Carbon Tracker Initiative

Spiralling disruption

The feedback loops of the energy transition

Analyst Note

August 2021

About Carbon Tracker

The Carbon Tracker Initiative is a team of financial specialists making climate risk real in today's capital markets. Our research to date on unburnable carbon and stranded assets has started a new debate on how to align the financial system in the transition to a low carbon economy.

www.carbontracker.org | *hello@carbontracker.org*

About the Author

Sam Butler-Sloss – Research Associate

Sam Butler-Sloss is a Research Associate in the energy transition team.

Kingsmill Bond – Energy Strategist

Kingsmill Bond is the Energy Strategist for Carbon Tracker.

Harry Benham – Special Advisor

Harry Benham is Chairman of UK energy think tank Ember, and Special Advisor to Carbon Tracker.

Any comments or critiques are appreciated.

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Key Findings

The fossil energy system is falling over the edge of the demand cliff. Peak fossil fuel demand likely occurred in 2019. This marks the beginning of runaway change: the tipping point where positive feedback loops start to dominate the system.

Positive feedback loops mean disruption. We identify seven virtuous and vicious feedback loops that are driving a rapid transformation of the global energy system, as renewables displace fossil fuels.

1. The volume-cost feedback loop. As renewable volumes rise, so costs fall which then spurs more volumes. Meanwhile falling fossil volumes mean lower utilisation rates which increase costs and drive down volumes. Witness the rise of solar and the demise of coal.

2. The technology feedback loop. As technologies build on top of each other, so they spur each other on: more electric vehicles mean lower battery costs which then increases renewable penetration. Meanwhile 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, and forecasters are obliged to change their models. As models change, so too do the perceptions of investors and policy makers, and this speeds up what is possible.

4. The finance feedback loop. As growth draws in more capital, the cost of capital falls and this enables more expansion. Meanwhile, declining growth scares investors, and falling share prices force fossil fuel companies to cut investment and change strategy.

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

6. The politics feedback loop. As technologies improve, voters and politicians realise that renewables mean gain not pain, and this drives 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 of the US in the energy technologies of the future, the US fears losing power and is obliged to retool for a renewable economy. This race for influence drives renewable technologies out into the rest of the world.

So the revolution begins. As one tipping point is breached, so the next tipping point moves forward. The 2020s will be a decade of cascading change, powered by interlinking feedback loops. Investors and policy makers need to understand the dynamics of change if they are to take advantage of the new world that is rapidly opening up.

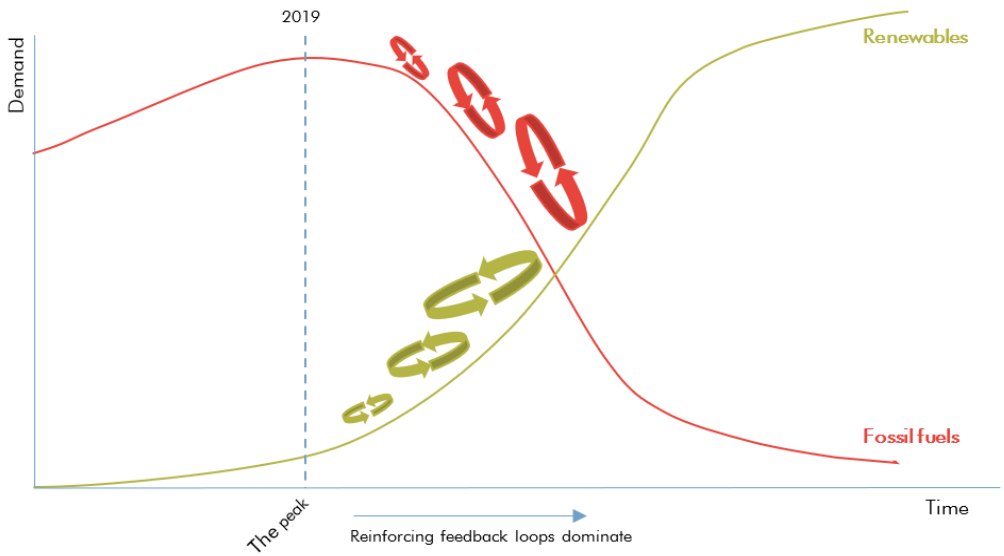
Introduction

> *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 technological revolutions, as laid out by Joseph Schumpeter,[1] Carlota Perez,[2] Sandy Nairn,[3] Tony Seba[4] and others. 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 challenges can take all the growth in a slow-growth market and drive the incumbent's peak.[5]

The incumbent's peak[6] is, in retrospect, a decisive tipping point. It simultaneously initiates a storm of virtuous and vicious spirals for the ascending *and* descending system respectively.[7] These spirals span technology, economics, politics and society, incessantly feeding off one another along the way. As complexity scholars note, once self-accelerating loops dominate the behaviour of a system, change runs away with itself.[8] This is where we are today: peak fossil fuel demand was likely 2019, and now the loops of change are gaining dominance.

