The exponential problems of predicting the future

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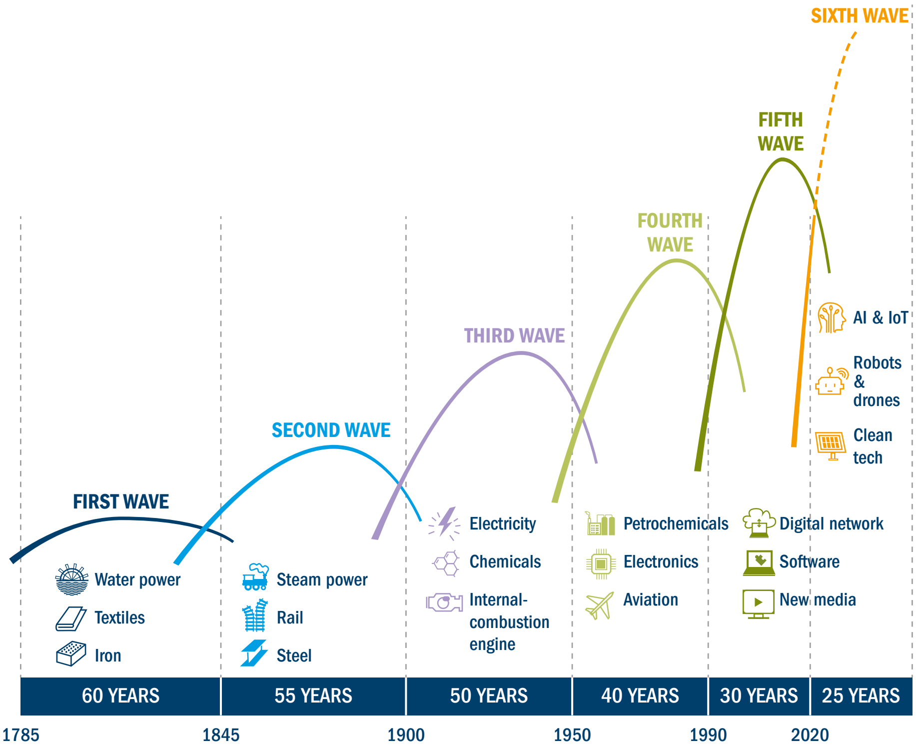
Figure 1: Waves of technological change



Source: Visual catalyst and Edison Institute, 2021

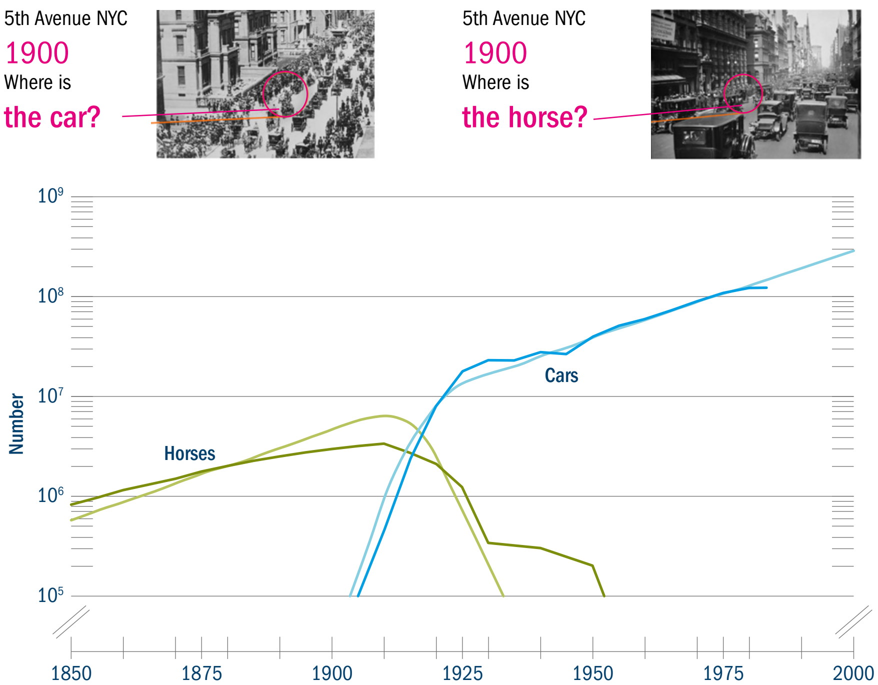
Technological change is an area in which individuals have consistently underappreciated pace. Through the decades our ability to adopt/consume technology has increased significantly (Figure 1). However, as humans, we regularly fail to appreciate this fact and as such disruptive technologies are often initially overlooked.

