Insights
Environmental, Social & Governance (ESG)

October 2021

Spiralling Disruption: The Feedback Loops of the Energy Transition

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Carbon Tracker Initiative is an independent financial think tank that analyses the impact of the energy transition on capital markets and the potential investment in high-cost, carbon-intensive fossil fuels. Carbon Tracker has helped to popularise the terms “carbon bubble”, “unburnable carbon” and “stranded assets”.

State Street Global Advisors has co-authored this report on the energy transition with Carbon Tracker. The original Carbon Tracker analyst note can be found here: Spiralling Disruption: The Feedback Loops of the Energy Transition — Carbon Tracker

We are at a tipping point. Positive feedback loops underpinned by innovation will likely lead to a mass displacement of fossil fuels by renewables. In this article, we identify seven feedback loops that are driving a rapid transformation of the global energy system.

Key Highlights

Peak fossil fuel demand likely occurred in 2019. This marks the tipping point where positive feedback loops start to dominate the system. We identify seven virtuous and vicious feedback loops:

1 **The volume-cost feedback loop** As renewable volumes rise, so costs fall, which then spurs more volumes. Falling fossil volumes mean lower utilisation rates, which increase costs and drive down volumes.

2 **The technology feedback loop** More electric vehicles mean lower battery costs which then increases renewable penetration. In contrast, peaking fossil fuel demand means a collapse in innovation of fossil technologies.

3 **The expectations feedback loop** As renewables continue to grow, so incumbent forecasts look ever less credible. As models change, so too do the perceptions of investors and policymakers.

4 **The finance feedback loop** As growth draws in more capital, the cost of capital falls, enabling more expansion. Declining demand growth for fossil fuels force fossil fuel companies to change strategy.

5 **The society feedback loop** As society becomes more concerned with the climate crisis and sees the attractions of renewable technology, more people embrace the new technologies. Adoption becomes more attractive due to learning and network effects.

6 **The politics feedback loop** As technologies improve, voters and politicians realise that renewables can mean more gain rather than pain, thus driving political support for change. Meanwhile, declining industries lose money, power and credibility, and their political backing shrinks.

7 **The geopolitics feedback loop** As China races ahead in renewable energy technology, the US is obliged to retool. This race for influence drives renewable technologies out to the rest of the world.

The 2020s will be a decade of cascading change, powered by interlinking feedback loops. Investors and policymakers need to understand the dynamics of change to take advantage of the new world that is rapidly opening up.

Foreword by Carlo M. Funk

That we are living through an unprecedented era in the way we generate and use energy should come as no surprise to most investors. Just as the 19th century ushered in the Industrial Revolution powered by fossil fuels, our current generation is experiencing a green revolution, in which solar, wind and other renewables are rapidly displacing particularly coal, but also oil and gas. Indeed, we may have already witnessed peak fossil fuel demand in 2019.

We have written previously about the scale of the energy transition and the opportunities in renewables in 'The Trillion Dollar Energy Windfall'. In this new article, we focus on **seven feedback loops** that will shape the energy sector — and the way we will live our lives — potentially irreversibly. These feedback loops range from the declining costs of solar and wind brought about through technological advances, to evolving political and societal attitudes across the globe, which are becoming increasingly favourable to renewables and less so to fossil fuels. Together, these loops could reinforce each other and lead to a rapid transition from fossil fuels to renewables.

Reviewing the history of epochal economic and political transitions, one sees a critical feature: change unfolds much faster than expected. Take the shift away from horse-drawn vehicles to cars in the 1920s, or the rise of the internet in the 1990s, which many first dismissed as a gimmick. Therefore, it pays to be fully prepared for the shift to renewables, something that the global COVID-19 pandemic will only catalyse, as we discussed in 'COVID-19 and Energy in the New World'.

Clearly, we will not stop using fossil fuels overnight — the global economy is still underpinned by oil and gas. The recent spike in European gas prices to all-time highs,[1] and the consequent impact on companies in the food and utility sectors, reminds us that we still rely heavily on fossil fuels in our everyday lives. However, a move away from fossil fuels is inevitable, which is why investors should engage companies on their long-term strategy and preparedness for the energy transition.

At State Street, we offer equity and bond clients the opportunity to mitigate the impact of the shift to a low-carbon world, maintain portfolio resilience to future climate events and benefit from opportunities in the green transition. Underpinning our investment processes is a robust stewardship approach that may engage companies on climate-related risks, disclosure and climate preparedness, to understand how they are proactively addressing climate issues that could impact long-term performance. We may also vote on a range of climate-related proposals, from progress on greenhouse gas emissions reduction targets to the transition to renewable energy. Our investment capabilities include climate-specific reporting so that clients can align their portfolios with the evolving science, regulatory landscape, and investment risks and opportunities related to climate change.

We are fast approaching COP26, which could prove to be a turning point in global action to tackle climate change. More than ever, we stand ready to support you as we navigate the rapid and inevitable transition to a low carbon world.

Introduction

In economics, things take longer to happen than you think they will, and then they happen faster than you thought they could.

Rudiger Dornbusch

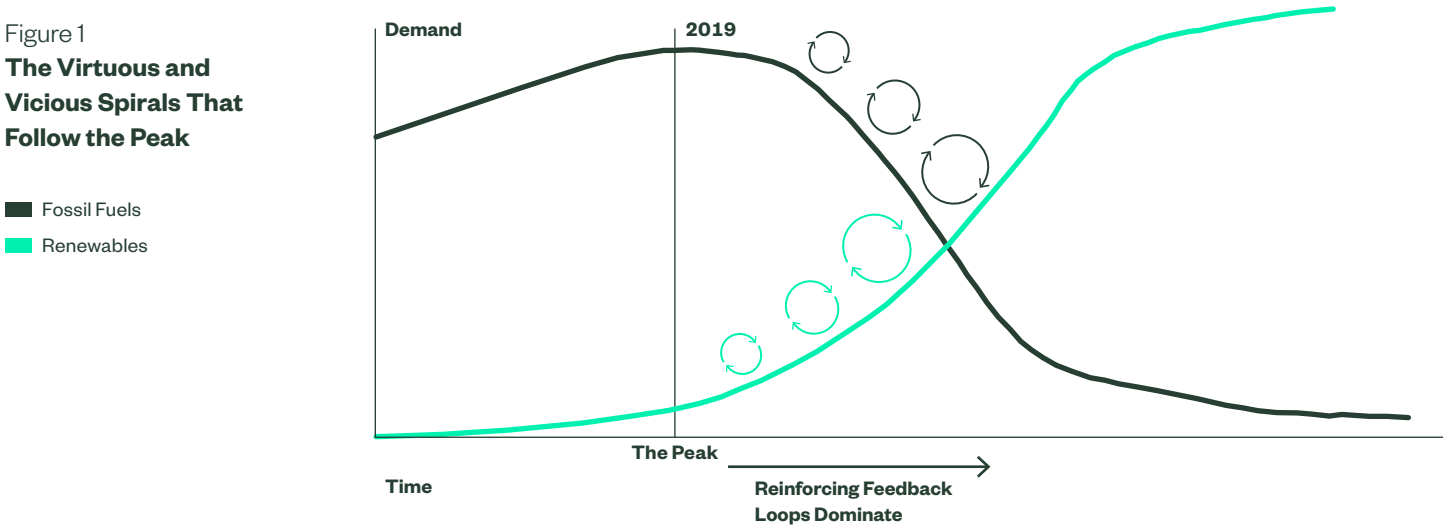
The energy transition is following the well-trodden path of many past technological revolutions. The rapidly falling costs of the new and superior technology overwhelm the seemingly impregnable incumbent system. With a market share of as low as 2–3%, fast-growing challengers can take all the growth in a slow-growth market and drive the incumbent's peak.[2]

The incumbent's peak is, in retrospect, a decisive tipping point. It simultaneously initiates a storm of virtuous and vicious interacting spirals, which span technology, economics, politics and society. Many overestimate how long it takes to meet a peak and underestimate the impact of it.

As complexity scholars note, once self-accelerating loops dominate the behaviour of a system, change runs away with itself.[3] This is where we are today: peak fossil fuel demand was likely 2019, and now the loops of change are gaining dominance.

If these self-reinforcing feedbacks loops are the engine of technological revolutions, then the climate imperative adds further impetus to this already powerful engine. Technology transitions can be fast; this one may be faster.

Figure 1
The Virtuous and Vicious Spirals That Follow the Peak



Note: Stylised graph. Source: Carbon Tracker Initiative.

As these loops amplify each other, they give rise to the non-linear "S-curve" typical of technology transitions. Investors and policymakers can harness these well-understood dynamics of change.

Seven Feedback Loops

We summarise seven feedback loops of the energy transition observed across **costs, technology, expectations, finance, society, politics and geopolitics.** Critically, all of these feedback loops are positive for renewables and negative for fossil fuels.

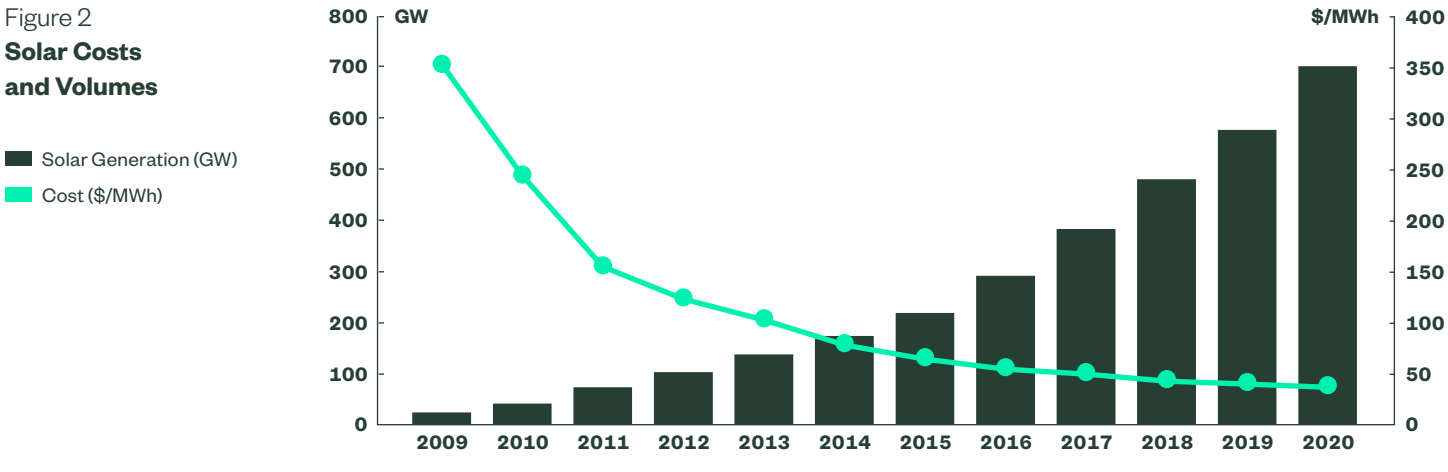
Cost

Rising Volumes and Falling Costs: A Virtuous Spiral

Rising volumes for clean technologies are accompanied by several reinforcing feedbacks that reduce costs and thus stimulate more volumes. This relationship between volumes and cost is captured in the learning curve: as you build more, you build better, cheaper and faster. Crucially, a technology's learning curve is persistent and predictable, as documented by academics.[4] Furthermore, this level of predictability and persistence rises with a technology's 'granularity' smaller unit sizes, shorter construction times and higher frequency of unit deployment.

Solar and batteries are granular technologies: they ride learning curves. This explains why for every doubling of cumulative production in the last decade, the cost of solar and lithium ion batteries has fallen by 28% and 18% respectively.[5] Improvements in these technologies are continual: wind capacity has achieved average growth of 15% every year since 2010 and solar capacity has achieved 35% annual growth, as the Figure 2 shows.

Figure 2
Solar Costs and Volumes



Source: IRENA and Lazard (2021).

Falling Volumes and Rising Costs: A Vicious Spiral

The incumbent fossil fuel industry is subject to a vicious spiral as demand peaks and then starts to decline. Falling demand leaves fossil fuel firms with overcapacity, which can lead to lower utilisation rates, higher unit costs and stranded assets.

This vicious cycle is happening to each fossil fuel in turn: first was coal, now oil and next will be gas. Globally, the capacity factor of coal power generation has fallen to below 50%.[6] Similarly, the European electricity sector wrote down $150bn in unused fossil fuel capacity in the decade following its 2007 fossil fuel peak.[7] The falling oil demand in 2020 resulted in record write-downs for North American and European oil companies of approximately $145bn.[8]

Conventional car manufacturers are being forced to sell factories in the face of their electric vehicle (EV) competition. Some analysts, such as Morgan Stanley, argue that internal combustion engine (ICE) manufacturing capacity already has no value.[9]

Technology

Untapped Innovation Potential: A Virtuous Spiral

Technologies come in clusters. Demand and value have a mutually reinforcing relationship: demand for solar energy creates demand for batteries; better batteries enable more supply of solar.

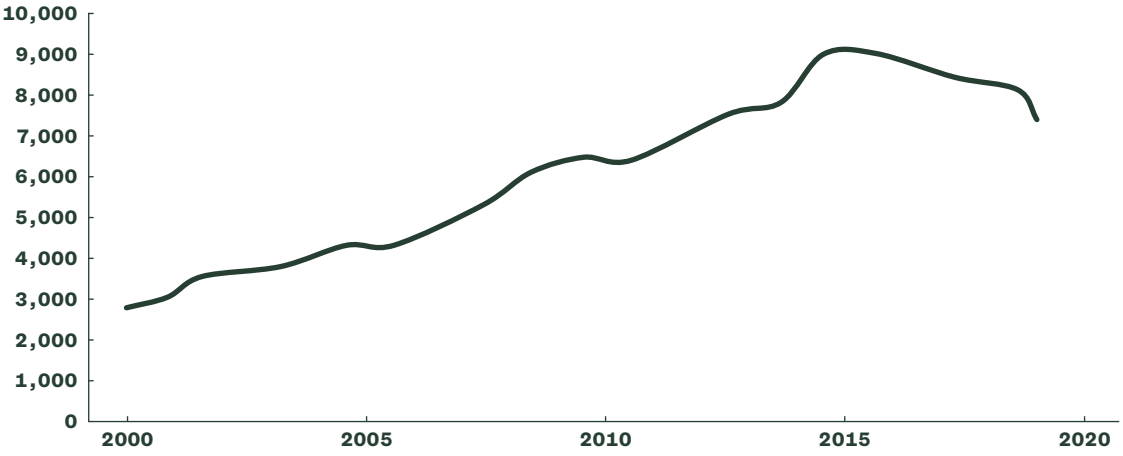
As innovations around clean energy increase, so the value of clean energy technologies rises. For example, as smart grid innovations rise, the grid gets more demand-responsive, so the problem of intermittency reduces, and more renewables are rolled out. The digital 'green marriage' is one of many live examples of technological convergence accelerating change.[10]

Exhausted Innovation Potential: A Vicious Spiral

Over time, the innovation potential of an industry becomes exhausted. This technological dead-end is fundamental to the decline process: it redirects the wit and will of engineers to the growth sectors of tomorrow at a time when incumbents need them most. Incumbents are slower to accept the decreasing returns of ageing, but once they do, their capital follows the growth story.

Technological exhaustion may have hit the aged fossil fuel industry, observed in the number of fossil fuel patents tracked by the European Patent Office (EPO) and the International Energy Agency (IEA), which are down 18% since their peak in 2015. Notably, this has happened despite fossil fuel firms' best efforts to drive innovation when they need it most (see Figure 3).

Figure 3
Technological Dead-End: The Global Decline in Fossil Fuel Patents



Source: 'Patents and the Energy Transition', IEA & EPO (2021).

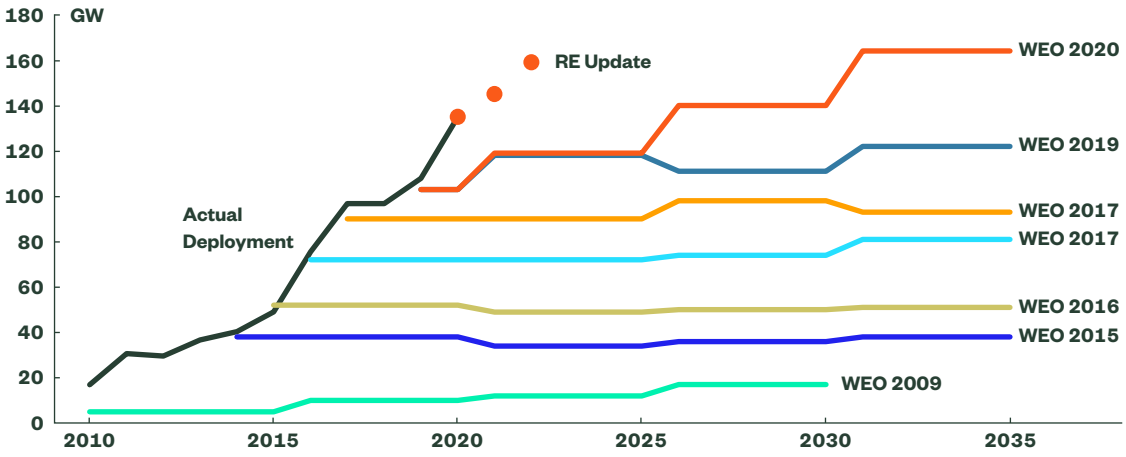
Expectations

Green Expectations: A Virtuous Spiral

Expectations are central to the process of economic change: when enough people hold expectations of change, they become self-fulfilling.[11] The moment the mainstream expects the world to rapidly decarbonise and leave carbon assets stranded is a key tipping point.

We believe that moment could be upon us. Mainstream expectations are tipping and perhaps already have.[12] For decades, climate concerns were peripheral and a transition away from fossil fuels deemed painful or distant. However, climate and the energy transition is perceived as central, with the World Economic Forum ranking climate change as the greatest global risk.[13] Central banks and regulators routinely cite it as one of the largest sources of financial risk.[14] The mentions of climate change in investment firms' meetings have soared in the last year.[15] Furthermore, key forecasters, such as the IEA, have belatedly moved from forecasting linear growth for renewable technologies to forecasting exponential growth.[16]

Figure 4
IEA Forecasts of Solar Deployment



Source: Carbon Brief. Projections represent the IEA's Stated Policies Scenarios (STEPS) taken from the World Energy Outlook (WEO) (2021).

Fossil Expectations: A Vicious Spiral

Fossil expectations face a vicious spiral: as the incumbent forecasts of 'business-as-usual' are continuously challenged, forecasters are obliged to change their models or forego credibility.

The IEA finally acknowledged that global coal demand peaked in 2014[17] and that oil demand for cars likely peaked in 2019.[18] The Agency released a 1.5°C scenario,[19] explicitly stating that it means no new fossil fuel development. Oil companies, such as BP, have released forecasts suggesting oil demand has peaked, as the range of industry forecasts has never been wider.[20] Elsewhere, forecasts integrating the feedback-rich dynamics of transitions are coming to the fore, for example, in analysis from Oxford University.[21]

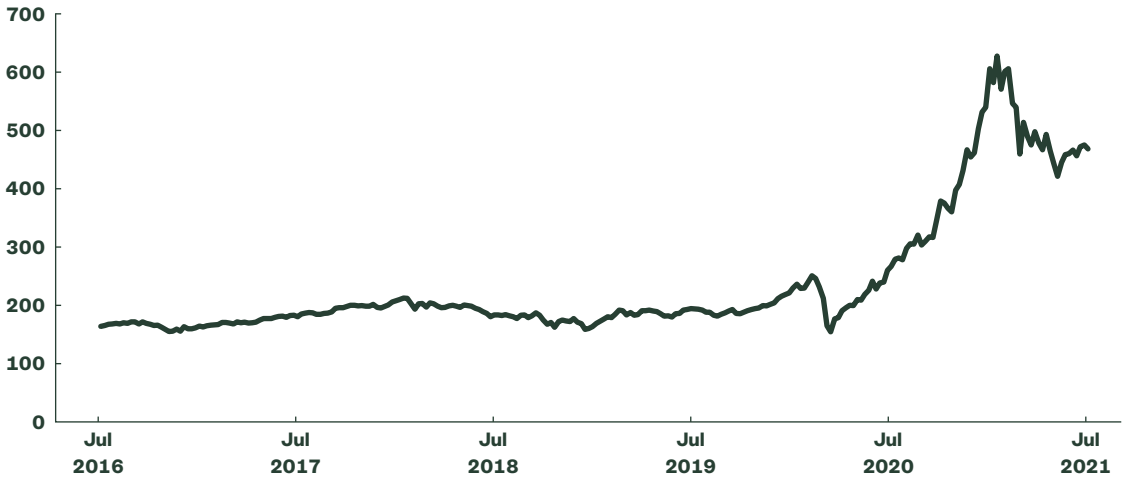
Finance

Reflexive Green Finance: A Virtuous Spiral

Investors are often enthused by the growth story of technological revolutions. This exuberance has a reflexive and recursive loop: finance accelerates the transition, thereby generating more excitement.[22] As growth expectations climb, capital flows into clean energy technologies. Higher volumes of capital bring down the cost of finance and speed up deployment. More deployment means lower costs, better technology and more growth, which attract more finance. A classic example of this was the rise of the internet economy at the end of the 1990s.

The last two years has been characterised by financial market exuberance about the prospects for green technologies. The NEX index of renewable energy stocks, for example, is up by 110% relative to the start of 2020. Meanwhile, money is entering into selected new energy technologies such as batteries, hydrogen and EVs.

Figure 5
Renewable Energy Stock Performance: NEX Index



Source: Bloomberg (2021).

In 2020, the EV sector raised $28bn in new capital from equity markets, ten times more than it raised in previous years.[23] According to PwC, cleantech venture capital has soared from $400m in 2013 to $16bn in 2019 — a 40-fold increase.[24] The number of battery Gigafactories (very large factories) being built has gone from 1 to over 150 today in just five years.[25] Chinese solar panel manufacturing capacity has increased a startling 10-fold in the last decade.[26]

Reflexive Fossil Finance: A Vicious Spiral

The incumbent industry faces the opposite dynamic: more and more finance challenges the incumbents, thereby accelerating the tendency for decline. As capital flees, the cost of capital rises. Incumbents are therefore forced to stop expanding and to change their strategy.

The decline of the fossil fuel sector in the stock market has been dramatic. Since 2011, the global coal index fell 75%, and the US coal index fell by 99% and had to be discontinued.[27] The energy sector's share of the S&P 500 index over the last decade has fallen from 13% to 3%.[28]

In response to falling share prices and investor pressure, fossil fuel companies are starting to change strategy. ExxonMobil and Chevron have both faced shareholder rebellions, while BP and Shell are beginning to reduce their capital expenditure on fossil fuels and increase allocations to renewables. Most car companies have already decided to pivot into electric vehicles.

As financial market participants realise that they are overexposed to the fossil fuel system, there is the real risk of a 'Minsky Moment', where they all sell — as identified by former Bank of England Governor, Mark Carney.[29]

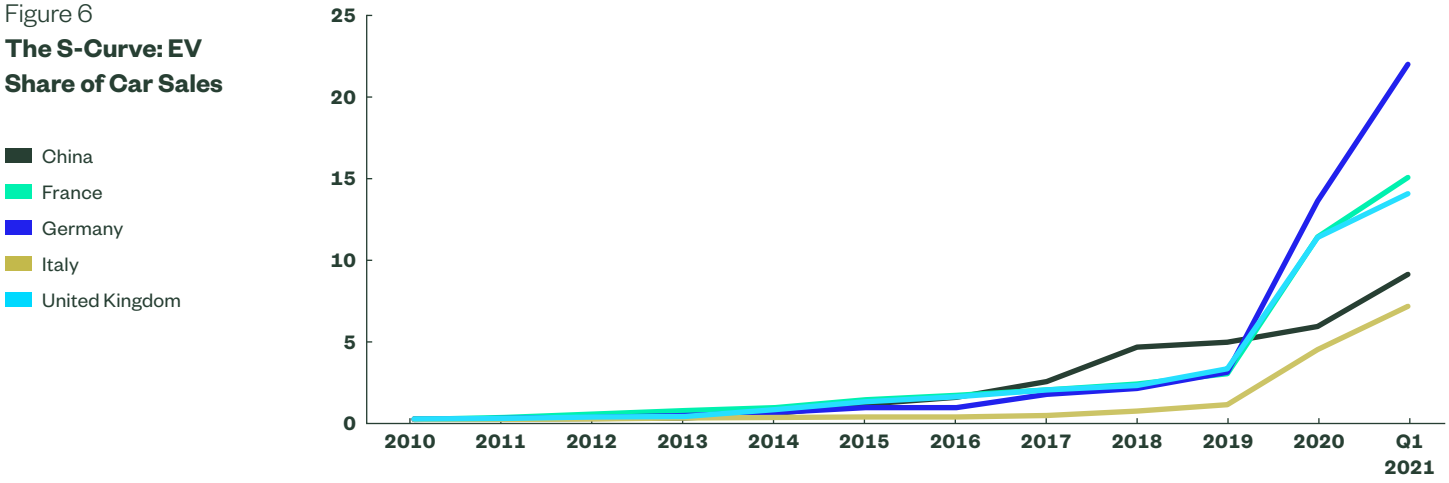
Society

Green Diffusion: A Virtuous Spiral

Social contagion, or the phenomenon of people copying their neighbours and peers, is as empirically sound as it is intuitive. Social contagion applies to the adoption of clean energy, behaviour change or public opinion. If each person who buys an electric vehicle, or attends a protest, spurs more people to join them, then this gives rise to the S-curve of diffusion.

The adoption of electric vehicles is proving to be a classic illustration of the S-curve. As more people buy EVs, so more charging stations are built (a 'network effect') and more adopt. As adoption rises, more people see and talk about EVs and adoption expands further.

Figure 6
The S-Curve: EV Share of Car Sales



Source: IEA and Rystad (2021).

Fossil Support: A Vicious Spiral

Changing social norms can, however, put products out of fashion quickly. This is playing out as society turns against fossil fuels and plastics. As markets and government policy react to this, awareness rises, alternatives improve and the prices of the old products rise (through falling demand or policy), thereby reducing public support.

For example, IPSOS polling finds that 70–80% of the public wants to reduce plastic usage, including a ban on single-use. With this kind of public opinion, plastic regulation rises and the market for alternatives grows. Future falling plastics demand is significant for the oil industry, with plastics being the largest source of forecasted growth.[30]

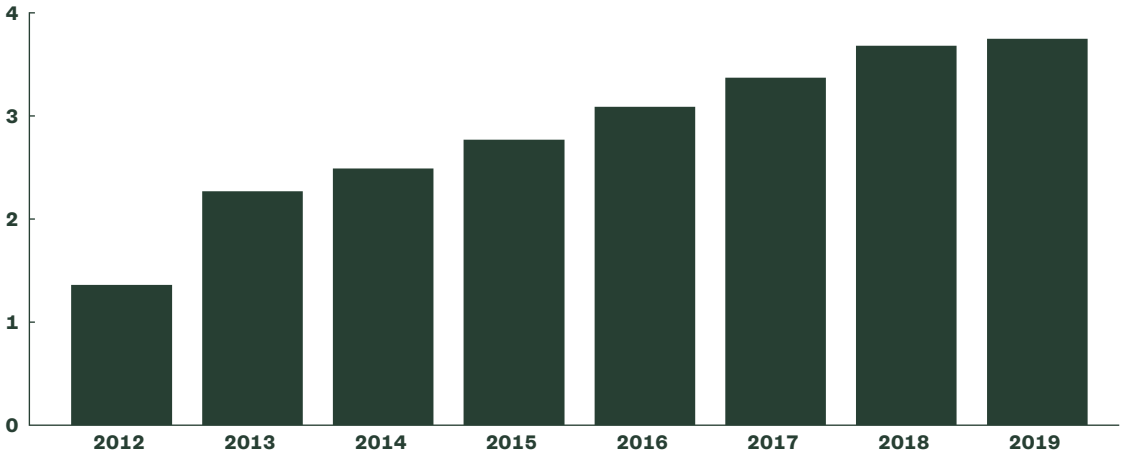
Politics

Green Political Capital: A Virtuous Spiral

The political capital of the new green system is in an upward spiral. As the industry grows, so too does its political clout. As technological gains ease the politics of the energy transition, the political narrative is flipping from pain to gain. As politicians realise that the industries of the future are green, so they too focus on where opportunities lie.

Renewable energy jobs are rising as a function of deployment and in many regions now outnumber those in fossil fuels.[31] This shift in employment is happening fast, given renewable energy's growth.[32]

Figure 7
The Rise of Solar Jobs (Millions)



Source: IRENA (2020).

Country by country, the green coalition is beginning to outmuscle the fossil fuel coalition at the same time as the economics of clean become ever more attractive. The implication is the inevitability of an ever more aggressive policy response.

Fossil Political Capital: A Vicious Spiral

Despite the historic political influence of the fossil fuel industry, it is now in a downward trend. As public pressure increasingly focusses on the fossil fuel majors, the social licence to operate is being increasingly challenged. The combination means less power, credibility and policy support.

The US oil sector's lobbying capital expenditure peaked in 2009 and is down by 36% since then.[33] Legal risks are also rising as the science of attribution improves.[34] Meanwhile, Europe is proposing a carbon border tax (a process that could set off a carbon pricing domino effect)[35] and the global share of emissions under a carbon tax has increased from 5% to 22% in the last decade.[36]

Geopolitics

The Race to Power: A Virtuous Spiral

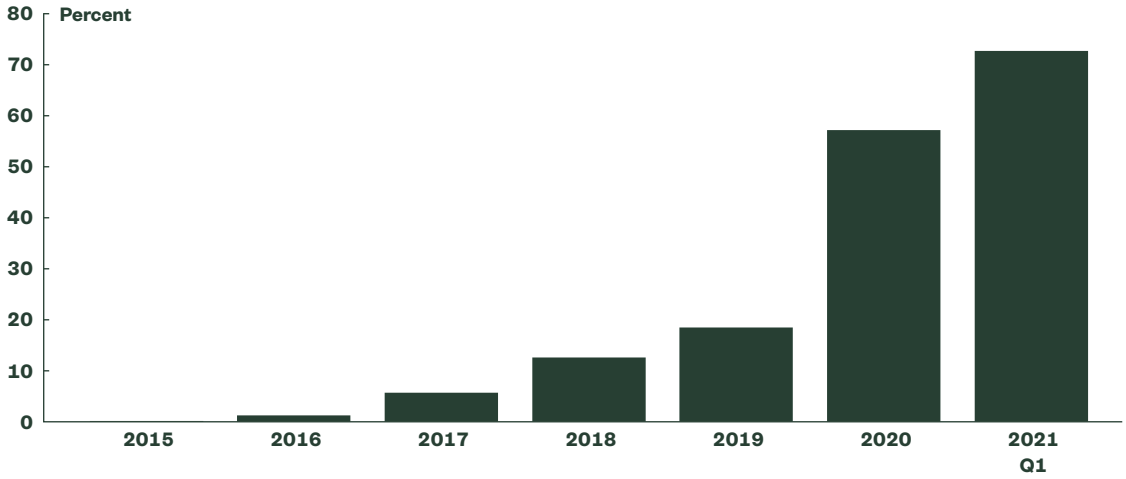
Geopolitical competition is spurring technological progress forward. The most consequential case of this race is between China and the US.[37] Both have their eyes on the prize of technological leadership in the energy economy of tomorrow and the geopolitical power that comes with it. Where the motivation is not influence, it is energy independence, and the economic and geopolitical benefits that come with that. Globally, 80% of people live in countries that import fossil fuels, so most of the world has a strong incentive to shift to domestic renewable energy.[38]

China is far ahead of the US and the rest of the world in the production of batteries, solar and EVs, but the US leads China in low carbon patents. Elsewhere, many other geographies (particularly India and Europe) seek the international competitiveness that comes with leading the world into the green digital age.

The Race to Zero: A Virtuous and Vicious Spiral

The race to net zero emissions is equally the race out of fossil fuels as climate commitments breed more commitments. This is playing out faster than many predicted. In 2017, 6% of the world's CO_2 emissions were covered by net zero targets; in 2021, that number is 73%.[39] First comes the spread of distant targets, then comes the spread of interim and specific targets.

Figure 8
Percentage of CO_2 Emissions Covered by Net Zero Targets



Source: IEA (2021).

This is happening with coal: Indonesia and Malaysia recently set no new coal targets, while the South Korean and Japanese governments have committed to stop funding coal overseas.[40] China's Belt and Road Initiative is also foregoing coal for green technology.[41]

Tipping Points

Quite how fast the energy transition will unfold is not yet clear. But, if the history of technological revolutions teaches us anything, it is the rapid speed at which change can occur once an interconnected set of positive feedback loops dominate the behaviour of a system.

Clearly, no cluster of positive feedback loops is perpetual. The engine will stop accelerating — negative feedback loops and diminishing returns will begin to take back control of the global energy system.

However, that is a story for another decade — a story to be told in a world transformed.

Endnotes

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- Invest as stewards
- Invent the future

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*Pensions & Investments Research Center, as of December 31, 2020.
† This figure is presented as of June 30, 2021 and includes approximately $63.59 billion of assets with respect to SPDR products for which State Street Global Advisors Funds Distributors, LLC (SSGA FD) acts solely as the marketing agent. SSGA FD and State Street Global Advisors are affiliated.

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ID778253-3810600.1.2.GBL.RTL 1021
Exp. Date: 31/10/2022