THE VIRTUOUS-VICIOUS SPIRALS THAT FOLLOW THE PEAK



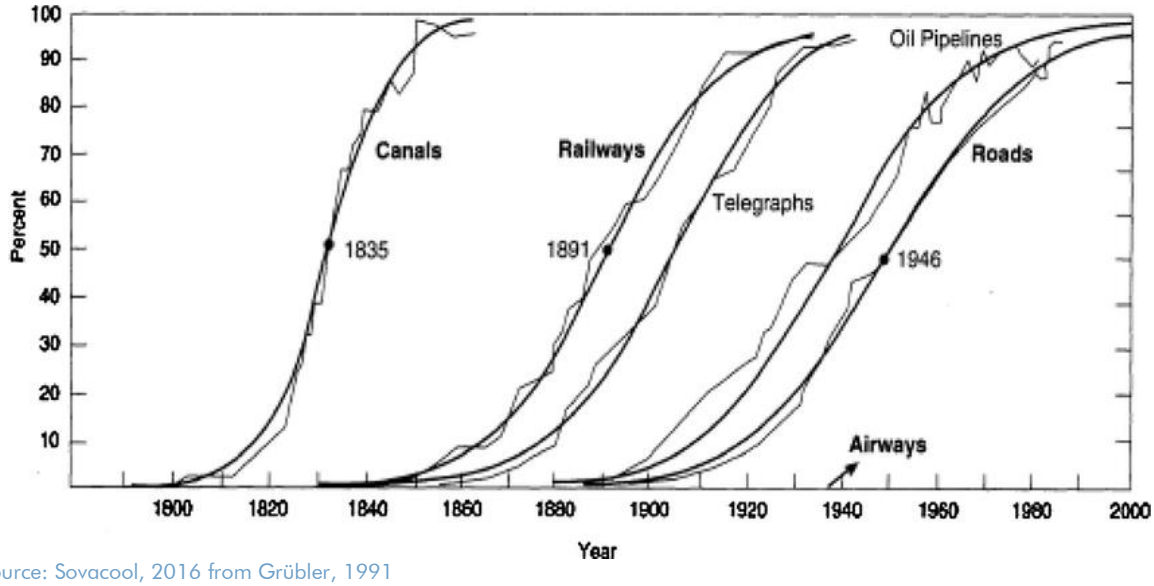
Note: Graph stylised; Source: Carbon Tracker

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

[1] *Source: Creative destruction and the future of the global economy, Schumpeter, 1942*
[2] *Source: Technological revolutions and financial capital, Perez, 2002*
[3] *Source: Engines that move markets, Nairn, 2002*
[4] *Source: Rethinking Humanity, Seba & Arbib, 2020 or Rethinking Energy 2020-2030, Seba & Dorr, 2020*
[5] *Source: Renewables are too small to matter, Carbon Tracker, 2018*
[6] *The peak does not happen overnight and is only clearly visible in retrospect. It could also be described as a plateau, where demand bumps along for a few years at the peak level before finally falling off the cliff. In hindsight that looks like a peak; at the time it is a long haul.*
[7] *The virtuous-vicious cycles that rapidly drive one industry's demise and another's rise is a framework well explored by Tony Seba. For example, see p.17 of Rethinking Energy*
[8] *Sources: Sensitive intervention points in the post-carbon transition, Farmer et al, 2019; The Model Thinker, Page, 2018*

As these loops amplify each other, they give rise to the non-linear "S-curve" typical of technology transitions. Underplaying the self-accelerating, non-linear nature of this engine (and its rocket fuel) is at the heart of misunderstanding the shape and speed of the energy transition. While many of the details are unknown, the dynamics of change are well understood – investors and policy makers must harness them.

THE S-CURVES OF TECHNOLOGY SHIFTS



Source: Sovacool, 2016 from Grübler, 1991

In this piece, we summarise this engine: the seven feedback loops of the energy transition observed across **costs, technology, expectations, finance, society, politics** and **geopolitics**. It is a summary. The list of loops is not exhaustive; each area is not comprehensive. The aim is a short and simple illustration of the cumulative and cascading nature of change, supported with examples and referenced with more detailed analyses. The story is told in 14 pages, one page for each virtuous and vicious spiral.

A BOX ON LANGUAGE

A positive feedback loop is when, for example, an increase in "A" produces a change in "B" which in turn produces more of "A". Or, in other words, the effect comes back around to become the cause. In which case, all else equal, change is "self-accelerating", "self-amplifying" – it runs away with itself.