A famous example of the underappreciation of the pace of technological change is telecommunication firm AT&T asking McKinsey in the 1980s to forecast mobile phone adoption in the US in 2000. At the time handsets were clunky, calls were filled with static, data services were non existent and coverage was patchy – yet it was already becoming clear that mobile technology had practical benefits. McKinsey ultimately concluded there would be 900,000 mobile phone users in the US in 2020; the actual figure was just over 100,000,000. McKinsey had failed to account for the significant cost reductions in the core components of handsets coupled with the growing capabilities of networks such as the introduction of data services. Thus, a £3,000 phone in 1984 became a £200 handset in 2000.[1]

A key tenet of human behaviour is the systematic tendency to incorporate heuristics, for example rule of thumb, into decision making and/or the construction of narratives. However, this can often be inherently limiting. For example, one of the most pervasive biases in human decision making is anchoring, whereby individuals confronted with figures have a systematic tendency to fix upon some available reference point, adjust their responses around it and provide a linear extrapolation to arrive at their projection.

Forecasting is one such discipline where the anchoring bias is particularly prevalent but overcoming it is challenging. In the short term a forecaster may get lucky and be correct as an exponential curve at this point is closer to being linear, but as time moves on the divergence of the exponential effect increases and the forecast becomes less and less accurate. Successful forecasters tend to unshackle themselves from the

Figure 2: How New York became a one-horse town



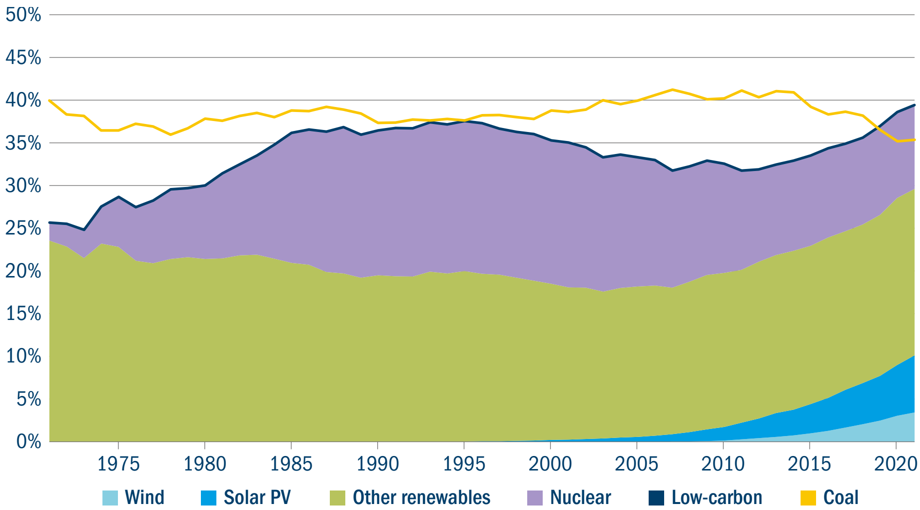
Source: An age structured demographic theory of technological change, Jean-Francois Mercure, 2013

anchoring bias and are able to consider the future in a nonlinear manner.

History is littered with examples of forecasters failing to do this and with hindsight it is easy to mock. However we are living through a period where the social and environmental risks to the global economy have arguably never been higher and this is likely to drive technological progression at an unprecedented level, thus providing significant investment opportunity for those able to ride the wave. On the other hand, there will likely be financial consequences for those who fail to anticipate the rapid rates of adoption of some of these technologies.

In 1890 there were 13,800 companies in the US in the business of building carriages pulled by horses. And in 1900 in New York alone there were 6,000 horses hauling New York trolleys – more

Figure 3: Share of low-carbon sources and coal in world electricity generation



Source: IEA 2021

than in all US cities combined. But just 17 years later the horse-pulled trolley took its last trip, and by 1920 only 90 carriage building companies remained[2]. This disruption was driven by the exponential rise of the automobile shown in Figure 2.

