the option[4]. The idea of applying this to real projects has been around for some time, but in practice has not taken off, particularly in regulated sectors involving infrastructure investment, where one might have expected it to have significant benefit.

[2] A support mechanism for low carbon generation

[3] It is accepted that the opposite does not apply – building the network will not on its own ensure that generation comes forward

[4] http://people.stern.nyu.edu/adamodar/pdfiles/papers/realopt.pdf

As discussed below, even if it is not practical to carry out a formal real options assessment there are insights that come from real options thinking that help in identifying other choices that could be pursued over time – to abandon, delay, invest to learn or expand.

An article by McKinsey emphasises that this is about changing management thinking - thinking incrementally about how to shape projects to give yourself more options. Similarly, Triantis in reviewing the use of real options across sectors suggests that this thinking underpins many strategic planning approaches such as splitting up major investment programmes into stages or developing competing prototypes for new products. It is also akin to project management techniques that build in checkpoints throughout the project life and focus on the critical path activities.

Konstantelos and Strbac (2015), in looking at how to value electricity system flexibility, highlight that a multi-stage problem formulation is required to shift from "now-or-never" decisions to an integrated strategy that considers the value of delaying decisions until more information is known. This can also be characterised as moving from a "predict-then-act" approach to one of "monitor and adapt".

In electricity distribution Ofgem have placed a strong emphasis on the need for companies to consider flexibility as an alternative to conventional reinforcement. However, as Konstantelos and Strbac make clear, much of the value in flexibility comes from the option it provides to defer reinforcement until it is clearer whether the demand growth will materialise. As such the choice is not simply between conventional investment and flexibility but "flexibility with the option to then invest or not". In contrast conventional investment is irreversible.

For networks, thinking about the options they have in this way – and in particular about the next steps rather than the whole path – can prompt the development of other solutions. For example, in the debate around investment-ahead-of-need the question that needs to be answered is what the distribution network actually needs to do in advance to allow them to respond quickly to requests for new connections. This could, for example, simply be the acquisition of land for a new substation (which takes time but ultimately is not necessarily wasted investment if it can be resold).

This sort of thinking – also known as "adaptive pathways" or adaptive decision making (as discussed by Roelich) – is central to thinking about handling climate risks. The Thames Estuary 2100 Plan, looking at options for replacing the Thames Barrier in the face of significant uncertainty about climate impacts, includes as part of its plan the need to safeguard land which may be needed for future flood risk management purposes.

Alleman and Rappoport look explicitly at the use of real options assessment in regulatory decisions in telecommunications. They argue that one problem is that regulators (or public policy makers more generally) find some of the ideas in a real options approach uncomfortable. This is understandable. Abandoning a project can look like an admission that you got it wrong; similarly, delaying a decision while you learn/wait for more clarity can look like indecision or a failure to deliver. However, accommodating a much wider range of options that are not simply yes/no decisions is key to managing investment under uncertainty.

6) Evaluating Options – "Robust" decision making

Where detailed system modelling is involved as it is with the NOA, there is a need for some sort of computational approach to support decision making. There are differences of view as to whether LWR is an appropriate decision rule and in particular whether a risk averse approach to investment is appropriate in the face of a net zero challenge. Importantly whatever tool is adopted should be seen as a decision aid not a decision rule – helping decision-makers understand the tradeoffs, not simply treated as a black box. The concept of "robust decision making" is aimed at identifying options that perform well under all scenarios and involves both deliberation and analysis.

For individual investment decisions there is scope to make use of simpler and perhaps more intuitive approaches such as probabilistic CBAs.

More fundamentally, where flexible solutions are being considered, techniques are needed that take account of the real option value, which conventional discounted cashflow does not. Even where it is not practical to carry out a formal real options appraisal, the concept remains important and "light touch" approaches as advocated in Treasury Green Book Supplementary Guidance should be considered.

These various points are considered in more detail below, looking in turn at issues with LWR as a decision rule, whether regret is even a helpful concept, robust decision making as a decision aid not a decision rule, and assessing likelihood using Bayesian probabilities. The discussion then turns to real options as a way of valuing flexibility, how to value real options in practice, application to the energy sector, how a light touch approach is better than nothing and the importance of stakeholder engagement.

Issues with Least Worst Regret as a decision rule

The Least Worst Regret decision rule works by calculating the Net Present Value (NPV) of each proposal under each scenario. A measure of regret is then calculated for each proposal under each scenario which shows how much worse that proposal is than the best one in a particular scenario – ie how "wrong" would a decision to accept that proposal be. For each proposal one then identifies the scenario in which that decision would be most wrong ie where it has the greatest regret. The preferred option is then the proposal for which this "worst regret" measure is the lowest. This is effectively applying a "sod's law scenario" for each proposal (ie the worst scenario for that proposal) and looking for the proposal that is least bad in a sod's law world.

Zachary et al. are heavily critical of the LWR methodology commenting in one of the footnotes that such techniques "survive solely perhaps in that they allow simple exercises to be given to students in elementary OR courses!". They argue in particular that while one of the alleged benefits of LWR is that it does not require probabilities to be attached to different scenarios (which is often hard in practice or politically unacceptable) that it does not make sense to completely disregard any views that people have on relative likelihoods. They also stress that the choice of scenarios themselves is not an objective one.

Similar concerns were set out in a working paper by Frerk and Kenway which includes a worked example and notes that:

- the black-box nature of the LWR calculations as applied in the NOA makes open debate around the assumptions difficult;

- the inclusion of an additional option can change the preferred option (even where the additional option is not itself the preferred one[5]).

The University of Melbourne in their in-depth review of NOA look at a range of alternatives to LWR including weighted LWR (LWWR) and min-max cost. They describe the NOA as being at the "forefront of the state of the art" but they note that these alternative approaches to the final step of NOA (after the NPV has been calculated for all the relevant proposals under all scenarios) could be applied relatively easily. They illustrate how the different techniques produce different results based on the assumed probabilities of the different scenarios (noting that although LWR is always described as not requiring probability assessments it is implicitly assuming that all scenarios are equally likely). They argue for a unified framework which would present more transparently how different decision rules (with different probabilities attached to the scenarios) could lead to different results.

They also draw out that LWR is a risk averse methodology (ie aimed at minimising regret). They see this as appropriate in a regulatory process. However, it is not clear that this is right in the context of delivering net zero and it is important that the regulator both recognises and actively (and transparently) considers the level of risk aversion that they consider appropriate as this affects the choice of decision rule and hence the decisions that result.

Is regret even a helpful concept?

In its review of the NOA methodology in 2017, National Grid argued that the use of "regret" as a measure is supported by behavioural theory and the fact that it can be an important factor in individual decision making.

Frerk and Kenway argue that this does not mean it is an appropriate approach for a regulator to take. Arguably Ofgem's aim should be to deliver the maximum societal benefits on an expected returns basis while being very alert to situations where the preferred option may be significantly sub-optimal. Alternatively, Zachary et al. argue for "robust decision making" where robust decisions are ones that perform reasonably well across all scenarios.

The concept of "regret" is useful for understanding the risks in a particular option. However, the aim of the regulator should not simply be to minimise their own regret (even if one understands the desire of public bodies to want to avoid subsequent criticism).

One context in which this approach to risk is relevant is in considering environmental issues where the aim is to avoid catastrophic outcomes at all costs and where there is uncertainty about the science. As such the concept of regret has some similarities with the Precautionary Principle which is an established concept and under-pinned the case for action on climate change early on (in the 1992 Rio Declaration). Defra have recently highlighted it as one of the principles they will apply under the terms of new Environment Bill: "The precautionary principle states that where there are threats of serious or irreversible environmental damage, a lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

[5] This has been described as akin to going into a restaurant, reviewing the menu and choosing the salmon. The waiter then says he forgot to tell you about the special of the day – halibut. "Thank you", you say, "in that case I will have the beef".

Linked to this, a key factor that affects how far LWR is appropriate is whether all relevant considerations are built into the NPV calculation. This also applies to the focus on "no/low regret solutions" more generally. Society's biggest regret may be failing to hit net zero, noting that the full impacts remain uncertain if tipping points are hit with the melting of permafrost, for example. The question is whether these risks are properly reflected in the "regret" calculations or whether LWR (and the focus on low/no regret options generally) is essentially about minimising capital expenditure. In the NOA the inclusion of constraint payments in the calculations means that there is some cost attributed to under-investing but further work would be needed to determine whether it fully captures the externalities associated with climate change.

While policy makers are right to give the "green light" to obvious low / no regret options, they are unlikely to be enough to enable us to meet net zero. Some risks will need to be taken and unless the regret measure includes the wider climate impacts the framework will not help in charting an appropriate path.

In summary, regret is a helpful concept but minimising regret is not necessarily the right objective for a regulator. Moreover, if the concept of regret is to be used then it is clearly essential that the calculations take account of all relevant considerations. In particular the impacts of under-investment (whether on security of supply or achievement of net zero) have to be properly reflected in the NPV and hence the measure of regret.

Robust Decision Making – a decision aid not a decision rule

As noted above, Zachary et al. are very sceptical about LWR and advocate instead the idea of "robust decision making" as developed by Rand Corporation. Robust decision-making (RDM) is about identifying options that perform well under all scenarios. As noted above, this has some similarities with a "regret" approach as one is looking to avoid options that have a large regret (ie that perform particularly badly compared to others under some scenarios). However, it is not mechanistic in the way that LWR is.

Rather than using computer models and data to describe a best-estimate future, RDM runs models on hundreds to thousands of different sets of assumptions to describe how plans perform in a range of plausible futures. Analysts then use visualization and statistical analysis of the resulting large database of model runs to help decision-makers distinguish future conditions in which their plans will perform well from those in which they will perform poorly. This information can help decision-makers identify, evaluate, and choose robust strategies — ones that perform well over a wide range of futures and that better manage surprise.

RDM thus helps decision-makers address such questions as "What are the key characteristics that differentiate those futures in which a plan succeeds from those in which it fails?" and "What steps can be taken so a plan may succeed over a wider range of futures?".

RDM is clearly positioned as a decision aid rather than a decision rule and also enables the process to be more iterative. If an option is very poor in a particular scenario but strong in others the question can then become one of how to mitigate the downsides should the particular "negative" scenario unfold – rather than dismissing the option outright. As such RDM follows a "deliberation with analysis" process of decision support, as recommended by the U.S. National Research Council.

One refinement made to the NOA process a few years ago was the establishment of a NOA Committee (bringing together expertise from across the ESO, with the TOs in a supporting role) which considers the modelling outputs before a final decision is taken. Attention is focused on options where recommendations are driven by a single scenario or are considered sensitive. This helps move the NOA away from being purely a black box exercise and builds in elements of a "deliberation with analysis" approach - but could go further.

The NOA 2021 report included a visual representation of all the projects being considered, their earliest in-service dates (given construction lead times) and their required by dates under the 4 FES scenarios. From this it was easy to see which investments were needed by their earliest in-service date in all scenarios or where the investment could be significantly delayed under one particular scenario, for example. For most investments the proceed, delay or stop decision was clear simply from that graphic. For a small number of marginal cases where the conclusion was not clear cut and the result relied on LWR the basis for the decision remained opaque. This visual representation could be built on to support a more deliberative approach.

To be an effective decision aid it must be possible to explain why the model is generating the results that it is. This allows decision makers to gain fresh insights and to structure what may be complex decisions - and it also enables them to question the assumptions that underpin the model.

This can be a challenge where complex models are involved. Wilkinson and Krupers make the point that "large-scale quantitative models require considerable investment, which can lead to a kind of 'model lock-in'. Difficulty in changing basic assumptions, along with the natural authority of algorithmic calculations, can result in users' being blindsided by changes in the world that don't fit a model's parameters".

The RAND approach of carrying out large numbers of model runs may help show what is driving the model and may be necessary for looking at whole systems, but often a simpler model that captures the key drivers would be a better solution and should be practical when assessing individual investments, for example. As Triantis says, " theoretically accurate models are often poorly executed in practice because of their complexity, while simple models can often be quite effectively employed despite their lack of precision". It is better to be roughly right than precisely wrong.

In summary, the concept of robust decision making is a helpful one. The aim is to find robust options that hold up well across a range of scenarios, not to optimise on a measure of regret. This should not be a mechanistic exercise but a deliberative one in which the analysis is an aid to decision-making which is itself an iterative process. This links to the discussion on the role of judgment below and requires a different view on the role of models.

How likely is it? – using Bayesian probabilities

As Zachary et al argue, while techniques that avoid the need for probabilities to be applied to scenarios are appealing, it is wrong simply to proceed as if all outcomes are equally likely.

While it is not possible to determine precise probabilities for different future scenarios the use of Bayesian probabilities as articulated by Zachary et al provides some sense of relative likelihood against which decisions can be judged. Bayesian probabilities reflect expert judgment on likelihood rather than the frequency distribution of outcomes from repeat events.

Bayesian probabilities can be used either in a weighted LWR decision rule or as part of a deliberative approach aimed at identifying robust solutions. They can also be used for individual investments where the decision may depend essentially on a single unknown (eg the level of demand at a substation) – even if that is itself dependent on a range of factors around the take-up of low-carbon technologies and behaviour change, for example.

In this situation while the current approach would be to do a CBA on a central forecast (and perhaps some sensitivities) there is scope to carry out a probabilistic CBA (where the NPVs are weighted by the Bayesian probabilities).

SGN in their RIIO2 Business Plan[6] attempted to do this in relation to future investment in their gas distribution network applying a very rough 50-50 probability as to whether or not parts of the gas network would still be needed in 2040. While fairly crude it provided a framework for thinking about investments in the face of uncertainty and the risk of asset stranding. Ultimately Ofgem simply applied a payback cut-off of 16 years to investments on the gas network. Although a reasonable heuristic, the choice of cut-off did not have any theoretic underpinning and there clearly would be scope to apply a more sophisticated approach to the treatment of uncertainty around the future of the gas networks building on the SGN approach. There would be value in Ofgem starting to explore this well ahead of the next RIIO price control (GD3).

The use of sensitivity analysis around a central CBA forecast has some similarities with a scenario-based approach. If a decision is robust under various sensitivities then that is seen as positive. If it is not robust then one has to form a judgment - implicitly or explicitly - on the likelihood of the particular sensitivity materialising. Making those assumptions more explicit through a probabilistic CBA (and, if necessary, testing the impacts of different probabilities) would make the process more transparent.

Kay and King are sceptical about the use of such “subjective probabilities” other than in what they term “small world” settings. Their focus on radical uncertainty and the unknowable unknowns is an important counter perspective and certainly points to the need for caution in how such probabilities are used. As discussed below their value is in helping frame decisions which also draw on judgment.

In summary, while it may be hard to assign probabilities to different outcomes there is value in applying what insight there is on relative likelihood to help in reaching a robust decision and making trade-offs if required. Where possible, doing this through the use of subjective Bayesian probabilities adds transparency to the process.

Valuing flexibility – the nature of real option value

The other crucial element to build into assessments of investment under uncertainty is to properly value the real option value inherent in flexible or adaptive approaches (introduced in section 5 in the discussion on real option thinking).

Dixit and Pindyck (1994) provide an early introduction to the concept of real options. In particular they argue that traditional investment appraisal techniques such as CBA fail to take account of the

[6] https://www.sgnfuture.co.uk/wp-content/uploads/2019/12/SGN-RIIO-GD2-Business-Plan.pdf (page 148)

interplay of the irreversibility of investments, uncertainty and the ability to delay. By investing you are giving up an option to not invest if events unfold in an unfavourable direction[7].

Schachter and Mancarella present a literature review of real options theory and consider its practical application to energy. In particular they highlight:

- the value in having the flexibility over the project lifetime to actively adjust decisions based on future conditions;
- the value in having the flexibility to wait until at least some uncertainty is resolved before making an investment;
- the value in the ability to adapt to varying conditions by changing the system design of the project or investment.

They argue that traditional discounted cash flow (DCF) undervalues this flexibility by ignoring the irreversibility of capital investment and by effectively assuming passive management that cannot respond to changing circumstances.

Similarly, Giannelos et al. (2015) make clear that assessing potential investments using conventional CBA will mean that you are failing to take account of the option value inherent in, for example, demand side response and other forms of flexibility which allow a “wait and see” strategy to be adopted. This then means that such options are undervalued compared to conventional reinforcement when there is a high level of uncertainty.

How to value real options

As most commentators accept, a formal approach to real options assessment using a Black-Scholes methodology is unlikely to be practical given its reliance on the underlying probability distribution taking a particular form and the need for data to calibrate the distribution.

However, what the literature suggests is that, even if you do not carry out a formal assessment, there can be value in bringing the insights from real options analysis into the way that one thinks about investing under uncertainty. This can be either through the use of simplified decision trees (multi-stage stochastic frameworks) or simply the application of the insights that option theory provides.

The use of decision trees in this context was set out in the Ofgem consultation paper on real options (Ofgem 2012) and has also been demonstrated by Dixit and Pindych, Schachter et al (2016) and Strbac and colleagues (various). Decision trees provide a structure in which decisions are clearly sequential, with the probabilities of different outcomes varying through time and later decisions informed by what happens in the intervening periods.

Konstantelos et al. use this approach to demonstrate that investment in non-conventional assets can hold significant value due to the ability to keep future options open and defer commitments to costly reinforcements. In addition, it shows that deterministic planning approaches can systematically undervalue the benefit that such flexible assets can provide. For networks looking at making choices between reinforcement and flexibility solutions this sort of framework would seem to be essential.

[7] It might also be noted though that carbon emissions are irreversible and not investing may remove an option to avoid catastrophic levels

Even if it is too onerous to do this for each individual investment case, doing it for a sample of decisions can provide insights and decision rules that can then be applied more readily in future decisions. On behalf of the distribution network ENWL, Schachter et al explored alternative investment triggers developed through this sort of analysis as a way of determining when to invest in flexibility and when to upgrade the network. This can be seen as an evolution of conventional engineering capacity rules such as P2/6.

Triantis argues that for more use to be made of real options evaluation there is a need for more heuristics to be developed (that are benchmarked against fuller modelling).

Moreover, even if it cannot be quantified, the clear insight from real options theory is that having options has a value. In comparing proposals using more conventional decision tools one should at least be acknowledging that proposals that are better able to adapt to changes in circumstances should be preferred to ones that cannot. This is made clear in the HMT Green Book Supplementary Guidance on climate adaptation that says:

"When making a decision on which option to pursue, some value should be given to options that address uncertainty. This, for instance, may mean that policy options which can flex over time may become relatively more valuable. It may be possible to value such flexibility using quantitative measures as part of the benefits appraisal, but, at the least, the benefits of flexibility should be considered when choosing between final options."

It gives the example of two projects to build flood water storage units, A and B, which are almost identical except that A has an option to increase capacity if needed over time and B does not. Even if B appears to represent better value for money now, project A, given its flexibility, may still deliver better value for money over time depending on the duration of the project costs and timings and given future uncertainties. It then talks about the need to continue to monitor and adapt the approach after the decision is taken.

Real Options Value – application to the energy sector

In the energy sector the regulatory framework itself has to evolve to accommodate real option thinking. Schachter et al (2016) concluded "The case study results indicate that DSR can be an economical option to delay or even avoid large irreversible capacity investments, thus reducing overall costs for networks and end customers. However, in order for the value and benefits of DSR to be acknowledged, a change in the regulatory framework (currently based on deterministic analysis) that takes explicit account of uncertainty in planning, as suggested by our work, is required".

In particular they highlight that the RIIO ED1 CBA framework is a deterministic NPV based on a single scenario forecast. It therefore takes no account of either the uncertainty or management's ability to respond.

The challenge then for the regulator is how to take account of the real option value of flexibility in assessing investment proposals and when benchmarking costs across the networks. While Ofgem's assumption seems to be that flexibility will be cheaper than reinforcement this is not necessarily the case (over the life of the asset) and based on a real options approach it could be worth pursuing a flexibility solution to defer a decision on reinforcement even if it was ostensibly more expensive. Schachter et al gives an example where conventional reinforcement can be the preferred option under a central growth scenario in which reinforcement will be needed at some point. However, a decision tree approach shows that once account is taken of the ability to avoid investment if the growth does not materialise, the use of flexibility in the early years is clearly justified.

That said, in addition to considering cost, the issue of interruptions risk also needs to be considered since using interventions such as DSR while waiting for more information exposes the network to the risk of a rapid increase in demand, which it might not be possible to address due to lengthy construction times - and if all flexibility has been utilised that may no longer be a short-term option. Schachter et al suggest this can be taken into account either by setting a threshold for acceptable risk (an updated engineering standard in effect) or assigning an economic value to the risk of interruptions (in line with IIS penalties for example).

The multi-step decision process can also provide a way to think about the "touch the network once" concept which has been advocated for distribution networks. Putting in oversized cables can be viewed as an option to more readily upgrade (by adding additional electronics but without needing to dig up the road again). That means it can be worth doing even if future demand is uncertain. A decision tree approach could be a way of structuring this issue.

Even for larger transmission projects this real options thinking is relevant. Ofgem in its Final Determinations has recognised the importance of funding pre-construction work – the early steps in a project around planning, for example, that are relatively low cost but create the option for the project to then proceed on a timely basis. While not discussed in real options terms this is in effect an example of an investment that creates value by giving you options.

One question is whether this could be taken further with large transmission projects broken down into phases where perhaps the first leg of the project delivers some benefits but also opens the door to more significant benefits if the full scheme is justified in future. The question of how the project is able to adapt to changing circumstances is one that should always be asked.

At a systems level, the current NOA process is based on what is termed a single year view LWR. Although one of the outcomes can be a recommendation to delay projects the LWR approach does not take account of the option value of projects. National Grid in their 2017 Review of the NOA identified real options thinking as an area for future work. The University of Melbourne also acknowledge that more work is needed on how to take account of real option value, acknowledging that this allows a better quantification of the benefits of flexible investments. This work is reportedly in hand.

Light-touch is better than nothing

The Green Book Supplementary Guidance acknowledges that the use of formal appraisal methods for decision making under uncertainty may not always be practical or appropriate. It presents a helpful table of the "light touch" variants of conventional methods highlighting that much of the value is in the framing of the issues rather than the detailed calculations.

Table: Light-touch appraisal methods to address climate uncertainty

Appraisal under uncertainty method	Light-touch version
Real Options Analysis	• Apply decision-tree structures to think through a dynamic decision problem qualitatively

	• Trace out possible outcomes and decision points to help make dynamic choices
Robust Decision Making	• Apply concepts of robustness testing when assessing options • Limit uncertainty to particular aspects of climate uncertainty e.g. uncertainty from climate models • Consider options against uncertainty by using expert opinion e.g. through workshops with key stakeholders
Portfolio Analysis	• Consider a portfolio of options
Iterative Risk Management	• Focus on evaluation and learning when assessing longer term options

Source: HMT Green Book Supplementary Guidance (Adapted from Watkiss and Cimato (2016))

Engaging with stakeholders is more important than ever

The deliberative-analytic approach to decision making, of which robust decision making is an example, can also be extended to incorporate stakeholder input, to further help in navigating through uncertainty.

The University of California highlight the importance of participatory engagement as follows: "In general, simple problems with low uncertainties, no controversial value and clear consequences only require the involvement of decision-makers. In contrast, highly complex or ambiguous problems that involve normative values (e.g., human health, environmental protection, ethics) and/or where uncertainties cannot be reduced sufficiently should not be solved by decision-makers and technical experts alone, but should also consider stakeholders, Indigenous peoples and the public's concerns and perceived trade-offs". They term this participatory – analytic.

How to do this effectively so that the model helps inform the debate and is not simply a black box is a challenge. However, whether it is to inform decision makers or stakeholders the ability to explain the rationale for a proposed decision is clearly important both to facilitate engagement and for legitimacy of the overall process.

With increased uncertainty and more complex trade-offs the need for stakeholder input is of increasing importance. Finding ways to secure meaningful input with models framing but not usurping the debate should be the goal.

8 Conclusions for regulation

Applying judgment and the need for a new set of principles

From the discussion above it should be clear that this paper is advocating a less mechanistic approach to managing investment decisions under uncertainty.

Similarly, the Ofgem commissioned report by Zachary et al argues for the importance of judgment:

"It is our view that, especially in the context of long-term decision-making in which deep uncertainties are present, there is no simplistic or "automated" method of analysis for the management of these uncertainties so as to arrive at an optimal decision. (We are particularly concerned about the use of least worst regret analysis in this context.). Rather, as discussed in the rest of this report, judgments are required at many stages in the decision-making process". (Section 5.3)

In particular they see analysts serving decision makers but argue that decision makers have to apply judgment. On this basis, the aim of modelling should be to provide insight not answers.

This can be difficult for regulators where models can create a veneer of evidence-based decision making. Going forward regulators may need to take a different approach to what they see as acceptable levels of evidence to support investment cases. With increased uncertainty a mechanistic approach can no longer be relied on. Evidence is still important but the final decision will more often have to be one of judgment. While regulators may be used to this in forming policy (what impact will opening up a market have?) they seem to find it particularly hard when approving investments by companies where historically a high evidential burden has been applied.

This concept is also articulated by Kay and King who argue that "Sensible – adaptive – public policy and business strategy cannot be determined by quantitative assessments of policies and projects, made by an industry of professional modellers using probabilistic reasoning" (p17).

However, if judgment is increasingly to be relied on then the mindset of decision makers making those judgments needs to reflect the new world, not what they may have learned from their experience of the past. This requires a new set of principles or heuristics to inform that judgment. Examples drawing from the sources discussed in this paper would be to recognise for example:

- Resilience is important - Spare capacity isn't necessarily wasteful it contributes to resilience
- Agility is valuable – Options are to be preferred where they allow decisions to flex
- You may never get certainty – there is value in deferring decisions to get more information but at some point you may just have to jump.

Diversity of thought and wider perspectives are important at all stages in the process.

Conclusion

Recognising the uncertainty around the pathways to net zero, Ofgem has signalled a shift to more adaptive regulation. In large part this is about trying to move away from a five-year price control cycle, to take more decisions in period once better information is available. However there is a sense that these will still be treated as one-off yes/no decisions requiring the same level of evidence that has always been expected. Ofgem also originally proposed that if a price control deliverable (eg a major project) is ultimately not delivered in full then all the allowed revenue should be recouped. That is being reviewed and the detail worked through but it is clearly important that companies can flex their plans as the external context changes.

For electricity distribution, adaptive regulation is also expected to mean more reliance on volume drivers that capture the impacts of the key uncertainties on company costs. Again, the precise mechanics are being worked through but it is important that the drivers that are put in place (for example adjusting for capacity utilisation) do not discourage companies from taking a broader view of efficiency or from building option value into the way they structure their projects.

Bringing all this together adaptive regulation needs to not just be about when decisions are taken but how they are taken, in line with the framework above:

Understanding the uncertainties: While the FES presents a helpful set of well-developed core scenarios, there is a need to also think with an open-mind about what might be seen as more extreme scenarios. In particular there is a need for scenarios or sensitivities to focus on the particular question in hand.

Developing options: This needs to be an iterative process where the results of the analysis and thinking about scenarios help identify options that would be more robust. In particular real options thinking points to the need to identify approaches that can adapt to changing circumstances.

The decision framework: There are significant issues with the LWR decision rule which underpins the NOA and with the concept of minimising regret more generally. The aim should be to identify robust decisions that perform well under all scenarios. If the concept of regret is used then it is important that all considerations (eg the impacts on resilience or the ability to meet net zero) are captured – "low regret" should not simply mean low cost.

In looking to take account of a wider range of scenarios, it is important to be explicit about views on their relative likelihood, drawing on expert opinion. Account also needs to be taken of the value created through flexibility – which conventional discounted cashflow approaches undervalue. Decision trees which are used to assess multi-stage decisions can demonstrate the value in being able to adapt as events unfold. But even where this is not practical simply acknowledging the real option value in flexibility is important.

Increasingly then the decision process has to be one of deliberation informed by analysis – rather than applying a decision rule mechanistically. Decision makers will need to apply more judgment using the models to help structure decisions and provide insight. Stakeholder input becomes increasingly important in this context.

The approach advocated here is very much in line with that proposed by Zacahary et al. in their paper for Ofgem. However, that focussed primarily on the challenge of energy system planning and the NOA which is a computationally complex issue raising particular challenges around the relationship between analysts and decision-makers which that paper focussed on. This paper has broadened the thinking to consider also the individual investment decisions that form part of the RIIO process and where conventional CBA is no longer an adequate approach as it does not reflect the value in being able to adapt as events unfold. Strbac and Schachter et al. both provide worked examples to demonstrate the need for a multi-stage stochastic approach (decision trees) which takes account of the option value in order to properly value flexibility in the energy system. HMT's Supplementary Green Book Guidance gives a similar message about the value of solutions that can adapt.

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