Uncertainty, Regulation and the Pathways to Net Zero[1]

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Abstract

In this paper we focus on suggestions on how energy regulation needs to change in the light of the likely ongoing and possibly increasing uncertainty which the path to net zero involves. We argue that there are things that regulators can do in the circumstances (and that their governments could encourage them to do). We begin with a discussion of the uncertainty problem of regulation on the path to net zero. Next, we consider what regulation for net zero should focus on. We then move on to the role of regulation within the national governance system for the energy sector. After this we outline how best practice regulation should evolve in the light of both theory and experience. Theories of regulation suggest key roles for both learning and for trade-offs in regulation. We advocate for the development of a 'learning regulator' which simultaneously learns from the past (dynamic regulation), in the present (responsive regulation) and anticipates future learning points (adaptive regulation). While current best practice regulation involves the first two types of learning, the third remains a work in progress. Finally, we introduce some possible regulatory lessons from other sectors, namely water, autonomous vehicles and airports.

Keywords: uncertainty, energy regulation, net zero

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Introduction

In this paper we focus on suggestions on how energy regulation needs to change in the light of the likely ongoing and possibly increasing uncertainty which the path to net zero involves.

Net zero involves a significant challenge for conventional economic regulation of electricity and gas sectors. Many energy regulators already struggle with the conventional regulatory trilemma of keeping prices down, delivering adequate security of supply and minimising environmental impact. Add a hard target of delivering economy wide net zero by an exact date and the conventional energy trilemma either threatens an explosion of system costs and/or a substantial deterioration in quality of service. Even leading jurisdictions are beginning to experience the degree of the challenge they face. A good example being the recent abandonment of an interim 2030 target of a 75% reduction in total GHG emissions (on 1990 levels) by the Scottish government.[2] Net zero by 2050 (or even 2060 or 2070) must now be delivered in ever shorter time frames at ever faster rates.

If possible, economic regulation needs to rise to the challenge of net zero. In doing this, we argue that regulation will have to get better at learning by incorporating information from the past, the present and the future as it unfolds. It will have to do this in conditions where there is currently a large amount of uncertainty, some of which could be reduced by government policy but much of which will have to be lived with for the foreseeable future, until net zero is realised (or abandoned as a policy goal). Economic regulators are one part of the energy system governance landscape in any jurisdiction, and they can only play the hand that they have been dealt as well as possible.

We argue that there are things that regulators can do in the circumstances (and that their governments could encourage them to do). We begin with a discussion of the uncertainty problem of regulation on the path to net zero. Next, we consider what regulation for net zero should focus on. We then move on to the role of regulation within the national governance system for the energy sector. After this we outline how best practice regulation should evolve in the light of both theory and experience. Finally, we introduce some possible regulatory lessons from other sectors, namely water, autonomous vehicles and airports.

The paper makes use of information from a 2022 consultation process on the future of regulation from 2026 run by the Great Britain regulator, Ofgem[3]. While Great Britain is the jurisdiction we have in mind in discussing changes in regulatory practice, other

[2] 'Scottish government abandons flagship climate goal', *Politico*, 18 April 2024, https://www.politico.eu/article/scottish-government-abandons-flagship-climate-goal-mari-mcallan-says/#:~:text=LONDON%20—%20The%20Scottish%20government%20will,2030%2C%20compared%20to%201990%20levels

[3] https://www.ofgem.gov.uk/publications/open-letter-future-systems-and-network-regulation

leading jurisdictions (such as The Netherlands[4]) have run similar exercises considering how their regulation needs to change in the light of a policy commitment to net zero.

Uncertainties which regulators need to live with

By way of context for our discussion of regulation for net zero it is useful to consider the nature of the uncertainties with which regulators are currently living (and likely to continue to do so until at least 2050). We identify a non-exhaustive list of seven uncertainties in what follows below.

Uncertainty 1: Technological wishful thinking

Technological wishful thinking is a fact of life in any jurisdiction which has a policy commitment to net zero. There is a genuine hope that the energy system will follow one of the prescribed pathways to net zero, thus meeting the target at reasonable cost. The problem for the regulator is that, so far, these pathways have become shorter and increasingly challenging to deliver. A good example of this are the Future Energy Scenarios pathways from NG ESO, the electricity system operator, for Great Britain (GB). These are not predictions of the future, but they are meant to be authoritative and plausible routes to net zero. However, even these contain aspects of technological wishful thinking.

For example, the 2022 scenario contains four projections (out to 2035) of heat pump uptake to hit the government's near-term target of 800,000 p.a. One hits the target in 2024, one in 2028, one in 2035 and one does not hit the target by 2035[5]. Given annual installations of 200,000 in 2023, at least two of these projections look very unlikely. The same scenario has projections of annual hydrogen boiler installations which range from 0 installations to 2035, to 300,000 in 2028 and 1.2m in 2030[6].

Uncertainty 2: Technological surprises

Net zero targets are promoted by 'good' technological surprises and threatened by 'bad' technological surprises.

So far net zero has been substantially helped by positive surprises in onshore and offshore wind, solar PV and lithium-ion batteries. All of these have turned out to be cheaper than expected (so far). Offshore wind has benefited from economies of scale and the availability of large quantities of seabed on which it can be located. PV production costs and grid-parity have promoted a significant roll-out by prosumers.

However carbon capture and storage (CCS), nuclear power and hydrogen from electrolysis and synthetic fuels (from hydrogen) have not shown significant enough cost reductions to encourage their uptake at the scale that would be necessary to get to net

[4] See DNV (2023).
[5] NG ESO Future Energy Scenarios, 2022, p.84.
[6] NG ESO Future Energy Scenarios, 2022, p.85.

zero (see Pollitt and Chyong, 2021; Chyong et al., 2021).[7] Their underperformance threatens current net zero targets to the extent that it currently limits their expansion at scale.