In 1903, the year Henry Ford founded Ford Motor Company, 11,235 automobiles were sold to Americans. Just a decade later Ford flipped the switch on the first assembly line, cutting the time it took to build a car from 12 hours to 2.5 hours. That year the number of cars produced in the US mushroomed to 3.6 million – a 300-fold increase. By 1923 the country was producing 20 million automobiles a year.[3]

The next rapid transition?

Climate change is impacting decisions at all levels of the global economy, ranging from governments through to corporates and individuals. A key driver in the world's decarbonisation plans is renewable energy and specifically the ability for swathes of the economy to increasingly run off variable renewable energy sources such as wind and solar energy. Today, all forms of renewable energy (including hydropower and nuclear) account for just under 40% of total electricity produced globally (Figure 3). This has been driven by an exponential reduction in renewable energy costs which have come about initially through policy support and a necessity for emissions reductions.

However, the snowball effect and magnitude of this increase in renewables was not anticipated. In fact, the International Energy Agency (IEA) has systematically underestimated the amount of electricity generated by solar power in the past 20 years (Figure 4). In 2009 it predicted that by 2015 there would be 5GW of solar power installed globally. In fact, the actual figure for 2009 itself eventually turned out to be 8GW. In 2010 the forecast for 2015 was upgraded to 8GW, and in 2011 to 11GW. In 2012 the IEA further revised its prediction for 2015, this time to 24GW, and in 2014 the forecast for 2015 was for 35GW of solar capacity. In the end the actual capacity installed by 2015 was 56GW. This trend of underestimating continued, and by 2019 the annual growth forecast for 2020 was off by 100%.

This demonstrates two characteristics (and biases) about human behaviour.

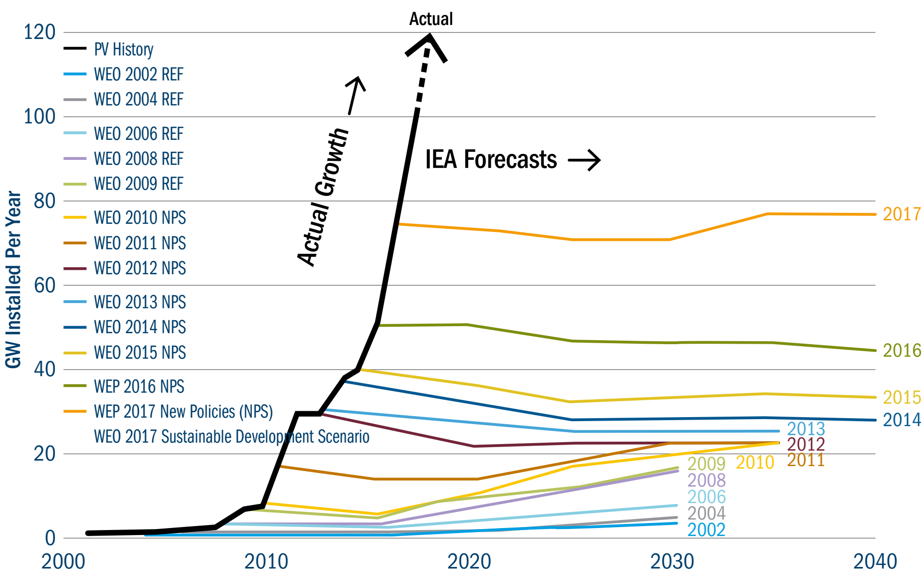
1. Changing our initial belief is emotionally challenging (Confirmatory Bias)

2. We struggle to forecast exponentially (Anchoring)

These biases can influence policy and investment decisions by overestimating the costs of the energy transition and underappreciating the potential for disruptive non-linear change. Models that often inform policy decisions are regularly based on assumptions that fail to capture the exponential nature of technology change. The IEA forecasts are a perfect example of this.

Other relationships such as feedback loops are poorly incorporated into most models. Doctor Matthew Ives from the University of Oxford gives the example of electric vehicles (EVs), whereby the uptake of EVs drives the demand of additional electricity which in turn furthers the experience curves of renewable generation, which in turn drives cost declines for renewable energy as well as reducing operational costs for EVs – further accelerating EV uptake[4]. Examples of this include Daimler, which forecast 2021 sales for new EVs to be 2x 2020, but the first half (H) year results of 2021 actually showed them at 4x; and Mercedes, which expected it would almost double its EV share in 2021 from 7% to around 13% – however EV sales more than quadrupled in H1 2021 alone to a share in excess of 10%[5].