For example, as a tree grows, it gets more light and then grows further ahead (**virtuous spiral**). Then as the other trees are starved of light, they grow less and thus get even less light (**vicious spiral**).

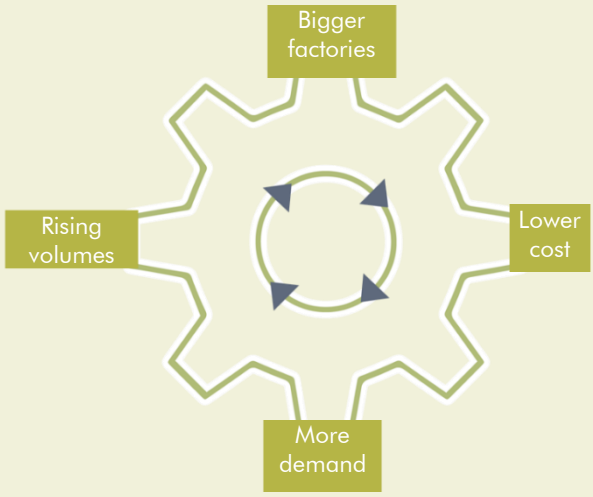
Tipping points are thresholds after which positive feedback loops dominate the behaviour of the system.

1. Cost

1.1 Rising volumes and falling costs: a virtuous spiral

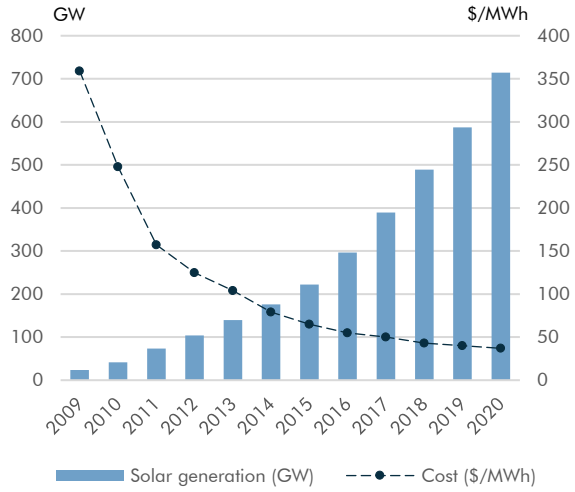
THE LOOP: IN THEORY

Rising volumes for clean technologies are accompanied by several reinforcing feedbacks that bring down 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 in detail by two Oxford mathematicians.[9] Furthermore, this level of predictability and persistence rises with a technology's "granularity" (i.e. smaller unit sizes, shorter construction times and higher frequency of unit deployment).[10]



THE LOOP: IN MOTION

1.1 SOLAR COSTS AND VOLUMES



Source: IRENA, Lazard

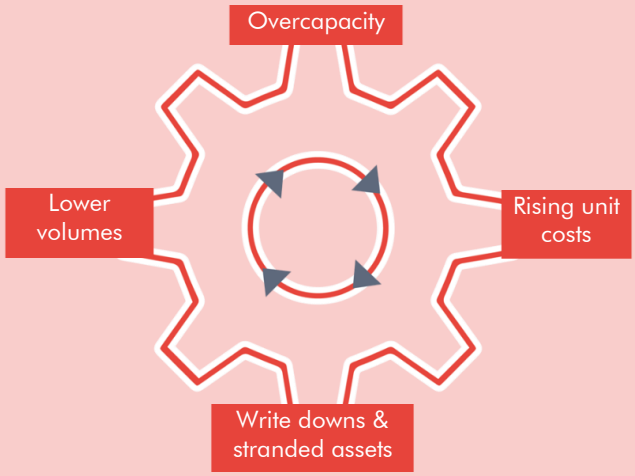
Solar and batteries are granular technologies: they surf learning curves.[11] This explains why for every doubling of cumulative production in the last decade the cost of solar and lithium-ion batteries has fallen by 28% and 18% respectively.[12] Improvements in these technologies are continual: solar efficiency records (commercial and lab) are broken year on year.[13] The diameter of the largest commercial wind turbine has gone from 90m in 2010 to 220m in 2021.[14] And in turn solar capacity has grown on average at 35% a year and wind at 15% since 2010.

[9] *Source: How predictable is technological progress?,* Farmer & Lafond, *2016; Estimating the costs of energy transition scenarios using probabilistic forecasting methods, Way et al, 2020*
[10] *Source: For a key paper on technological "granularity" and decarbonisation, see Granular technologies to accelerate decarbonization,* Wilson et al, 2020
[11] *The choice between renewables or fossil fuels is a choice between a technology or a commodity, that is, harvesting energy under increasing or decreasing returns. The economics of each is fundamentally different.*
[12] *Source: BNEF Executive Factbook, BNEF, 2021; New Energy Outlook, BNEF, 2020*
[13] *For a visual illustration of the evolution of solar panels' efficiency, see: Best Research-Cell Efficiencies,* NREL, 2019
[14] *Source: Offshore Wind Outlook,* IEA, *2019*

1.2 Falling volumes and rising costs: a vicious spiral

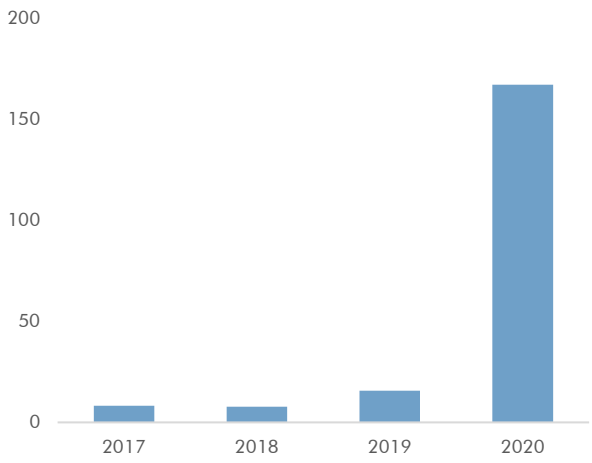
THE LOOP: IN THEORY

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. That leads to lower utilisation rates, higher unit costs and stranded assets. As sales stagnate, so they then start to struggle to repay loans and are obliged to sell off parts of the business to survive. This pattern is made more dramatic by incumbents failing to see peak demand and planning for continued growth.[15]



THE LOOP: IN MOTION

1.2 WRITE-DOWNS BY NORTH AMERICAN & EUROPEAN OIL-AND-GAS COMPANIES, $BN



Source: Wall Street Journal, Carbon Tracker

This vicious cycle is happening to each fossil fuel in turn: first it was coal, now it is oil, next it will be gas. Half the US coal sector went bust within two years of peak global coal demand in 2014. Globally, the capacity factor of coal power generation has fallen to below 50%.[16] Similarly, the European electricity sector wrote down $150bn in unused fossil fuel capacity in the decade following its 2007 fossil fuel peak.[17] The falling oil demand in 2020 resulted in record write-downs for North American and European oil companies of over $150bn. Conventional car manufacturers are being forced to shut down or sell factories in the face of their electric competition.[18] And analysts such as Morgan Stanley argue that internal combustion engine (ICE) manufacturing capacity already has no value.[19]

[15] *For example, the European electricity sector failed to forecast peak fossil fuel electricity in 2007, the coal industry failed to foresee peak coal demand in 2014, the car sector did not forecast peak ICE demand in 2018, and the oil industry failed to forecast the peak demand that most likely occurred in 2019.*
[16] *Source: Ember, 2020*
[17] *Source: Lessons from European electricity for global oil and gas, Carbon Tracker, 2018*
[18] *Ford recently ended production in Brazil, with an expected cost of $4.1b; in Q1 2021, Honda sold its UK manufacturing, to name only a few.*
[19] *Source: EV asset and ICE liability, Morgan Stanley, 2021*

2. Technology

2.1 Untapped innovation potential: a virtuous spiral

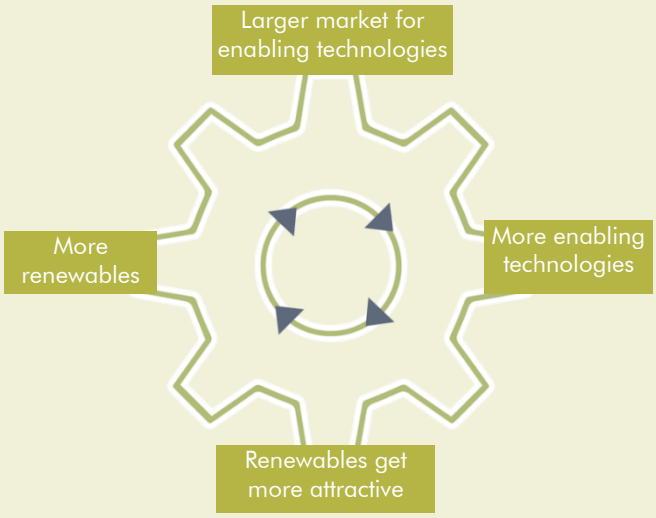
THE LOOP: IN THEORY

Technologies come in clusters. Their demand and value have a mutually reinforcing relationship.

Demand for solar creates demand for batteries; better batteries enable more supply of solar.

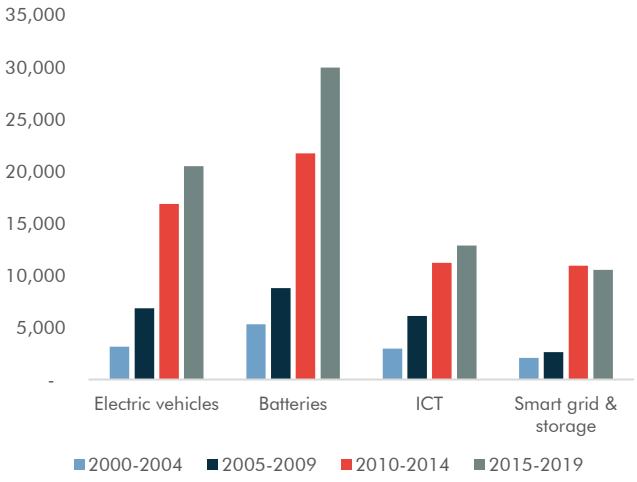
More electric vehicles create more demand for batteries; cheaper batteries enable more supply of electric vehicles.

Electric vehicles create demand for clean electricity;[20] clean electricity creates a greater justification to electrify transport.



THE LOOP: IN MOTION

2.1 THE NUMBER OF LOW CARBON PATENTS GLOBALLY



Source: EPO & IEA[22]; Note: the figures represent the total number of patents in selected time intervals

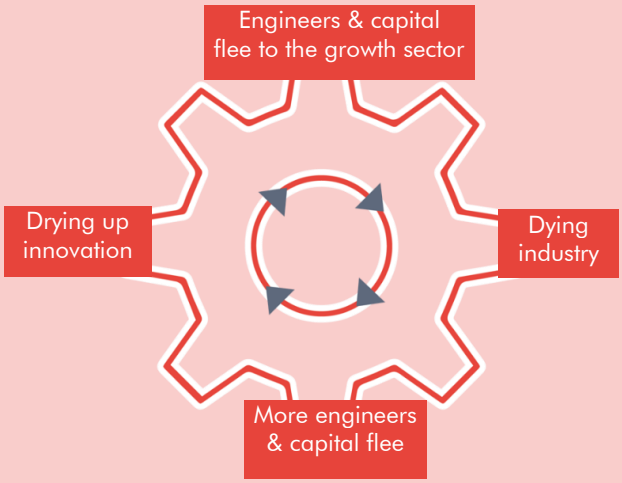
The low carbon technology cluster is still young. Data from the European Patent Office shows a rising number of patents for low carbon technologies, with an increase of 50% in the last 10 years. As innovations around clean energy increase, so the value of clean energy technologies rises. For example, as smart grid innovations rise, the grid gets more demand-responsive, so the problem of intermittency reduces, and more renewables get rolled out. The digital-green marriage is one of many live examples of technological convergence accelerating change.[21]

[20] *To the extent there is green motivation, governments and consumers do not want electric cars powered by coal*
[21] *For the self-reinforcing technology feedback loops see for example: World Energy Transitions Outlook, IRENA, 2021 or Making clean electrification possible, Energy Transitions Commission, 2021 or The power revolution, Actis, 2021*
[22] *Source: Patents and the Energy Transition, IEA & EPO, 2021*

2.2 Exhausted innovation potential: a vicious spiral

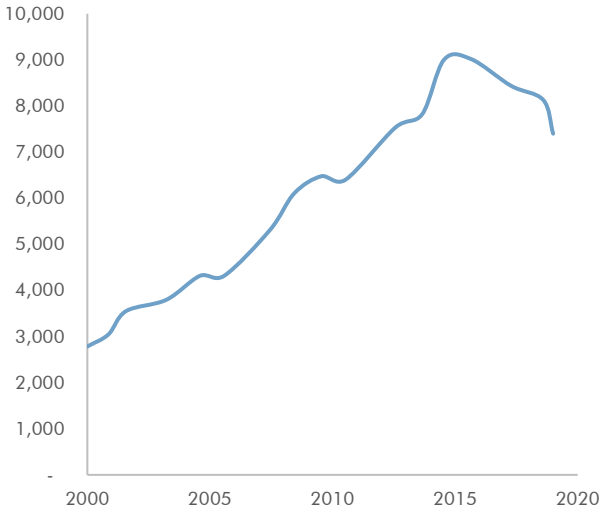
THE LOOP: IN THEORY

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 the 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.



THE LOOP: IN MOTION

2.2 THE TECHNOLOGICAL DEAD-END: THE GLOBAL DECLINE IN FOSSIL FUEL PATENTS



Source: EPO & IEA[24]

Technological exhaustion has hit the aged fossil fuel industry, observed in the number of fossil fuel patents tracked by the EPO 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. Only 3% of over 9,000 patents filed by UK and Norwegian fossil fuel extraction firms since 2012 were related to climate mitigation.[23] If and when fossil fuel companies shift their R&D, clean innovation will be further bolstered. Car companies already have dramatically shifted their investments, with most of the key players such as VW and Volvo having declared an end date for the sale of ICE cars. As more engineers and capital continue to switch tracks in response to diminishing returns, the industry decline process will be further accelerated.

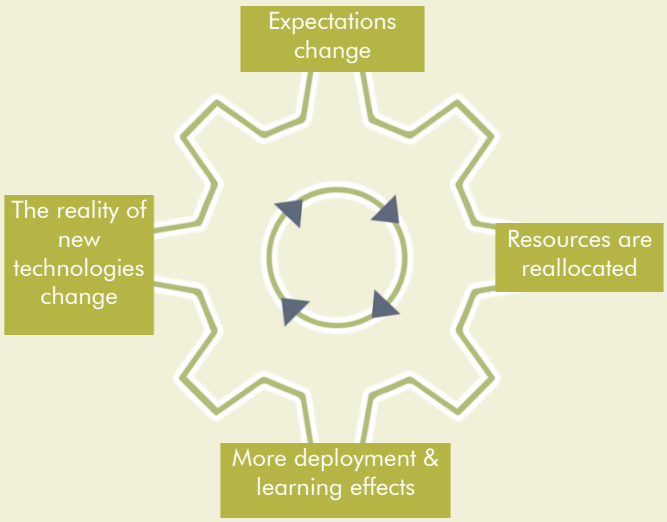
[23] *Source: R&D tax credits can be a significant source of taxpayer support for fossil fuel innovation, McDowall, 2021*
[24] *Source: Patents and the Energy Transition, IEA & EPO, 2021*

3. Expectations

3.1 Green expectations: a virtuous spiral

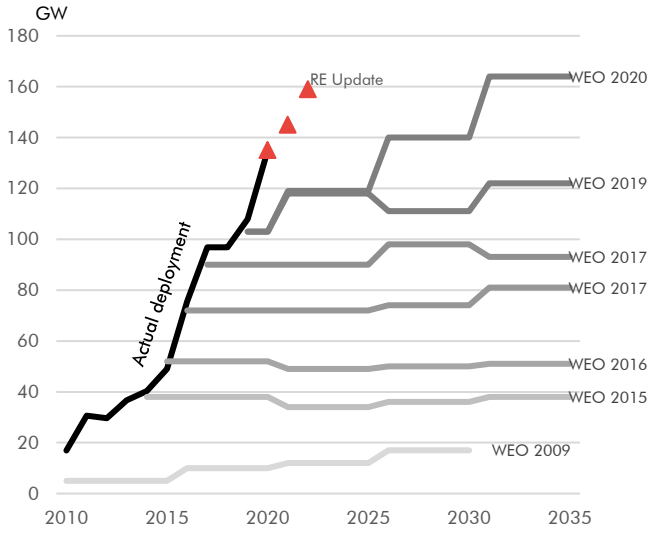
THE LOOP: IN THEORY

Expectations are central to the process of economic change: when enough people hold them, they become self-fulfilling.[25] It is almost too obvious to say, but the more people who think renewables are the future, the more that they become it and so the easier it is for more people to think it. Similarly, the more people who think net zero targets are credible, the more credible they become as more policy and resources are aligned to that future. The moment the mainstream expects the world to rapidly decarbonise and leave carbon assets stranded is a key tipping point.



THE LOOP: IN MOTION

3.1 IEA FORECASTS OF SOLAR DEPLOYMENT



Source: Carbon Brief; Notes: projections represent the IEA's Stated Policies Scenarios (STEPS) taken from the World Energy Outlook (WEO); RE Update from the IEA's Renewable Energy Market Update[30]

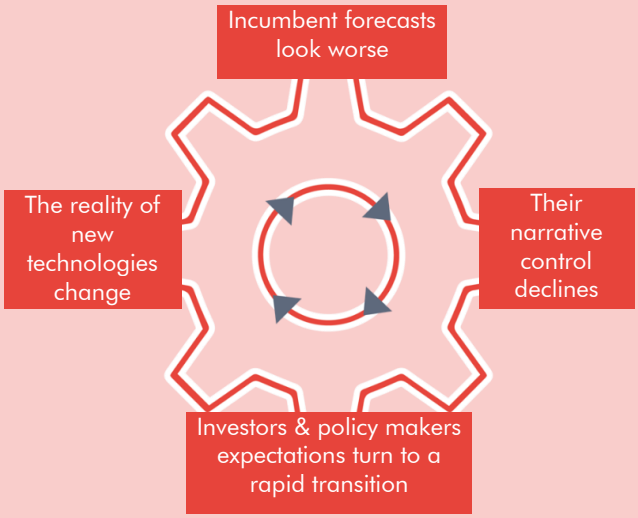
That moment is upon us. Mainstream expectations are tipping – perhaps already have.[26] For decades, climate concerns were peripheral and a transition away from fossil fuels deemed painful or distant. But now markets perceive climate and the energy transition as central: The World Economic Forum ranks climate change as the greatest global risk.[27] Central banks and regulators routinely cite it as one of the largest sources of financial risk.[28] The mentions of climate change in investment firms' meetings have soared in the last year.[29] And key forecasters, such as the IEA, have belatedly moved from forecasting linear growth for renewable technologies to forecasting exponential growth.

[25] *The importance of expectations has been emphasised by many, for example: Mind over matter, Zenghelis, 2021; Uncertain Futures, Beckert & Bronk, 2018; Narrative Economics, Shiller, 2019; The General Theory (Chapter 12), Keynes, 1936*
[26] *Source: Climate Contagion, Gilding, 2020*
[27] *Source:* The Global Risks Report 2021, WEF, 2021
[28] *Source: Open letter on climate-related financial risks, Carney et al, 2019*
[29] *Source: Carbon is now a buzzword on corporate earnings calls, UBS via FT, 2021*
[30] *Source: Renewable Energy Market Update – Outlook for 2021 & 2022 (p.8), IEA, 2021*

3.2 Fossil expectations: a vicious spiral

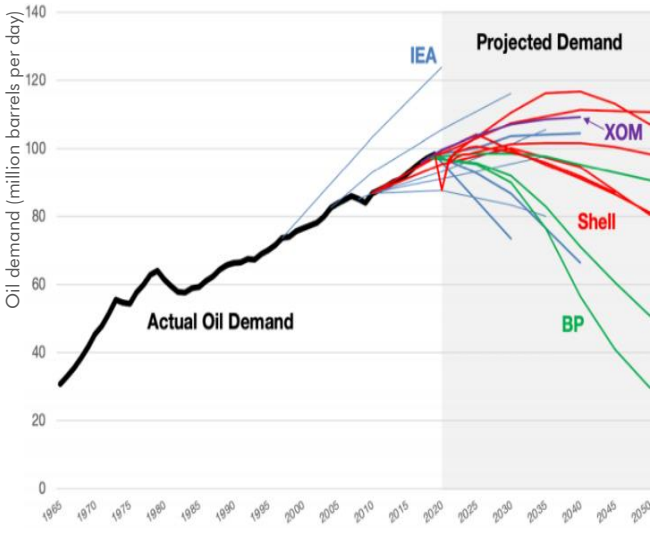
THE LOOP: IN THEORY

Fossil expectations face a vicious spiral: as the incumbent forecasts of "business-as-usual" are continuously shown to be incorrect, forecasters are obliged to change their models or forego credibility. Meanwhile, as new forecasts able to grasp the feedback rich dynamics of technological change take the stage, the gradual transition narrative is falling apart.



THE LOOP: IN MOTION

3.2 THE FUTURE OF OIL DEMAND



Source: David Victor[38]

Forecasters of imminent peaks[31] and steep cost reductions[32] have been outside the mainstream for many years. But, this has all changed in the last year or so. The IEA finally acknowledged that global coal demand peaked in 2014;[33] it noted that oil demand for cars likely peaked in 2019[34] and it released a 1.5 degrees scenario[35] 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.[36] Meanwhile forecasts integrating the feedback rich dynamics of transitions are coming to the fore, see for example the work from Oxford University.[37] If the real end to fossil fuels is not when they have no future but when enough people *think* that they have no future, then the end of an era is upon us.

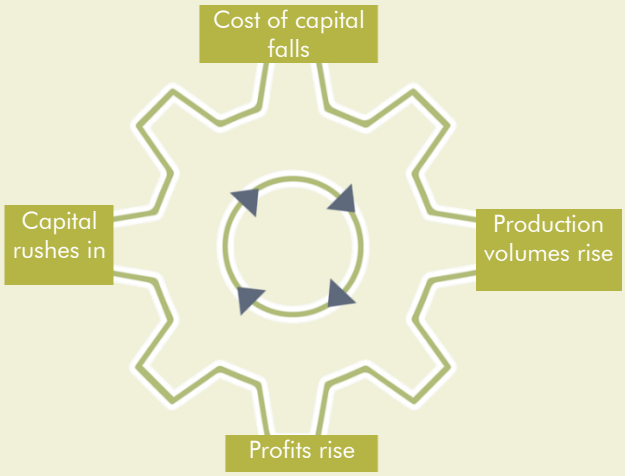
[31] *For example BNEF or Carbon Tracker*
[32] *For example Ramez Naam*
[33] *Source: WEO (p.195), IEA, 2020*
[34] *ibid (p.180-1)*
[35] *Source: Net zero by 2050, IEA, 2021*
[36] *Source: BP Energy Outlook 2020, BP, 2020*
[37] *Source: A new perspective on decarbonising the global energy system, Ives et al, 2021*
[38] *Source: Energy transformations: Technology, Policy, Capital and the Murky Future of Oil and Gas, Victor, 2021*

4. Finance

4.1 Reflexive green finance: a virtuous spiral

THE LOOP: IN THEORY

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.[39] 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. One classic example of this was the rise of the internet economy at the end of the 1990s.



THE LOOP: IN MOTION

4.1 RENEWABLE ENERGY STOCK PERFORMANCE: NEX INDEX

Source: Bloomberg

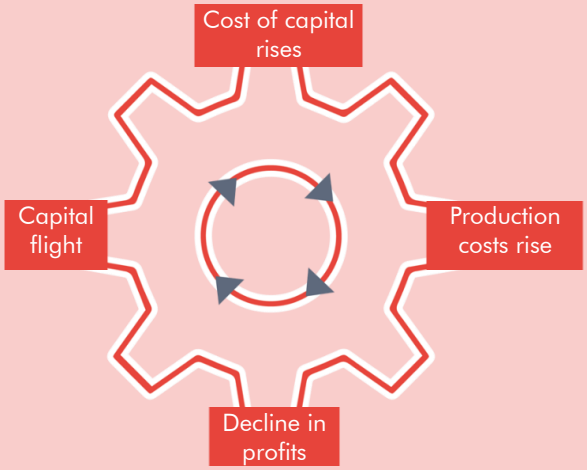
The last couple of years has been characterised by financial market exuberance about the prospects for green technologies. The NEX index of renewable energy stocks for example is up by 110% relative to the start of 2020. Meanwhile money is flooding into selected new energy technologies such as batteries, hydrogen and EVs. In 2020, the EV sector raised $28bn in new capital from equity markets, ten times more than it raised in previous years.[40] According to PwC, cleantech venture capital has soared from $400m in 2013 to $16bn in 2019 – a 40-fold increase.[41] The number of battery Gigafactories being built has gone from 1 to over 150 today in five years.[42] Chinese solar panel manufacturing capacity has increased 10-fold in the last decade.[43]

[39] *This reflexivity of finance is an idea popularised by George Soros in The Alchemy of Finance. And the financial frenzy that has been associated with the five previous technological revolutions is documented by Carlota Perez in Technological Revolutions and Financial Capital.*
[40] *Source: BNEF, 2021*
[41] *Source: The State of Climate Tech 2020, PwC, 2020*
[42] *Source: Global battery arms race, Benchmark Mineral Intelligence, 2021*
[43] *Source: Is India ready to compete with China in solar module production?, IEEFA, 2021*

4.2 Reflexive fossil finance: a vicious spiral

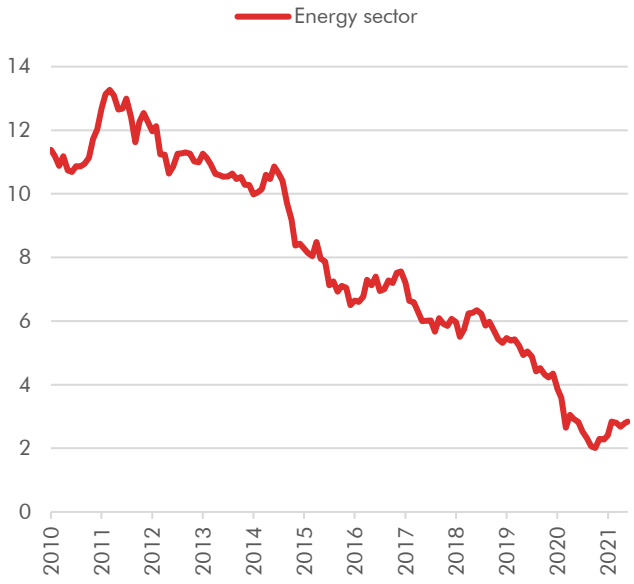
THE LOOP: IN THEORY

The incumbent industry faces the opposite dynamic: finance exits the incumbents, thereby accelerating their decline. As capital flees, the cost of capital rises. Incumbents are therefore forced to stop expanding and to change their strategy. This is initially not very profitable and only a few are successful, as pointed out in the Innovator's Dilemma.[44]



THE LOOP: IN MOTION

4.2 ENERGY SECTOR AS % OF S&P500



Source: Bloomberg

The decline of the fossil fuel sector on 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.[45] The energy sector's share of the S&P Index over the last decade has fallen from 13% to 3%. In response to falling share prices and investor pressure, fossil fuel companies are starting to change strategy. In recent months, ExxonMobil and Chevron, have both faced major shareholder rebellions. