Net zero and future energy scenarios: A response to the National Infrastructure Commission's report on future power systems

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1. Introduction

The National Infrastructure Commission (NIC, 2020a) has published its report analysing future power systems based on the new net zero legislative framework, updating Aurora (2018a,b). This note looks at the sensitivity of the costs of some of the chosen technologies to the real Weighted Average Cost of Capital (WACC) and, in the case of CCGTs used in back-up mode, their capacity factor (which effectively defines the required peak or stress period prices) and gas price. The costs are the average over operating hours excluding any balancing or back-up services required, so understate the cost of renewables (although NIC, 2020a, Table 2 gives some estimates discussed below). The figures published in NIC (2020b) in the References have been uprated from £2016 to £2018 using the CPI inflator, while the fuel and carbon cost assumptions are taken from the National Grid's 2020 *Future Energy Scenarios* (*FES*).

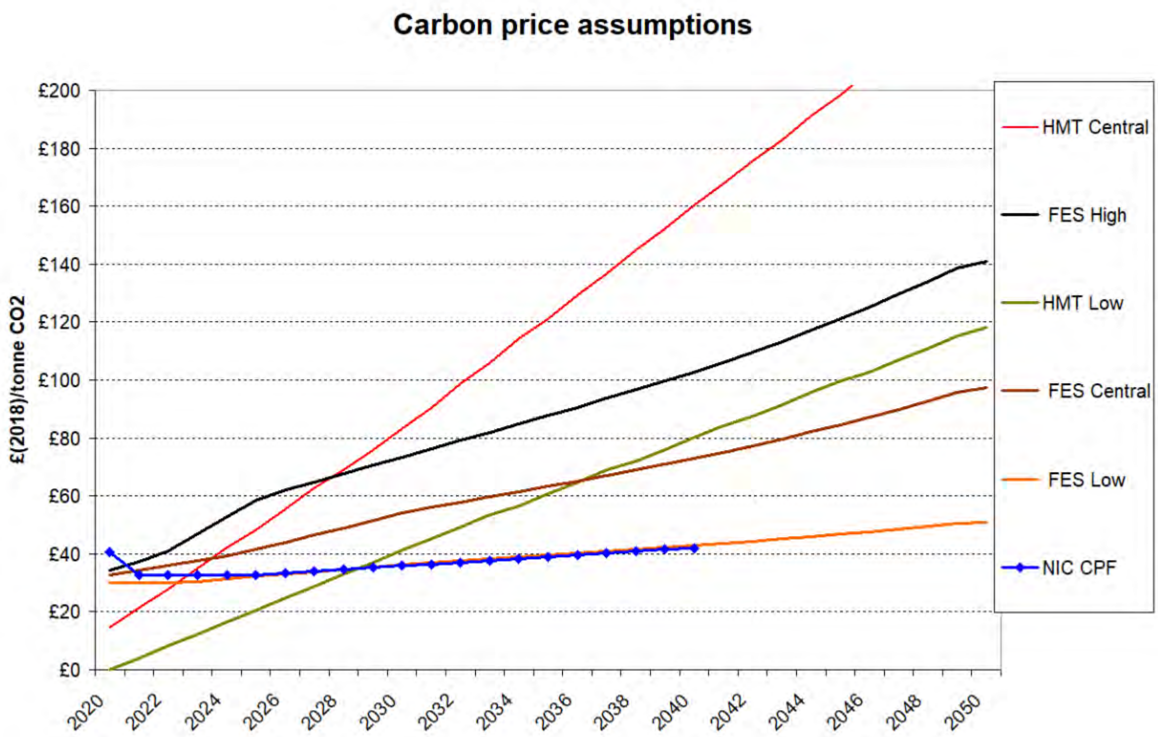

Figure 1 Carbon price assumptions used in this paper (FES) and by NIC (NIC)
Sources: *FES* 2020, HMT (2019) and NIC (2020b)

[1] The author is on the National Infrastructure Commission (NIC) Expert Advisory Group and is indebted to Nathan Wyatt for information, which is in the public domain at https://www.nic.org.uk/publications/technical-annexes-electricity-system-modelling/ and for comments on an earlier draft. This is purely the author's view and should not be taken to represent the views of EPRG or the NIC.

Figure 1 shows the various carbon price assumptions. The NIC CPF is an exogenous minimum assumed carbon price. In addition, the Aurora modelling has an endogenous carbon price which the model uses to solve for the least cost way of reaching the targets set for the energy sector, and thus is on a different standing to these assumed in other reports. The NIC prices appear to lie along the FES low trajectory, but the endogenous carbon price reaches much higher levels - averaging between £(2016)85 – 225/tCO_2 between 2030 to 2050 across all scenarios (NIC, 2020b). HMT (2019) central scenario reaches around £(2018) 237/tCO_2 by 2050, substantially above *FES* 2020.

The range of projected gas prices is wider and the values typically higher than those in BEIS (2018). Figure 2 shows the different trajectories where in each case where CO_2 is included high gas and high CO2 prices are combined, and similarly for the low prices.

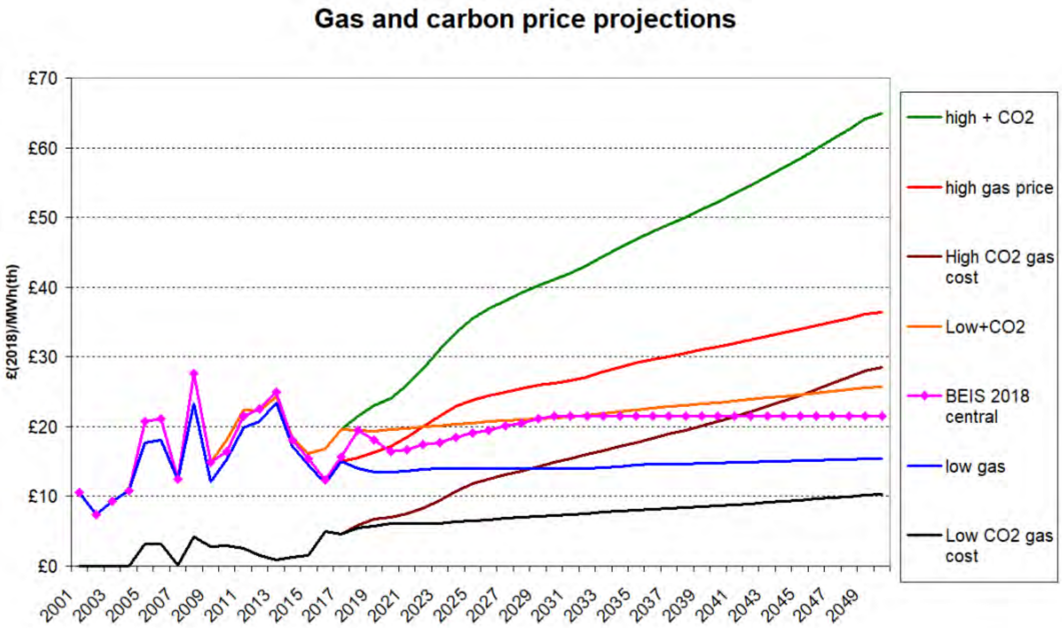

Figure 2 Gas prices with and without embodied CO_2

Sources: *FES* 2020 for fuel and CO_2 prices, NIC(2020b) for their gas prices

Notes: CO2 gas cost is the cost of the CO_2 added to 1 MWh_{th} of gas at the rate of 0.202 tonnes CO_2/MWh_{th} (COM, 2017).

Figure 3 shows the cost of using either natural gas unabated (but paying the carbon price) as a fuel for peaking gas turbines, or the cost of turning the gas into hydrogen through Steam Methane Reforming (SMR) and then capturing 90% of the CO_2 to produce a fuel to use in comparably expensive gas turbines. It includes the cost of CO_2 not captured, including the much higher HMT (2019) values for the central assumed CO_2 prices.

Figure 3 suggests that at these carbon prices the cost of hydrogen is cheaper than gas at high gas prices with the *FES* carbon prices after about 2033, and at the low prices around 2043, but at the central HMT carbon prices hydrogen is always cheaper than the central unabated gas prices. That suggests that using SMR hydrogen may become economic for decarbonising back-up gas turbine generation, perhaps in the early 2030's. It may be that stored hydrogen from electrolysis is more cost effective, but given the high capital cost of the electrolyser and its low capacity factor if relying on renewables this seems unlikely, at least until much later.

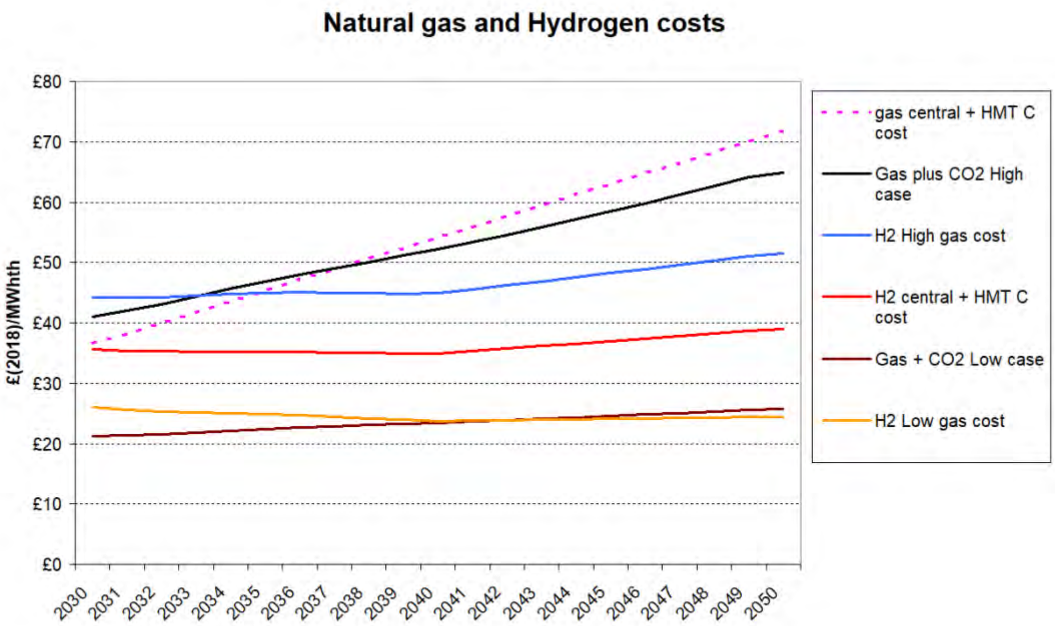

Figure 3 Cost per MWh_{th} of natural gas and hydrogen including the cost of CO_2
Source: NIC (2020b) and *FES* 2020 for fuel and carbon prices, HMT (2019) for HMT C cost, COM (2017) for emissions factor.

2. The importance of the Weighted Average Cost of Capital (WACC)

The reason for this short note is to stress the importance of the WACC in the relative cost of different generation types, which tends to be ignored where consultants consider the risk adjusted WACCs in liberalised markets. Thus NIC (2020b) takes typical hurdle rates for evaluating investments as 9%. Instead, the argument for embarking on a net-zero trajectory is that these investments are durable and capital-intensive, and in liberalised markets need to make projections of future fuel, carbon and sales prices that are inherently uncertain, for which futures markets and commercially available contracts only offer hedging options for a few years into the future, and which are fraught with uninsurable political and regulatory risk (e.g. over future attitudes to nuclear power, the extent and form of renewables subsidies and carbon prices that will impact future electricity prices). Unless risks can be hedged through long-term contracts or subject to the standard utility Regulatory Asset Based (RAB) model, the costs of delivering net-zero will be unnecessarily expensive. The Appendix sets out this key argument in more detail.

Figure 4 shows the relationships for four key options: unabated CCGTs paying the full carbon price, off-shore wind (slightly cheaper than on-shore wind in 2030), solar PV (neither de-rated[2] for their time of delivery) and nuclear power. The figures for nuclear power are taken from the NIC(2020b) with a more expensive variant based on more recent projected costs for the next potential EPR at Sizewell C (explained at greater length in Newbery et al.,

[2] High renewables penetration lowers the market clearing prices in hours of high resource (wind or sun) and so levelised costs are a misleading measure of their contribution to system costs.

2019). With that exception all data are taken from NIC (2020b) and the fuel and carbon prices as above come from the *FES* 2020.

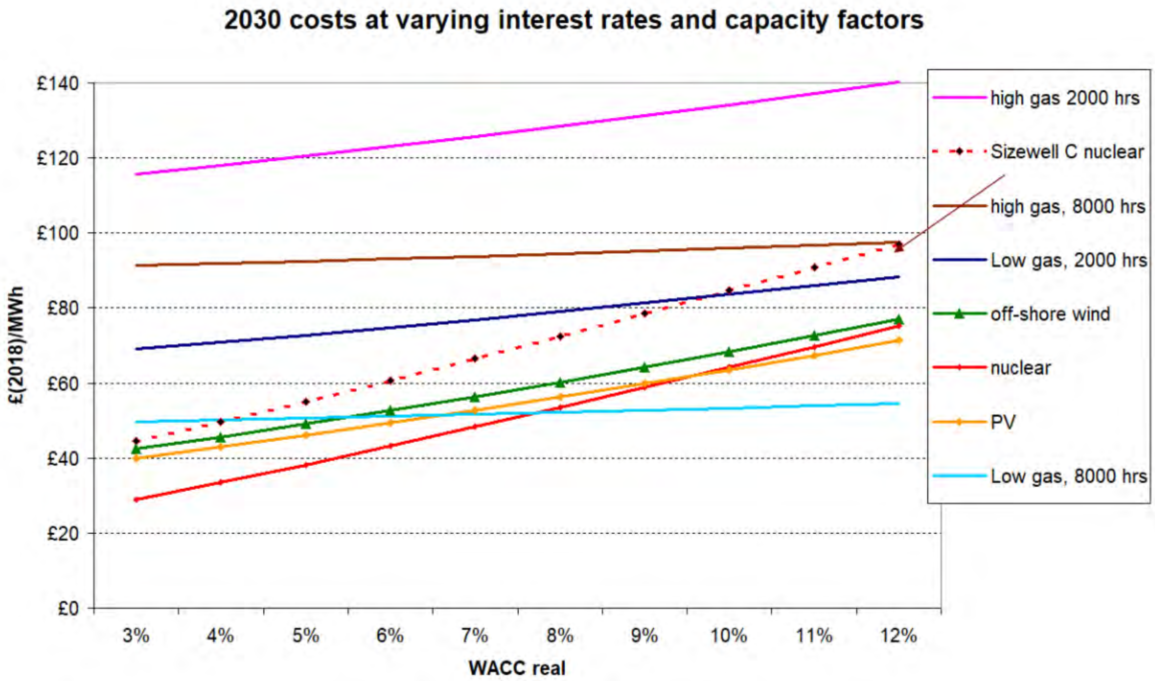

Figure 4 Average costs per running hour in £/MWh
Sources: NIC (2020b); *FES* 2020, Newbery et al. (2019)
Notes: Low and High gas costs include low and high CO_2 price projections from *FES* 2020

What the graph shows clearly is that the relative position of gas and zero-carbon options depends critically on the gas price projections, the WACC and the running hours per year (i.e. capacity factors). The running hours effectively gives the price needed in those running hours (closer to residual peak or stress hours) to cover the full cost, and as such can be used a measure of the cost of back-up power from unabated gas. In high renewables scenarios NIC (2020a, Table 2) gives Intermittency cost calculations of £24/MWh, although these should vary by technology, as solar PV has quite different requirements to the higher capacity factor off-shore wind. In 2030 these intermittency costs should be considerably lower, given the limited curtailment (accounting for £9/MWh in Table 2) and might be more like £8/MWh.

Above a WACC of 7% base-load CCGTs are cheaper in 2030 (with a 2030 Low gas and Low CO_2 price of £36.14/tonne CO_2 and an emissions factor of 0.202 tonnes CO_2/MWh$_{th}$ of gas, i.e. of the thermal content of the gas ─ see COM, 2017). At the high gas and carbon price (£73.31/tonne CO_2) all zero-carbon options are cheaper. Where nuclear is cheaper than all renewables depends on cost assumptions. On the more optimistic NIC assumptions (admittedly for 2030, while Sizewell C is for 2025) nuclear is cheaper than all renewables except solar PV above 10% WACC (and ignoring the extra balancing and back-up costs of solar PV). At the arguably more evidence-based nuclear costs for Sizewell C (based on experience with Hinkley Point C) nuclear is more expensive than renewables above 4% WACC (after including £8/MWh for intermittency costs).

2.1 2050 costs

Figure 5 shows the graph for 2050 of average costs per running hour (again excluding intermittency costs that NIC, 2020a, table 2 suggests might be £24/MWh) for baseload (8,000hrs) CCGTs and hydrogen from SMRs (both low gas and carbon prices), off-shore wind, (NIC) and Sizewell C nuclear and solar PV. In addition to test the relative merits of hydrogen and gas in CCGTs for peaking both are given at 2,000 hrs./yr. again with low gas and carbon prices (which flatter gas). At High gas and carbon prices hydrogen is only 85% of the cost of gas for 2,000 hrs running.

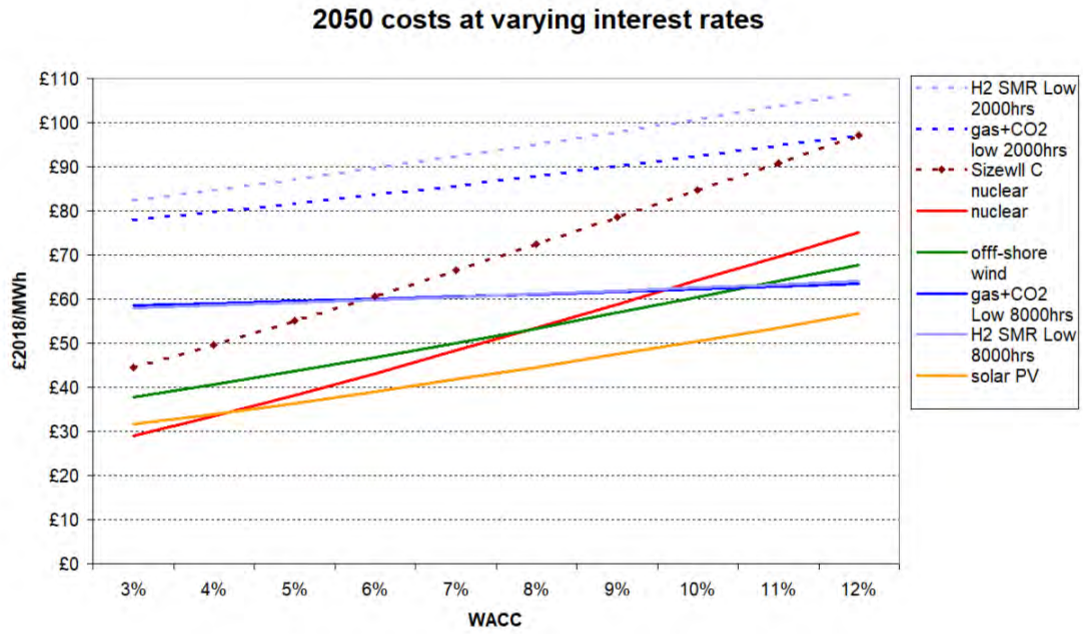

Figure 5 2050 average costs per running hour at different WACCs
Note: gas+CO2 low is running 8000 hours per year on baseload; the High price case is too high to graph (£140/MWh); as are peaking gas costs.
Source: NIC (2020b), *FES* 2020 for fuel prices

Baseload unabated gas is uncompetitive except at low gas prices and very high values of WACC (where it is almost the same cost including the carbon price as SMR hydrogen). Nuclear power, whose costs are not predicted to fall over the next 30 years, is still cheaper than renewables (when including intermittency costs) over a wide range of WACCs when using the NIC (2020b) data, and even with Sizewell C cost assumptions, would be cheaper at WACCs below 4%. For peaking/balancing gas is cheaper than hydrogen and low gas and carbon prices but hydrogen is cheaper than gas at high gas and carbon prices.

3. What should determine the WACC?

The *Stern Report* (Stern, 2007) lays out the arguments for a low social discount rate of 1.4% (real). It logically follows that the social discount rate should be used not only to measure the damage caused by releasing CO_2 now, but should also be the rate used to discount the future benefits of zero-carbon generation investments that avoid damaging CO_2 emissions. (There are additional arguments relating to risk and distributional concerns discussed in the appendix.)

The UK Government's Appraisal Manual (*The Green Book*, HMT, 2018) follows the same utilitarian public economics theory that guided the estimates of the discount rate in the *Stern Report*. It sets out the principles of social cost-benefit analysis for appraising projects whose private returns are likely to understate their social benefits. That is pre-eminently the case with investments in zero-carbon technologies to mitigate climate change. The rate used for long-term discounting by the UK Government was reduced after the *Stern Report* from 2.5% for projects lasting 75+ years to 2.14% (HMT, 2018, p104). That suggests a discount rate or WACC of 3% should not be too high.

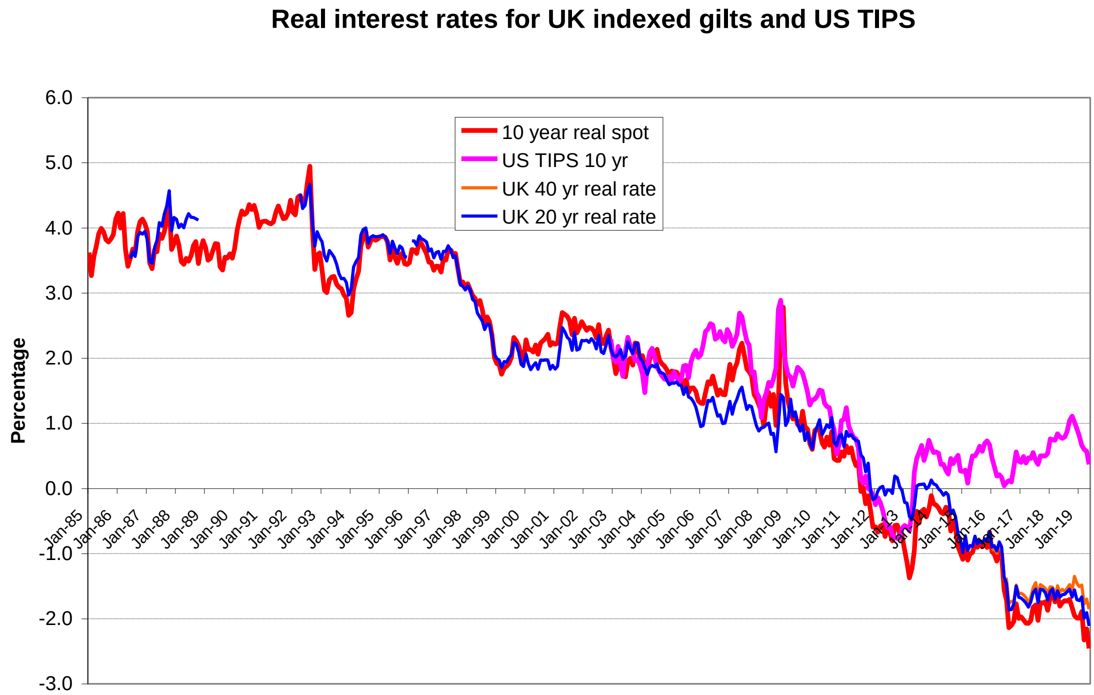

Figure 6 Real spot interest rates for UK index-linked gilts and US TIPS
Source: Bank of England https://www.bankofengland.co.uk/statistics/yield-curves and https://fred.stlouisfed.org
Note: the series ends before Covid-19 caused a further fall, which one hopes is temporary

Figure 6 shows that UK real indexed-gilt rates (both 10 and 20-year maturity) have declined roughly linearly from +4% in early 1994 to -2.5% real at the end of 2019. Even the 40-year maturity rate (for which data are only available from 2016) is only slightly higher than the 10-year maturity. The US real rate has remained (mostly) positive in the recent past but still exhibits the same long-term downward trend.

In addition to this graph, there are other compelling reasons for considering that the appropriate WACC is likely to remain low—an aging population leading to a savings surplus and lower rates of productivity growth, to name just two. In their important article, Rachel and Summers (2019, p1) demonstrate "that neutral real interest rates[3] would have declined by far more than what has been observed in the industrial world and would in all likelihood be significantly negative but for offsetting fiscal policies over the last generation. …We show …

[3] The interest rate consistent with stable macroeconomic performance.

that neutral real interest rates have declined by at least 300 basis points over the last generation. We argue that these secular movements are in larger part a reflection of changes in saving and investment propensities rather than the safety and liquidity properties of Treasury instruments. We then point out that the movements in the neutral real rate reflect both developments in the private sector and in public policy. …we suggest that the "private sector neutral real rate" may have declined by as much as 700 basis points since the 1970s. Our findings support the idea that, absent offsetting policies, mature industrial economies are prone to secular stagnation. … More broadly, a large share of the decline in risk-free rates has been mirrored in risky asset returns, such as rates of return on corporate bonds and on equites: notwithstanding some volatility, spreads have remained close to long-run historical averages." (Rachel and Summers, 2019, p2; fig 3, p5.)

4. The RAB model for finance

The *Green Book* and *Stern* discount rates are risk free (and, if they were to reflect the risk of really bad future outcomes it would lower rather than raise the social discount rate ─ see appendix). If zero-carbon generation is to be financed at low WACCs then risks have to be socialised, effectively with public sector under-writing (or government-backed regulatory assurances). This is socially efficient, as dividing risk across a larger number of agents (e.g. electricity consumers) reduces not just the individual cost, but the total cost of the risk, as shown in the appendix. The simplest way of achieving this is for the costs and revenues to be regulated under the standard Regulatory Asset Based (RAB) model used to finance networks (electricity transmission and distribution, water, gas pipelines).

An excellent example is the Thames Tideway Tunnel (TTT), (NAO, 2017; Ofwat, 2014). The TTT is a separate company from the host company, Thames Water, and as such is subject to a separate regulatory contract. Network utilities in the UK are familiar with RAB financing, in which at the start of each regulatory period the regulator and the utility agree an investment plan over the next five years (longer for projects which take longer to build). The RAB is incremented by the planned annual investment and decremented by the agreed depreciation schedule once commissioned. The RAB pays the WACC on the RAB at each date together with depreciation, so that investors receive a return on and of their investment.

The hybrid RAB model adopted by the TTT pays a return on the gradually increasing RAB during construction, and thereafter the return on and of the RAB as with the utility model. As such it differs sharply from the CfD model where the investors have to wait until successful commissioning to receive any return. It differs from the simple utility RAB model in that if the cost over-run exceeds the agreed amount, the investors will only pay an agreed share of the over-run (e.g. 60%) up to some upper cap, after which all additional finance falls on the consumers. In this hybrid RAB model investors raised capital at a very favourable WACC (2.5% real) and the regulator periodically revisits the project to ensure that the WACC is aligned with current market conditions.

The UK Government issued a consultation on the *Regulated Asset Base (RAB) model for nuclear* on 22 July 2019, effectively suggesting that it was a suitable financing model for new nuclear power projects.[4] Renewables are already offered long-term Contracts-for-

[4] At https://www.gov.uk/government/consultations/regulated-asset-base-rab-model-for-nuclear

Difference (CfD) that de-risk revenue streams and allow a low WACC. Indeed, the main reason for the dramatic fall in off-shore wind prices is the fall in the hurdle rate needed to finance them, once the supply chains had been developed, the technology tried and tested, and the CfDs put in place with the *Energy Act 2013* and auctioned.

5. **Conclusion**

The key but hardly mentioned determinant of the cost and optimal portfolio of zero-carbon technologies is the WACC, which we argue should be closer to 3% than the rates assumed in NIC (2020b) for their energy modelling. Until all the cost calculations have been redone, perhaps using a RAB finance model, it will be hard to judge whether the report (NIC, 2020a) is robust. Relative costs also depend critically on gas costs (as a back-up option, or as the source of blue hydrogen) and of course, carbon prices (at least for unabated gas and SMR hydrogen). The *Future Energy Scenarios* consider a range of values with a high future spread, while the HMT carbon prices are even higher, and make a considerably difference to the viability of unabated gas compared to other options including hydrogen. While the gas prices reflect genuine uncertainty, the carbon price is more a policy instrument to deliver the net zero ambitions, and could quite reasonably be stated as a single trajectory (although it would likely depend on future gas costs that affect the extent and route to decarbonisation). It could be misleading to iterate to just find a single carbon price that delivers a desired decarbonisation of electricity alone.[5]

The future price of gas might be low if the world moves down the nuclear/renewables/electrolysis route but high if SMR hydrogen is used for heat and electricity balancing (with peaking gas). Clearly there is an internal inconsistency in each of these configurations as low gas prices favour the latter and high the former. Endogeneity of fuel (and carbon to a lesser extent) prices makes modelling at global scales both more difficult and harder to understand/explain.

Without looking at the modelling in more detail, it is hard to judge how well high renewables cope with lengthy periods of low wind in the winter demand peaks, although NIC (2020a, Figs 8-9) suggest heavy dependence on imports and CCS). Imports could be problematic without knowing whether all other Continental countries are similarly relying on imports or whether all are relying on Stored hydro from Norway. If hydrogen can be stored in sufficient volumes that may solve the problem. That route may favour electrolysis of spilled renewables at zero price, as SMR hydrogen still has a considerable carbon footprint.

What needs to be stressed in all future scenarios is the very considerable range of costs and technology choices that arise from specific assumptions about future gas and carbon prices and the assumed WACC.

[5] It might be claimed that the carbon price has very little impact on the Net Zero scenarios that by definition should not release more than marginal amounts of CO_2 by the later stages. But note that the required carbon price will almost certainly depend on the WACC and future gas prices, so a single number would be misleading in any case.

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Appendix The cost of risk

It is often argued that creating a government-underwritten long-term contract (or its equivalent through a utility RAB model) does not lower the cost of risk, as it merely transfers risk from one side (the investor) to the other side (whoever bears the risk, which in the case of long-term contracts like the UK Government's Contracts-for-Difference for renewables, is normally the consumers). In short, the claim is that there is an irreducible cost to this risk and it does not magically vanish through the risk shifting and sharing.

This claim is deeply flawed. The workhorse of utility regulation and portfolio valuation is the Capital Asset Pricing Model (CAPM). At its heart, this is based on expected utility theory, in which an equal probability of an increase or decrease in wealth of X is worth less than the certainty of enjoying X (see below for a mathematical treatment). The cost of that risk can be measured by the risk premium r required to make the risky prospect $X+r$ have the same value or utility as the expected or certain value EX.

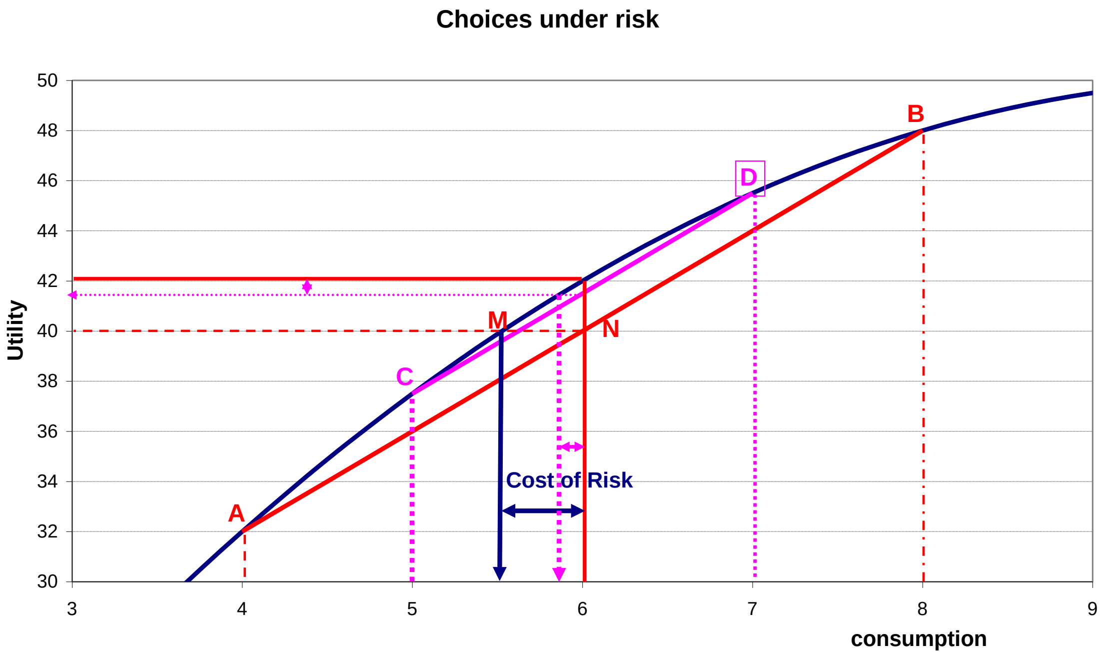

Figure A1 Illustration of cost of risk and risk premium

Note: The utility function is $U(C) = 10C - ½C_2$

Figure A1 illustrates this. The utility of (or value placed on) consumption, $U(C)$, is plotted against different values of consumption. The risky choice is an equal chance of receiving 4 or 8 units of consumption at points **A** or **B**, a deviation of 2 from the mean, with expected value 6. The utility value of a certain level of consumption 6 shown as 42 but the average or expected utility is $½U(4)+ ½U(8) = 40 = U(5.528)$. The cost of risk in this case is 6 - 5.528 = 0.472, shown as the distance **MN**. If the risk is shared between two agents with equally likely outcomes **C** or **D**, then the deviation from the mean is halved, and each now has an expected utility of $½U(5)+ ½U(7) = 41.5 = U(5.877)$ and the cost of risk is now 0.123. However, there are two agents bearing this cost, so the total cost is twice this, or 0.246, which is half the cost of risk if just one agent bears all the risk.[6] More generally, in this quadratic approximation to the local shape of the utility function, the total cost of risk divided equally among n equally placed agents is $1/n$ the cost of one similar agent bearing all the risk.

The implication is that placing all the risk on the developer is potentially very large compared to spreading that risk over, for example, all 28 million UK households who enjoy electricity, and the remaining 70% of industrial, commercial and other consumers who consume higher amounts. This is not a fair comparison, however, as in the case of building power plants, the construction and operating risks are likely to have a low correlation with GNP, Government income and public sector net assets, and with the stock market. In short, they are largely idiosyncratic risks. That might suggest that they can be widely diversified through the stock market, but here we run into the problems of asymmetric information and the perceived risk of political intervention. The problem is that the risks are not considered to be distributed around a known mean value. Especially with construction risk and even more for political risk, shareholders take the view that any financial proposal (particularly one coming from a company committed to such projects) is likely to have huge optimism bias.

Algebraic development of the theory of risk

The standard theory of risk taking (for example, that underlies the Capital Asset Pricing Model) assumes that agents experience less benefit from an equal increment in wealth to an equal decrement in wealth. Algebraically, if $U(W)$ is the utility of wealth level W, then U is convex, or $U'' < 0$. The value of risky outcomes is then determined by expected utility, $\mathrm{E}U(W)$, where W is now a random variable. This can be expanded around its mean value, $\mathrm{E}W$:

$$U(W) \approx U(\mathrm{E}W) + (W - \mathrm{E}W)U'(\mathrm{E}W) + \tfrac{1}{2}(W - \mathrm{E}W)^2 U''(\mathrm{E}W), \tag{A1}$$

$$\mathrm{E}U(W) \approx U(\mathrm{E}W) - \tfrac{1}{2}\,\mathrm{Var}(W).(-U''(\mathrm{E}W)). \tag{A2}$$

If r is the risk premium (i.e. the extra amount needed to compensate for the risk in W, so that $\mathrm{E}U(W) = U(\mathrm{E}W - r)$, then expanding around $\mathrm{E}W$:

$$\mathrm{E}U(W) = U(W - r) \approx U(\mathrm{E}W) - r.U'(\mathrm{E}W). \tag{A3}$$

Equation (C1) can be combined with (C2) to give

$$r.U'(\mathrm{E}W) = \tfrac{1}{2}\,\mathrm{Var}(W).(-U''(\mathrm{E}W)), \tag{A4}$$

The coefficient of absolute risk aversion, A, is defined as $A = -\,U''(\mathrm{E}W)/U'(\mathrm{E}W)$, hence

$$r = \tfrac{1}{2}\,A\mathrm{Var}(W). \tag{A5}$$

[6] This is true for a quadratic utility function. The algebra below considers more general utility functions where, measured in consumption units, the cost is only approximately halved.

The coefficient of relative risk aversion is R, defined as $R = -\mathrm{E}W.U''(\mathrm{E}W)/U'(\mathrm{E}W) = \mathrm{E}W.A$, so the relative risk premium, $r/\mathrm{E}W$, is

$$r/\mathrm{E}W \approx \tfrac{1}{2} R\mathrm{Var}(W)/(\mathrm{E}W)^2 = \tfrac{1}{2} R.\ \sigma(W)^2, \tag{A6}$$

where $\sigma(W)$ is the coefficient of variation of W. It is clear from the definition of R and equation (A3) that $R = \eta$, the elasticity of marginal utility, which is important for studying future climate change risks in the context of determining the risk-adjusted social discount rate.

The cost of risk and the benefits of sharing risk

Suppose that the risky prospect is shared by n agents, each of whom takes on W/n. The total cost of risk from (A5) is

$$\tfrac{1}{2} An\mathrm{Var}(W/n) = \tfrac{1}{2} An\mathrm{Var}(W)/n^2 = \tfrac{1}{2} A\mathrm{Var}(W)/n. \tag{A7}$$

The total cost of the risk has been reduced to $1/n$ by sharing it across n agents. This is particularly relevant when considering the balance of risk and cost in choosing between imposing more risk and hence cost on EDF compared to transferring much of the risk but at much lower cost of that risk to electricity consumers (or taxpayers).

The treatment of correlated risk

If the Government, consumers and/or shareholders hold equity in a nuclear power station, they add that equity and its risk to an existing portfolio of risky assets. If that existing portfolio is W, and the new project (Sizewell C) is the risky asset, X, then from (A2) but now measuring utility in cash terms (by dividing through by $U'(\mathrm{E}W)$):

$$\mathrm{E}U(W) \approx \mathrm{E}W - \tfrac{1}{2} A\mathrm{Var}(W).$$

$$\mathrm{E}U(W+X) \approx \mathrm{E}(W+X) - \tfrac{1}{2} \mathrm{A}[\mathrm{Var}(W) + 2\ \mathrm{Cov}(X,W) + \mathrm{Var}(X)], \tag{A8}$$

so

$$\Delta\mathrm{EU} \equiv \mathrm{EU}(W+X) - \mathrm{E}U(W) \approx \mathrm{E}X - \tfrac{1}{2} A[\mathrm{Var}(X) + 2\ \mathrm{Cov}(X,W)] \tag{A9}$$

$$\Delta\mathrm{EU}/\mathrm{E}X \equiv \mathrm{B} \approx 1 - R[r.\sigma_W\, \sigma_X + \tfrac{1}{2}\, \sigma_X^2(\mathrm{E}X/\mathrm{E}W)], \tag{A10}$$

where r is the correlation coefficient between X and W, and σ_W and σ_X are the coefficients of variation of W and X. If the risk is widely spread (e.g. over the entire economy, all electricity consumers, or all shareholders) then $\mathrm{E}X/\mathrm{E}W$ will be small, so the relative benefit of the project is just $1 - Rr.\sigma_W\, \sigma_X$. To give some sense of how large this might be, if $R = \eta = 1$, $\sigma_W = 10\%$, $\sigma_X = 40\%$, $r = 25\%$, then B $\approx 99\%$. The lower the correlation of the risks of the particular project with the relevant portfolio, the lower is the cost of that risk.

Future catastrophic risk

Suppose that the initial level of consumption is 100, but after 50 years there is a 75% probability that consumption will have grown at 1.65% p.a. to 227, a 20% chance that it will have fallen back to its initial value of 100, but a 5% chance that it collapses to 10. The simple expected value of these outcomes in 50 years' time is 191, equivalent to an average growth rate of 1.3% (Stern's value). However, the expected utility is 75%.log(227) + 20%.log(100) + 5%.log(10) = log(164.8) which is equivalent to all consumers experiencing an equivalent growth rate of g^*=1.1%, lowering the social discount rate from 1.4% to 1.2%. Small chances of catastrophic risk reduce, and possibly considerably reduce, the risk-adjusted social discount rate.

This is very much Weitzman's (1998, 2012) argument that a small chance of bad outcomes count very heavily. Specifically, rare events (disasters) happen by definition to infrequently for an accurate estimate of their probability, so that we cannot reject the hypothesis that the distribution of outcomes is "fat-tailed", and is not normally distributed but at best like the *t*-distribution.