Meanwhile other technologies remain wildcards in the sense that net zero modelling tends not to rely on them, but if they did occur, they could be potentially significant for the energy system. These include nuclear fusion[8], where there have been some encouraging technological breakthroughs recently. Artificial Intelligence (AI) might have the potential to massively increase overall electricity demand or to reduce energy consumption by better use of electrical devices or the design of new technologies that would make the achievement of net zero easier.[9]

Uncertainty 3: Gas vs Electricity Policy

In jurisdictions where both gas and electricity networks are significant, there is significant uncertainty as to the nature of the decarbonisation of current gas demand. The range of potential outcomes under plausible pathways for individual networks is large. A good example of this is in Great Britain where currently around 85% of homes are heated with natural gas.

According to NG ESO, GB electricity networks deliver 70% more by 2050 (relative to 2021) in the least ambitious scenario and 100% more by 2050 in the most ambitious scenario[10]; while interconnectors deliver net exports which vary by a factor of 2.8.[11] Methane networks deliver c.35% less by 2050 in the most optimistic (for methane, not net zero) scenario and 97% less in the least. This is the difference between a significant network, still bigger than all but one in Europe are now, and near complete shutdown of the current methane network. Hydrogen networks deliver almost nothing by 2050 in the least optimistic scenario and almost half of current methane demand (over 400 TWh) in the most optimistic scenario.[12] High hydrogen demand will also be associated with large amounts of electrolyser capacity.[13] A similar scenario could be identified for a CO2 network, arising from the capture of CO2 (CCS) from steam reformation of methane (to make blue hydrogen), bioenergy with CCS (to gain negative emissions) or conventional fossil fuel with CCS power production (Pollitt and Chyong, 2021).

Thus, while final electricity demand is up in all decarbonisation scenarios, gross electricity demand, electrolyser capacity, hydrogen and methane demand are subject to extreme uncertainty in terms of their role in net zero and the timing of any take-off.

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[7] Hydro dam costs are also high (see Simshauser and Gohdes, 2024) and demand side management flexibility remains a perennial under-performer relative to its theoretical potential (see D'Ettorre et al., 2022).
[8] 'Nuclear Fusion Breakthroughs Bring Near-Limitless Energy Closer', *Newsweek,* 30 April 2024, https://www.newsweek.com/near-limitless-fusion-energy-closer-nuclear-breakthrough-1895556
[9] See Luers et al. (2024).
[10] Table EC.02, National Grid ESO, *Future Energy Scenarios*, 2022, Data file.
[11] National Grid ESO, 2022, p. 220.
[12] National Grid ESO, 2022, p. 215.
[13] National Grid ESO, 2022, p. 11.

Uncertainty 4: The size of the (energy) economy

Net zero is an absolute target for reducing GHGs. This means that anything which affects the absolute size of the jurisdictions underlying demand for energy services is potentially problematic for the regulation of the energy system to achieve net zero. Changes in economic size and productivity are significant and, in many countries, subject to a great deal of uncertainty.

The table below illustrates how this might work for the UK over the course of the 2050 pathway to net zero. Looking at population growth and dynamics, there have been significant changes within the space of eight years (this covers the Brexit vote in 2016 to leave the European Union). A moving final absolute target for the uptake of low carbon technologies is potentially problematic for a regulator. Slower population growth and slower productivity growth might be associated with a lower absolute decarbonisation target, but also means greater financing constraints and less capacity to build new assets. By contrast, faster population growth and faster productivity growth raise underlying energy demand and the absolute size of investments required to decarbonise the economy.

	2022	**2042**	**2042**	**Relative Difference**
	(est)	(2012 est)	(2020 est)	2020 vs 2012 estimates
Population	67.6m	74.7m	70.6m	*5% lower*
Average Fertility	1.56	1.89	1.59	*16% lower*
Life expectancy male	79	84	82.2	*2% lower*
		(2036/7)	(2045)	
Life expectancy female	82.9	87.3	85.3	*2% lower*
		(2036/7)	(2045)	
Net migration	c.435k	200k p.a.	205k p.a.	*3% higher*
Productivity	1	1.15	1.06	*9% lower*
(per hour worked)		0.7% p.a.	0.27% p.a.	
		France est.	UK est.	

Table 1: Future Uncertainty in the UK Economy[14]

Uncertainty 5: The impact of extreme weather and climate change

Climate change is happening now and affects energy system supply and demand on route to net zero. Energy assets are vulnerable to climate change arising from

[14] Sources: ONS National Population Projections 2020 - based interim;
ONS National Population Projections 2012 – based Reference Volume Series PP2; ONS Long-term international migration provisional, year ending June 2022; https://www.niesr.ac.uk/blog/why-uk-productivity-low-and-how-can-it-improve

heatwaves, coldwaves, droughts, wildfires, floods and windstorms. Storms damage power lines and reduce wind power output (to protect the turbines). Extreme heat also reduces water for cooling – this recently happened with French nuclear power plants. Climate change may disrupt weather patterns. For instance, potentially leading to less wind in some places (wind speeds are falling across the UK). Higher and more variable temperatures effect demand for heating and cooling and increase the peakiness of demand. All of this has the capacity to add to system cost as and when it becomes manifest.

An increase in the frequency of extreme-weather events is expected to lead to more frequent damage to power supply infrastructure, raising the value of expected annual damage to asset operators and insurers (Forzieri et al., 2018). Increasing costs to the economy in real time potentially reduces the willingness and capacity to concentrate on climate mitigation expenditures relative to climate adaptation expenditures.

Uncertainty 6: The impact of war(s) and net zero

The world is currently a very uncertain place with respect to the nature of the economy we will face on the path to net zero. Between 2021 and 2023 Europe experienced the biggest spike in electricity and heating fuel prices in recorded history[15] exacerbated by the Russia-Ukraine war, this was following the disruption of the COVID19 pandemic which itself delayed a lot of renewable investment projects. The price effects of the war were experienced globally in record Asian LNG prices[16]. The impact of globally significant events on the energy system has the capacity to disrupt the path to net zero.