Figure 4: IEA new solar additions per year, forecast versus actual



Source: Visual Capitalist/IEA 2019

Cost parity between internal combustion engine (ICE) vehicles and EVs is likely to occur around 2024-26[6], which could well prove to be a tipping point for further acceleration. Other tipping points could be related to overcoming range anxiety and concerns around secondary market resale value. Resale value concerns apply to both EVs and ICEs: for the former, while the technology is still new and a small share of the market, resale value is less certain at the point of purchase; and for the latter resale value uncertainty increases as governments introduce low emissions zones which make ICE operating costs higher relative to EVs. These non-cost-related drivers make forecasting even more difficult as they have the potential to accelerate exponential uptake.

Wright's Law

In contrast to large energy models, there are already empirical models that can more accurately predict the cost declines associated with new technologies. One example is Wright's Law which shows that cumulative production creates a consistent decline in costs – i.e. the more we deploy the more we learn. Hence cost-decline graphs are often referred to as "learning curves". A US aeronautical engineer named Paul Theodore Wright observed this relationship while making planes in world war two (WW2)[7].

In 2016 academics J Doyne Farmer and Francois Lafond applied Wright's Law and the similar Moore's Law to multiple technologies and found that they enhanced forecast accuracy across many of them[8]. For solar photovoltaics, Wright's Law has accurately predicted cost declines since 2016, even with recent polysilicon price increases (Figure 5).

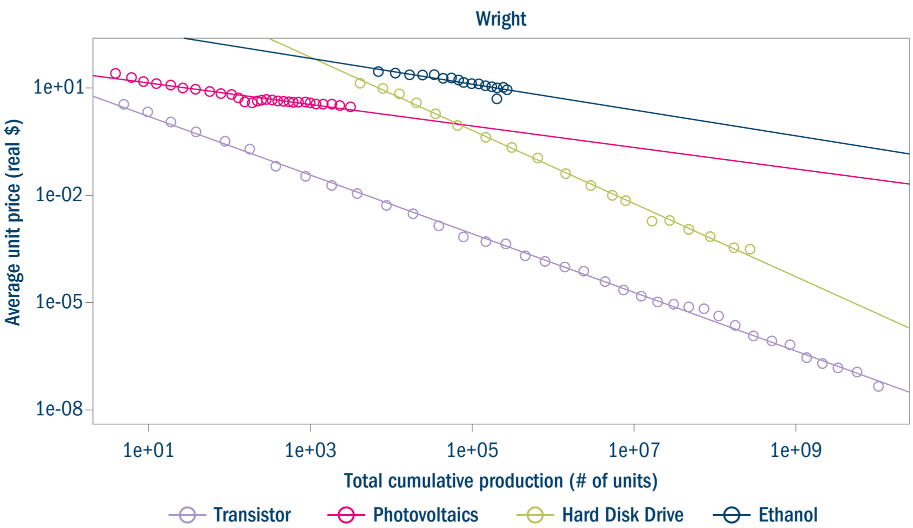
Using this research, Doctor Ives and his team found through using Wright's Law that renewable energy has the potential to disrupt the current energy system. This exponential growth starts from a relatively small base today but from 2025 starts to have a significant and non-linear effect (Figure 6).

This scenario sees an 80% emissions reduction by 2040, without the need to deploy carbon capture and storage technologies (in contrast to the IEA scenarios). Furthermore, it is based purely on technology economics and does not factor in any benefits from climate change mitigation.

Technology leap frogs

Partially as a result of such learning curves we have seen instances of "technology leapfrogging", whereby developing markets can skip the adoption of a precursor technology. Two notable examples are telecoms and banking in emerging markets (EMs), where the widespread use of landlines has been bypassed and countries have leapfrogged straight from having no phones to using mobile phones; and in banking where certain countries have leapfrogged large traditional banking branch networks and moved straight to digital banking in the first instance.

Figure 5: Wright's Law applied to different technologies



Source: Farmer and Lafond, 2016. The graph shows how the average price decreases as the total number of units produced increases. Both axis use a log scale.

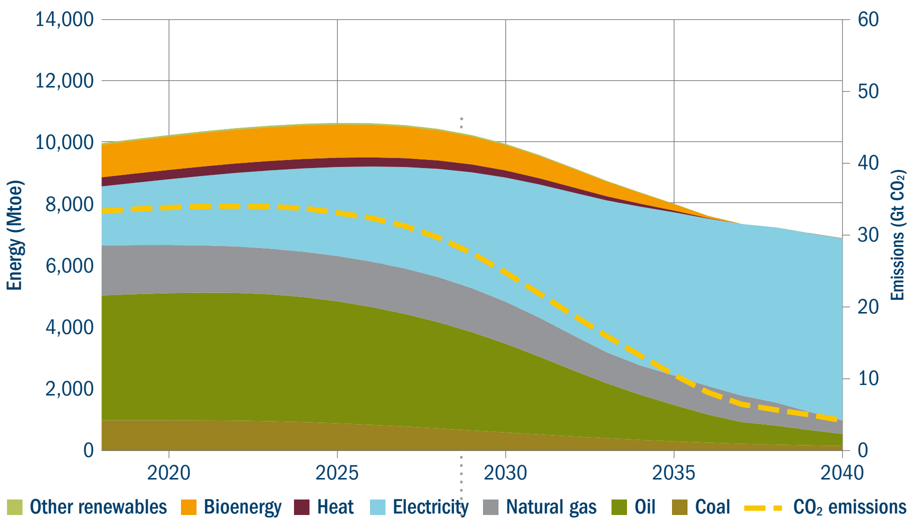
It is likely this phenomenon will occur to some extent with the energy transition. As renewable technologies become increasingly competitive, they will likely serve some of the demand that would otherwise have been met with fossil sources. In emerging market regions new demand is being met by leapfrogging straight to renewables. Indeed, according to independent think tank Carbon Tracker, in 2019 87% of the growth in electricity supply came from non-fossil sources in emerging markets ex-China[9].

Overcoming anchoring and conditions for exponential growth

A critical question is why certain technologies grow exponentially and how these areas can be identified. Exponential growth is driven by the convergence of new technologies which trigger causal feedback loops within and across markets and sectors. Historically, these loops interact with and amplify one another, accelerating the adoption of new technology in a virtuous cycle while accelerating the abandonment of old technology in a vicious cycle. The relationship between EVs and renewable energy highlighted above has the potential to be one such example.

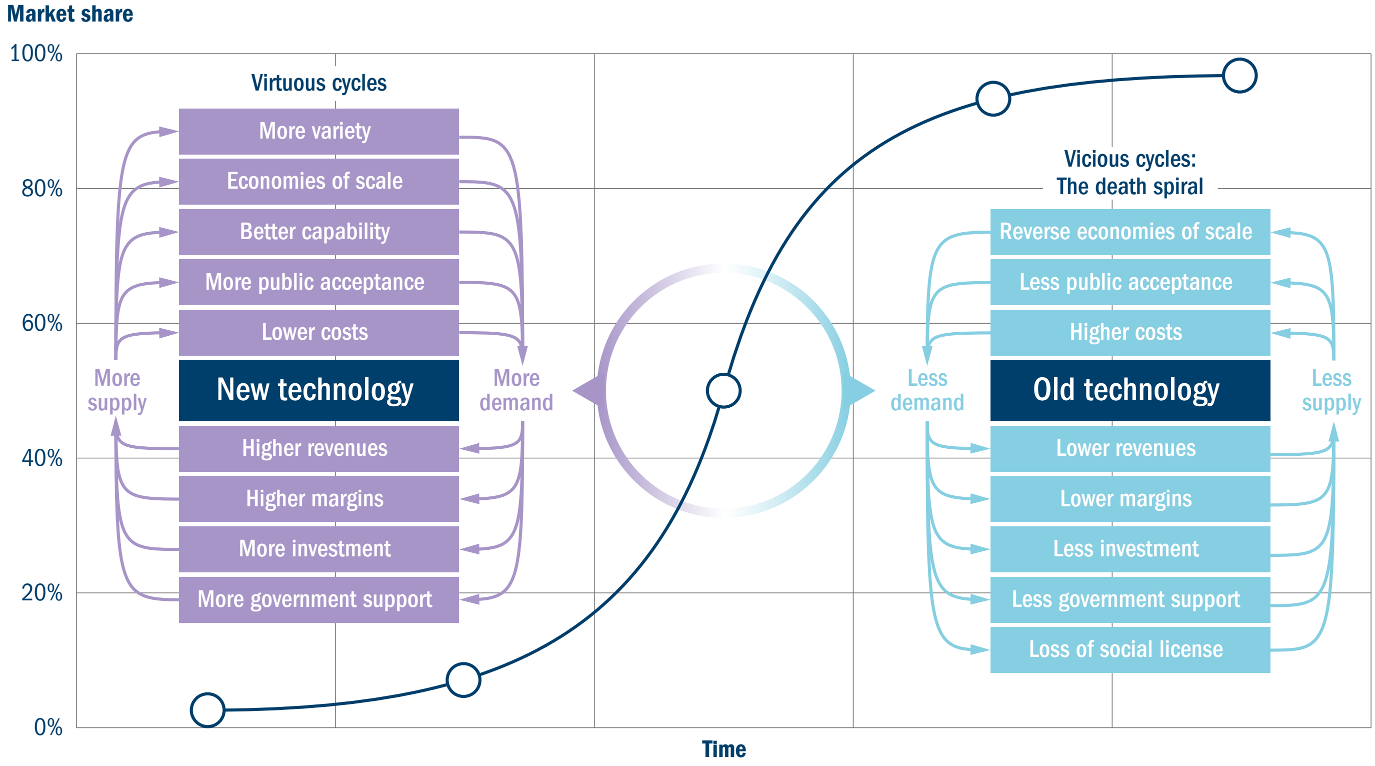
As a guide, Figure 7 serves as a high-level framework to consider new technology and whether it can achieve exponential status.

Figure 6: Global energy mix forecast using Wright's Law to predict renewable energy cost declines



Source: Farmer and Lafond, 2016. The graph shows how the average price decreases as the total number of units produced increases. Both axis use a log scale.

Figure 7: Virtuous and vicious cycles



Source: Rethink Disruption 2022

In summary

The behavioural biases discussed in this article go some way to explaining why industry and analyst predictions of the cost and capacity required for decarbonising the global economy have been regularly beaten by real-life progress. When the Paris Agreement was signed in 2015, the IEA thought the cost of solar would still be higher than fossil electricity in 2040, and it anticipated a total installed capacity of 360GW of solar by 2020. Both of these predictions have been blown out of the water: by 2020 90% of new electricity generation was cheaper from renewables than from fossil fuels, and 710GW of solar had been deployed – almost double the 2015 estimate[10].

Using the research of Dr Ives, Lafond, Farmer and others it is possible to start to look at more disruptive models and scenarios which, in our opinion, will be essential as the world moves along its bumpy road to net zero emissions.

> That's the thing about exponential growth, it doesn't do much for a long time and then it comes and smacks you in the face.
>
> *Dr Matthew Ives, 2022*

1 The Economist, Cutting the cord, October 1999
2 Microsoft Today in Technology, The day the horse lost its job, Brad Smith and Carol Ann Browne, as at August 2022
3 Microsoft Today in Technology, The day the horse lost its job, Brad Smith and Carol Ann Browne, as at August 2022
4 Daimler, Q2 quarterly report, 2021 and Mercedes, Q2 quarterly report, 2021
5 BNEF, 2021
6 Bloomberg NEF, May 2021
7 Wikipedia, Experience curve effects, as at August 2022
8 ScienceDirect, How predictable is technological progress?, J.Doyne Farmer and Francois Lafond, April 2016
9 Carbon Tracker, 2020
10 BNEF, Carbon Tracker, IEA, 2021

Energy transition engagement: Green hydrogen

Company

centrica

Sector and country

Energy, UK

Why we engaged

The company is in the process of updating its climate transition plan, with the aim to get to net zero by 2045, and for its customers to be net zero by 2050. This will include improving the number of smart meter customers, increases in the installation of EV charge points and heat pumps, and investing £100 million in low carbon and transition assets each year. We were interested in the role of green hydrogen in this process.

How we engaged

The company hosted an investor webinar.

What we learnt

The meeting enabled us to ask questions on the role of hydrogen in the domestic heating sector. Many experts are becoming sceptical around hydrogen's role in this area. One reason being that heat pumps are about six times more efficient than green hydrogen. It was good to see that Centrica is balancing its efforts between heat pumps and green hydrogen, and the company believes the hydrogen value chain will evolve, with green hydrogen initially used in industry but expanding into domestic use. The UK is likely to be a test case for domestic hydrogen heating due to the development of hydrogen hubs and an abundance of very inefficient housing stock that could be better suited to hydrogen than heat pumps.

Outcome

We will continue to monitor developments at the company and within this field. Centrica's leadership on energy transition and its role in the UK energy system provide a significant learning opportunity for us and the market more generally.