The European energy crisis put energy security back as a key issue within the energy trilemma, followed by energy prices. It highlighted the fact that events pose risks for energy technologies when they lead to their reappraisal and institute a change of direction. Natural gas was the first globally traded 'clean' fuel, which promoted European decarbonisation. The crisis was, probably, positive for promoting decarbonisation in Europe by encouraging the use of domestically generated energy from renewables. However, a future crisis might not do this: it might lead to withdrawals from international energy markets and/or pressure to burn more fossil fuels where these are available and cheap. Regulators will need to deal with this.

Uncertainty 7: Geo-politics and climate policy

Finally, the geopolitics of climate change (even absenting war impacts) remains highly uncertain, with uncertain impacts for individual jurisdictions. Goldthau et al. (2019, p.30) outline four potential climate policy scenarios for the world. First, the *Big Green Deal*, where the world completes a successful transition from fossil fuels to renewables by 2100. Thus, the UN Conference of the Parties (COP) process is successful. Second, *Technological Breakthrough*, here the world has a largely successful transition towards a substantially decarbonised energy system based on technological breakthroughs in

[15] See Pollitt et al. (2024b).

[16] See https://fred.stlouisfed.org/series/PNGASJPUSDM

low carbon technologies. Residual fossil fuels remain but are limited. Third, *Dirty Nationalism*, where fossil fuels continue at a high level and renewables only succeed in stopping them growing. Fourth, *Muddling On*, here fossil fuels begin a gentle decline but are still significant by 2100 and the prospect of a completely decarbonised world economy is still some way off.

At the moment we seem to be somewhere between Muddling On and Dirty Nationalism. Both of these scenarios leave climate policy, even in jurisdictions committed to net zero (and predisposed to Muddle On regardless of what is happening globally) vulnerable to policy reversion and under scrutiny as to whether climate policies are really in the interests of domestic citizens. We have also learned that Dirty Nationalism is not just about the willingness to use domestic fossil fuels, but about the willingness to use critical minerals and industrial policy as an economic (and military) weapon regardless of the impact of doing this in reducing the prospective of a worldwide decarbonisation[17].

Economic Regulation of Energy Under Net Zero

In the light of the uncertainties that we have just outlined what does a Net Zero policy target mean for an economic energy regulator?

Net zero requires a massive change in most existing energy systems and policy support, which cannot be delivered by regulators alone. Indeed, regulators need to stand ready to change if necessary if societal preferences and hence policy changes. We discuss what net zero involves, what it means for economic regulation and what should regulators do along the way.

What does net zero involve?

Net zero is currently uncertain as to how exactly it will be achieved. However, modelling strongly suggests that a net zero that adds up will have certain features (see Pollitt and Chyong, 2021; Banet et al., 2021). These features will favour particular types of regulation.

Features of net zero include: lower energy consumption compared to business as usual; an increase in final electricity demand driven by electrification; in addition electricity will also be used to produce hydrogen and synthetic fuel; more variable renewable electricity (VRE) and hence more investment in electricity grids and electricity storage to support this; decarbonisation of fossil fuel heating via some combination of electrification, hydrogen, biomethane and synthetic fuel; and decarbonisation of transport via some combination of electrification, hydrogen and synthetic fuel.

The backdrop to this transformation in the use of energy will likely include: substantially higher carbon prices than now; more interjurisdictional and international trade in

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[17] See Lewis (2024).

electricity (not just in Europe and North America); and negative emissions required via bioenergy with carbon capture and storage.

Higher 'average' marginal unit energy and carbon prices seem the inevitable consequence of currently modelled net zero policy. Marginal prices may be cheap at certain times of the day or the year but an energy system which is based on renewables will be capital intensive and require high system peak energy prices.

What does net zero mean for economic regulation?

This implies that regulators will be under pressure to allow (and regulate) the use of more pricing and/or control in electricity to match supply and demand in real time. There will be increased value in locational price and/or control signals around energy networks that can help manage local congestion issues and match local supply and demand in real time.[18] The public acceptability of net zero solutions will be particularly challenging in heating. In transport smart charging and its pricing will be important, with regulators under pressure to facilitate public charging which will remain expensive relative to home charging, in an environment where richer consumers will be making disproportionate use of public charging infrastructure.

Rising unit prices and increasingly differential impacts of net zero policy on individual households will likely bring in more taxpayer (or general energy levy) funded energy infrastructure and regulators will be expected to interact with local and regional governments over their energy policies.

Net zero is about the assertion of true economic efficiency with suitable attention to fairness. It is about reflecting the carbon externality in the energy system and hence it is firmly an exercise in economic regulation of the economy. As such, economic regulators need to continue to advocate for the appropriate use of prices, incentives and high-quality institutional arrangements and be alert to distributional impacts, market power and vested interest arguments based on partial data and suspect modelling.

For developing countries, below full economic cost prices for fossil fuel prices continues to be a curse in many economies with often the rich disproportionately benefitting from access to limited quantities of subsidised energy, while the poor suffer from unreliable or expensive energy and the environmental consequences of excessive fossil fuel use.[19]

Net zero makes 'good' economics more important not less. If net zero targets were cheap to achieve, willingness (and ability) to pay would cover up marginally inefficient costs and negative distributional effects. However net zero policy will be expensive (at the margin and in terms of the unit cost of energy) and therefore only attention to

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[18] See Pollitt (2021) on two possible future designs of the electricity system using either price or automated control to match supply and demand at every node.
[19] On general impacts of fossil fuel subsidies see Couharde and Mouhoud (2020). On the health impacts see Solarin (2022).

economic cost and equity will facilitate it, especially the closer a large jurisdiction gets to achieving it[20]. As countries progress toward net zero, the pathway to net zero becomes more not less important. Thus, there needs to be scope for learning, encouragement to behavioural change and carefully planned discrete transitions (e.g. switching off a natural gas network). Co-benefits will become more important to justify costs and so wider economic assessments of benefits (and costs) important, such as the inclusion of the valuation of local health impacts.[21] Trusted analysis, such as that undertaken by an independent energy regulator, will be at a premium given the need to convince citizens, politicians, companies and other stakeholders to go along with policies which are fundamental driven by the need to meet a net zero target.[22]

What should economic regulators do on the path to net zero?

The above suggests the continuing importance of the sort of economic analysis at the heart of economic regulation of utilities: efficiency analysis and the design of regulatory incentives; economic assessment of the valuation of innovation expenditures; analysis of gaming behaviour in the face of big energy data; monitoring of market power in the face of increased scarcity pricing; analysis of distributional impacts of price changes; social cost benefit analysis of actual and proposed policies; discrete choice analysis and randomized control trials on consumer behaviour; analysis of weather and climate impacts on the energy system; and economic stress testing of the energy system.

It is important for the economic regulation of energy to stay focussed on the things that the regulation has always done.[23] The primary of these is the monitoring and regulation of both average prices and price structures in order to limit excess profits and achieve societal goals around fairness, such as supporting social tariffs. A second is the delivery of energy with sufficient levels of security of supply and the enforcement of penalties for failure to meet pre-agreed target levels of performance. A third has been the meeting of certain local and national environmental targets and constraints, such as minimising the visual impact of energy infrastructure in certain protected areas.

Net zero policy puts increased pressure on each of these basic areas of responsibility of the regulator by pushing up average costs and raising distributional concerns by potentially favouring richer consumers who can better respond to incentives for flexibility, promoting use of intermittent (and hence less reliable) energy sources and by requiring the building of more infrastructure.

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[20] As discussed in Banet et al. (2021).

[21] See Karlsson et al. (2020) who list: improvements in air, soil and water quality; better diet and increased physical activity; increased biodiversity and energy security; and higher economic growth as co-benefits identified in the literature.

[22] Support for net zero policies is higher when the decision makers involved are trusted by the public (see Perlaviciute et al., 2021).

[23] The OECD (2017, p.17) describe the role of economic regulators as follows: ‘Economic regulators seek to address market failures and promote competition where possible. To address these market failures, Economic regulators generally seek to put in place arrangements to facilitate competition where possible, or alternatively seek to address the market failure by making decisions on price and non-price terms for the services provided by the regulated businesses.’

In short, the 'day job' of being of being a regulator continues and gets more salient under net zero.

The changes that net zero policies introduce also heighten the regulator's role: in consumer protection from mis-selling of particular tariffs and energy equipment and from cyber-attack and data loss; in consumer protection from bankruptcy costs due to service provider failure in an environment where energy service providers also face policy uncertainty and; in the promotion of both innovation and competition in the supply chain, as well as the final retail market.

Governance and Institutions: Regulators in Context

Net zero is an enormously ambitious policy for a country to deliver. It is important to draw attention to the wider institutional environment in which the energy regulator sits. The regulator plays a key role within this. It important that statutory duties are divided up clearly and that institutional change, both in terms of appropriate new entities and/or reallocation of existing roles, is considered where this may be necessary. Given the scale of the challenge of national decarbonisation, it would be surprising if no institutional change was necessary to achieve it.

The regulator and its counterparties

An example of an institutional arrangement, arrived at to help deliver net zero, is given in Figure 1. This reflects the emerging arrangements in the economic regulation of the electricity and gas sectors in Great Britain.

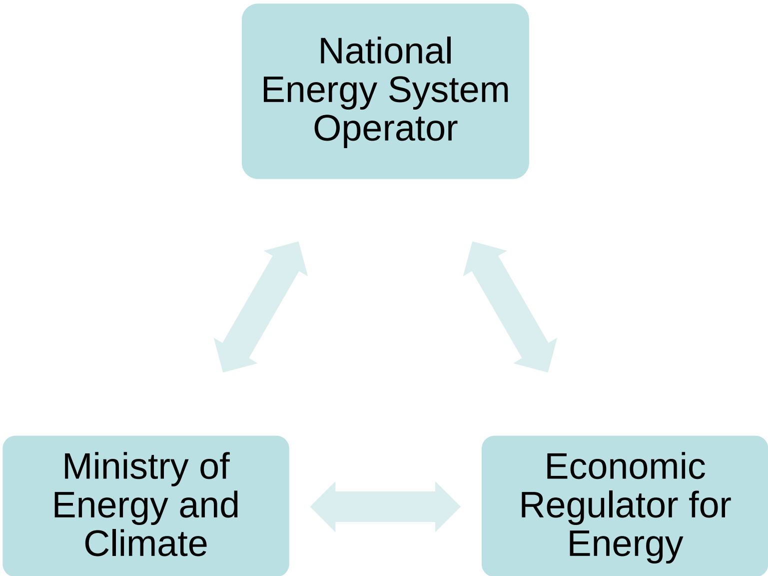

Figure 1: A National Governance Triangle in Energy

The *National Energy System Operator* (NESO) is responsible for real time monitoring and system regulation (in electricity) and expert planning and assessment of electricity and gas (both methane and hydrogen) systems.[24] The *Ministry of Energy and Climate*

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[24] https://www.nationalgrideso.com/what-we-do/becoming-national-energy-system-operator-neso

(currently DESNZ)[25] is responsible for legislation, big distributional decisions and offering political leadership. The *Economic Regulator for Energy* (Ofgem)[26] is responsible for balancing consumer and producer interests, monitoring NESO and keeping politicians honest. This arrangement is currently (July 2024) being formalised by the creation of a state-owned company (NESO) to replace certain system operator functions of the privately owned National Grid, to solve conflicts of interest arising from private ownership and to provide impartial advice on the evolution of the entire system. At the same time Ofgem has recently been given a statutory responsibility to support the Government in achieving net zero by 2050.[27]

The regulator has been heavily involved in the process of creating NESO in order to facilitate the will of the Ministry and to create a trusted third party with whom it can interact and who can undertake planning functions that it cannot.[28] An important consideration in the evolution of such an arrangement is whether the solution of conflicts of interest justify the costs of separation plus any ongoing additional costs? The costs of the separation of NESO from National Grid are material, as is any forced separation within the energy system.[29] A cost benefit analysis[30] should examine the impact on: competition; operating, materials and capital costs; and on security of supply.

The GB example illustrates that net zero raises issues of the interaction between ownership, regulation and market structure. These are in a dynamic tension where the 'optimal' (in terms of social welfare) mix is context dependent. It was successfully argued that arrangements which have worked for decades are due for a change (after 34 years in the case of GB). In that time the context has changed with respect to: the heightened level of concern about climate change; the increasingly technical nature of regulation; falling public support for fully private arrangements in system operation; increased distributional concerns, and; heightened attention to perceived conflicts of interest.

The hope with NESO is that it will be a more pro-active and trusted vehicle to guide the evolution of the electricity and gas systems to net zero. It will be able to run procurement auctions for network and non-network solutions to the provision of transmission and distribution capacity, while taking an integrated view about electricity and gas. It is however important to point out that no matter how good the link between NESO and Ofgem, the links with the government Ministry remain critical, especially when it comes to expensive decisions that require political support. NESO can be net zero enabling but is not a game changer by itself for a policy that requires large levels of fiscal support.

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[25] https://www.gov.uk/government/organisations/department-for-energy-security-and-net-zero
[26] www.ofgem.gov.uk
[27] UK Energy Act 2023: https://www.legislation.gov.uk/ukpga/2023/52/enacted
[28] See Ofgem (2021).
[29] For a discussion of the pros and cons of forced vertical separation in the energy sector see Pollitt (2008) on transmission and Nillesen and Pollitt (2019) on distribution.
[30] See Strbac et al. (2014, p.309), for a discussion of cost benefit analysis (CBA) of the creation of separate system operator.

Potential asset reorganisations to facilitate net zero

GB has also considered other net zero enabling institutional changes.

Helm (2017) suggested a set of Regional System Operators (RSOs) for electricity which would separate distribution assets from the system operator at the distribution level. This would create a sort of Independent Distribution System Operator (IDSO). This is still under consideration as a way to better facilitate decarbonisation of lower voltage and pressure energy networks at the sub-national level. The case for this is less clear than for NESO, which draws on the experience of US ISOs and RTOs[31]. In the meantime, the leading GB electricity distribution company, UKPN (which includes London), have created their own version of an IDSO (UKPN DSO), putting their system operation function in a separate business, with separate governance.[32]

The Labour Party (2019) proposed to take back into public ownership all electricity and gas networks, both transmission and distribution under the slogan 'Bringing Energy Home'. The proposal aimed to: 'Provide better value', 'Accelerate and coordinate investments', 'Provide democratic control' and 'Ensure decentralisation occurs equitably'. It highlighted weak regulation of networks and rejected just nationalising the system operator, as is now occurring. One very interesting aspect of this policy was the idea that gas and electricity distribution network companies would be merged and reorganised on the areas of the current electricity distribution networks to facilitate better coordination of decarbonisation policy. This would have replaced the current separate non-contiguous ownership of electricity and gas distribution networks.

The above examples illustrate that ownership and regulation potentially trade-off and that public ownership and asset reorganisation may be a part of delivering net zero. Europe, North America and Australia have latterly pursued a 'separate and regulate' model for their energy networks, consistent with privately owned profit motivated network companies.[33]

A major barrier to effective regulation globally remains the disparate nature of ownership of many electricity and gas networks. Many networks are small and lacking in the resources to respond effectively to challenges of net zero especially where these involve learning from best practice elsewhere or costly coordination with external stakeholders. Smaller gas networks in particular, faced with extreme policy uncertainty as to their future, currently look particularly ill-equipped to plan effectively for net zero.[34]

While healthy competition between public and private ownership may have a role in advanced countries, it is important to note that pervasive public ownership of networks

[31] As suggested in Pollitt (2012).
[32] https://dso.ukpowernetworks.co.uk
[33] See Kufeoglu et al. (2018) for a review of the diverse global ownership arrangements in electricity distribution networks.
[34] See Pollitt et al. (2024a).

continues in many countries, with weak regulation and poor attention to economic cost recovery.

In sum, it would be odd if net zero did not require ownership reorganisations, given the scale of the challenge. The reorganization of ownership, especially of gas and electricity assets, to achieve net zero remains a potentially viable alternative to regulatory solutions, especially in jurisdictions with no experience of effective independent regulation. In privately owned systems some of this might be motivated by higher shareholder returns from collecting assets in a way that better delivers net zero, but in many systems this will require supporting legislation.

The future of regulation: Beyond RIIO?

The RIIO model in Great Britain is widely considered a best practice approach to incentive regulation of networks.[35] It is an ex-ante model of regulating network revenue (R) while giving incentives (I) to both innovate (I) and achieve a range of energy and non-energy outputs (O). The model was formulated in 2010 and introduced formally in price controls from 2013.

In September 2022, Ofgem, the Great Britain energy regulator, issued an open letter on future of the price controls which explicitly asks the question should RIIO continue for price controls from 2026.[36] The context is a discussion whether Great Britain's regulatory regime for networks based on RIIO remains fit for purpose, in the light of net zero. Ofgem raised the following questions, inter alia:

1. Should there be a continued use of a periodic price control?
2. Is there an alternative to the current ex ante price control regime?
3. Is there scope for greater stakeholder participation in the regulation of networks?
4. Is it possible to have an ex post regulatory regime?

The reason to ask these questions is because net zero heightens existing regulatory trilemmas.

Net zero and regulatory trilemmas

The wider literature on regulation discusses a regulatory trilemma of effectiveness, responsiveness and coherence (Parker and Braithwaite, 2005; Teubner, 1986).

Effectiveness assesses the extent to which the regulated entities comply with the regulation, looking at the cost of compliance, creative adaptation, and loopholes.

Responsiveness is the ability of regulation to maintain desirable social practices that form the core of the regulated activity's functioning and contribution to welfare. Overly effective regulation can discourage positive self-regulation, incentive led market behaviour and co-regulation revealing private information.

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[35] See Girouard (2019) and IEA (2023) for positive assessments of RIIO.

[36] https://www.ofgem.gov.uk/publications/open-letter-future-systems-and-network-regulation

Coherence is a desirable regulatory principle. By paying too much heed to current and different social norms and behaviours, one may reduce the consistency and predictability of the regulatory regime, failing at upholding some of the most relevant principles of regulation, such as equal treatment and fairness.

Applying this first trilemma to economic regulation, we can speak of a similar energy regulatory trilemma – ensuring a balance between *coordination*, *motivation* (i.e. incentivization) and *transaction costs* (Eskesen, 2021). A regulator with a social focus will pursue all three objectives but will face trade-offs. Moving closer to one objective means moving away from at least one of the other two. For example, coordinating and linking the preferences of customers and stakeholders and the capabilities of network companies is highly desirable – being the reasoning behind negotiated regulatory settlements – but will come at the expense of higher transaction costs of regulation. Similarly increasing the length of regulatory periods may improve motivation but also increases the transaction costs of regulatory interventions; shorter regulatory periods may increase coordination but reduce motivation for network companies to take a long-term view. The trilemmas are illustrated in Figure 2.

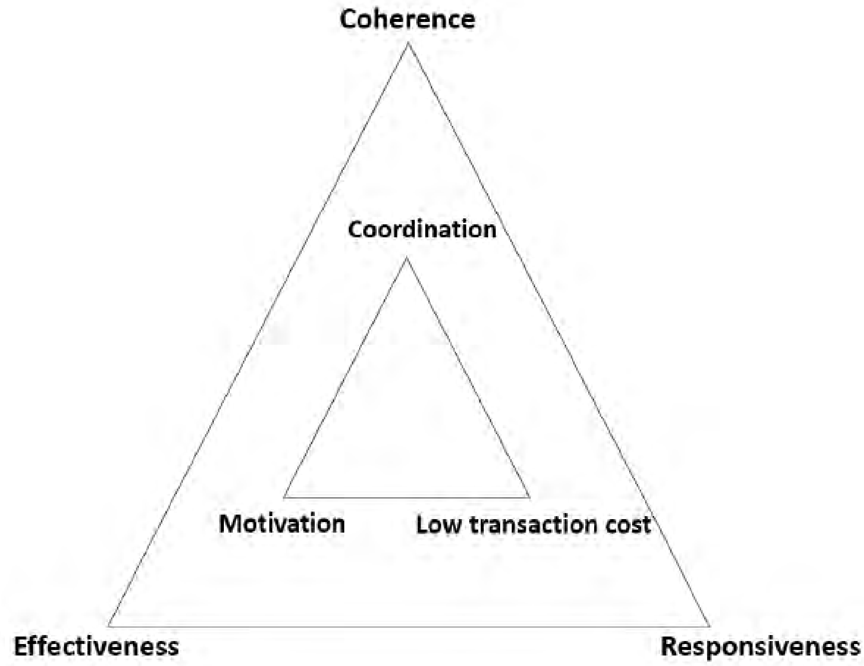

Figure 2: Regulatory Trilemmas

Net zero puts pressure on existing regulatory arrangements and sharpens the above trade-offs. As investment requirements become larger and more uncertain as to their exact timing, price control processes (such as RIIO) must accommodate a greater level of uncertainty and more over- (or under-) investment will have to be tolerated. The credibility of ex-ante controls can be undermined by the frequent use of reopeners which are needed to adapt to changing circumstances. The risks associated with ex-post rulings may translate into a higher cost of capital demanded by investors. As decentralization and democratisation of the energy system continues, more numerous and diverse stakeholders may emerge, but the cost of managing them rises if the regulator is to ensure that they are informed enough to make choices on complex issues.

Innovation may become more consequential but also more difficult to manage. For instance, the temptation to reward only the innovator that is successful will discourage future innovation, while too much regulatory support for innovation expenditure may be wasteful. This suggests regulatory trade-offs between coordination, motivation and transaction costs will only heighten.

How can the regulator respond to heightened regulatory trilemmas?

Drawing on the literature on regulation we suggest the need for a 'learning regulator'. This learning regulator exhibits the capacity to learn from past information, from real time stakeholder engagement and incorporates future learning points into regulatory planning. The regulatory concepts we draw on are dynamic, responsive and adaptive regulation (see Figure 3).

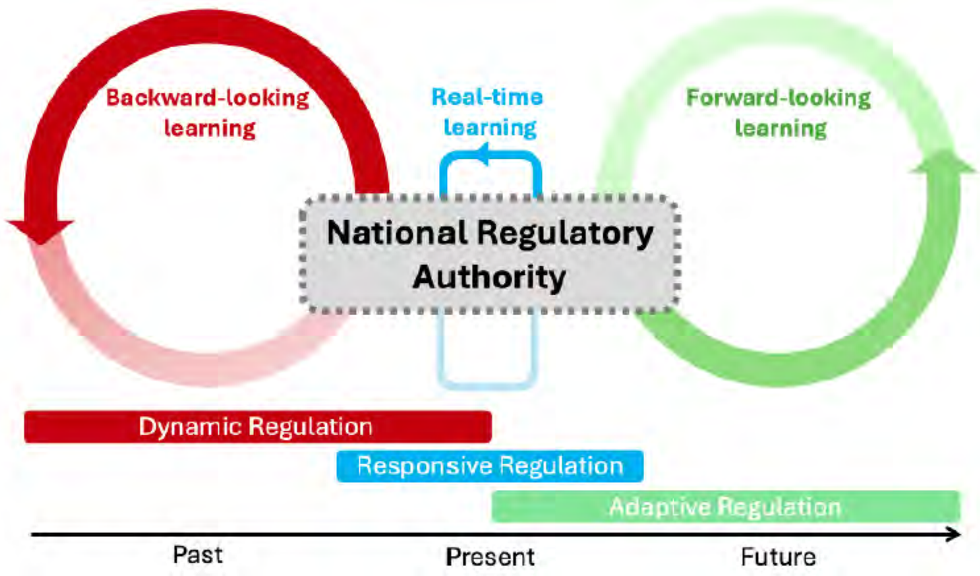

Figure 3: The Learning Regulator

Dynamic regulation is defined by two features. First, it is regulation that efficiently incorporates information gathered through repeated interactions – i.e. over previous regulatory cycles (Agrell and Bogetoft, 2003). Second, it is regulation that focuses more on incentives for investment and innovation for meeting future needs of the system than on optimizing the existing system (Bauer and Bohlin, 2008). Both are based on setting incentives based on what we know from past information.

Responsive regulation moves away from the exclusive use of reward and punishment as determinants of behaviour and encourages stakeholder participation and the perpetuation of positive social norms around the regulated activity. Responsive regulation is an approach that attempts to find a middle ground between two extremes: regulation relying solely on strict reward/punishment, on one hand, and laissez-faire/self-regulation, on the other. Ayres and Braithwaite (1995) argue that a whole range of options lie between these extremes and the act of regulation should excel at understanding the context well enough to judge what regulatory approach is suitable and to be flexible about changing it over time. This way of thinking lies behind the use of stakeholder engagement to decide certain aspects of regulation, such as quality standards.

Adaptive regulation is another concept born from the agenda of regulatory reform that aims to improve learning in the system and avoid mis-regulation (Bennear and Wiener, 2019). Adaptive regulation replaces big one-time decisions with a series of partial sequential decisions based on pre-determined indicators. Triggering each of these partial decision processes can be planned or unplanned, automatic or discretionary, depending on the particularities of the regulated sector. Adaptive regulation could, for instance, anticipate that a re-opening of a price-control would be necessary if the government made a significant commitment to replace gas boilers with electric heating and schedule a conditional regulatory reopening should that event occur.

Arguably, Ofgem's RIIO incorporates the first two features of the learning regulator but not the third.

Ofgem consultation postscript

41 stakeholders, including all regulated network companies, responded to the 2022 Ofgem consultation on the future of regulation from 2026.

Pollitt et al. (2024a) identified 7 areas in which stakeholder recommendations that were made. First, some proposed extending the *planning* horizon beyond the current price control. Second, current *uncertainty mechanisms* such as automatic revenue reopeners needed to be made less burdensome to access. Third, *incentives* were seen as not sufficiently targeted on key aspects of net zero (such as hydrogen networks or EV charging points). Fourth, increasing investment needs and rising uncertainty raised issues of whether allowed *financial returns* were adequate. Fifth, there was a need to include a larger and more diverse set of *stakeholders* in regulatory decision making. Sixth, encouragement to technological and business model *innovation* was seen as becoming more valuable. Seventh, *whole system governance* was recognised as being important.

Some ideas from other sectors on regulation under uncertainty

We offer three examples from non-energy sectors on how regulation can better deal with uncertainty. These are drawn from the water industry in England and Wales, the autonomous vehicle sector in Singapore and airports in Australia.

Adaptive Regulation in Water Regulation in England and Wales

Faced with the implications of climate change for the water sector, the need for investments and the cost-of-living crisis, Ofwat, the water regulator in England and Wales, chose to include adaptive pathways planning for its latest price control from 2024 (PR 24)[37]. Regulated water companies adopted an adaptive pathways method into their 5-year business plans.

The business plans were meant to cover five years but need to be presented within 25 years strategies, emphasizing the ways in which each period contributed to long-term goals. Each company needed to define a core pathway for 25 years, describing the most likely scenario (see Figure 4).

They also needed to present relevant indicators and thresholds for triggering alternative pathways that deviate from the core. The companies assigned reasonable probabilities as to when the threshold may be reached based on the available information and the likely changes needed to their business plans.

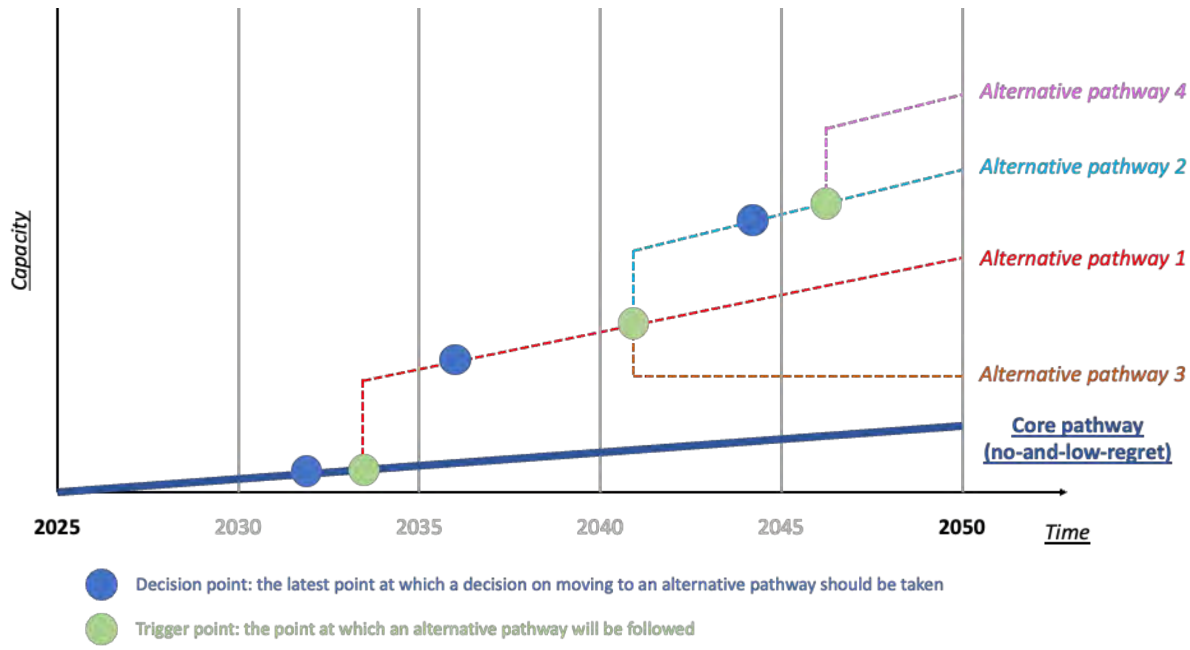

Figure 4: Example core and alternative adaptive pathways
Source: Ofwat (2022, p.7)

Regulation for Innovation in Singapore

In 2014, the Singapore Autonomous Vehicle Initiative (SAVI) was launched, which aimed to research the autonomous vehicle transportation sector and provide test-bedding. It created a cross-industry committee – which included both public and private representatives – to better anticipate and integrate autonomous vehicles, after the Land Transport Authority agreed to more flexible testing of these solutions.

[37] See Ofwat (2021) and (2022).

The initiative developed an open platform that allows authorities, research centres and think tanks, or industry companies to jointly run self-driving trials, to test various scenarios and solutions. As a result, it attracted the attention of multiple foreign investors into the sector.

In 2016, an AV piloted by nuTonomy collided with a lorry, leading to an immediate investigation of the accident. Once the safety concerns were addressed, the pilot project was resumed.

Long-term regulatory challenges remain, e.g. behavioural changes in AVs due to deep learning, cyber-attacks, and workforce disruptions (Tan and Taeihagh, 2021). To this end, the regulatory designs for the medium and long term also embed high uncertainty that can deviate from baseline scenarios.

Regulation of Australian Airports

Airport charges (which finance the airport itself) were historically set based on costs, including in the case where governments own and operate these facilities. The price capping system emerged in the UK in 1986, when the UK Civil Aviation Authority (CAA) followed the mechanism used for other utility companies, which had price caps (Adler et al., 2015).

From 1997 to 2022, the Australian Government privatized 23 airports with 99-year leases, including eight general aviation airports. Eleven out of twelve largest airports (Sydney was excluded) had prices caps, which allowed for the necessary new investment costs.

The price cap was meant to be a temporary measure, which would need re-evaluation after a 5-year period by the Australian Competition and Consumer Commission (ACCC). To ensure objective evaluation, the Productivity Commission (PC) was tasked with the review. Following a multi-staged process – and following the Productivity Commission's recommendations – the Government eliminated price controls and implemented a system of price and quality monitoring (see Figure 5).

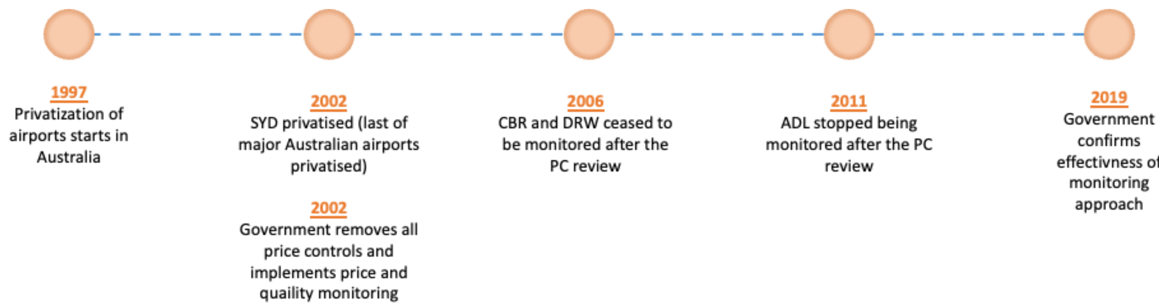

Figure 5: Timeline of actions in Australian airports
(Airports: SYD – Sydney, CBR – Canberra, DRW – Darwin, ADL – Adelaide; PC – Productivity Commission)
Source: ACI Europe (2021, p.11)

According to industry associations – both from Australia and abroad, that evaluated this case study –the removal of prices caps brought several benefits, including AUD15 billion in investments between 2002 and 2018, two-thirds of which focused on aeronautical assets, leading to a growth in passengers, from 76 million in 2002 to 159 million in 2018. This is an illustration of how a formerly regulated network monopoly could move beyond a conventional price control.

A key element of this process has been the fact that airlines can represent ultimate customers effectively and ensure that any stakeholder engagement process balances customer and producer interests. Well-informed customer representatives with strong incentives to balance price and quality trade-offs can deliver beneficial outcomes without the need for formal regulation. Of course, both producers and consumers can still appeal to the responsible government body but have a vested interest in settling rather than opening the regulatory process up to additional external scrutiny which may not improve on their negotiated outcome.

The direct applicability of this to electricity and gas networks is somewhat limited by the fact that energy retailers are not subject to the same competitive pressures as individual airlines at a given airport, especially where transit traffic is significant and very price sensitive. However, the potential to learn lessons from the evolution of regulation at airports under uncertainty and with strong cost-quality trade-offs remains.

Concluding thoughts

We have argued that net zero implies a high and continuing level of uncertainty facing energy regulators which they will have to both manage and live with.

To some extent regulators can know what net zero implies for the scale of the challenge they face and the continuing importance of good economic regulation. Net zero is an increasing economic challenge which requires increasingly good economic regulation of the energy sector.

Institutional arrangements around regulation, likely, need to change in the face of net zero. Regulators need complementary institutional structures with which to work, and they need sufficient powers to do their job effectively. Possible institutional changes may involve vertical and horizontal reorganisations of the energy sector and the strategic use of public (and private) ownership. It would be surprising if industry ownership and sector governance structures designed prior to the net zero era could not benefit from some reorganisation.

Best practice regulation continues to evolve. Theories of regulation suggest key roles for both learning and for trade-offs in regulation. We advocate for the development of a ‘learning regulator’ which simultaneously learns from the past (dynamic regulation), in the present (responsive regulation) and anticipates future learning points (adaptive regulation). While current best practice regulation involves the first two types of learning, the third remains a work in progress.

Other regulated sectors can offer lessons for energy. We highlight some examples from water, road transport and airports where regulators are implementing the features of both responsive and adaptive regulation to better deal with uncertainty.

This paper has looked at how even best practice current regulation might need to evolve to meet the challenges of net zero. However, many jurisdictions cannot hope to facilitate net zero with regulatory systems that are a long way from best practice. For them learning the lessons from existing best practice regulation remains the priority.

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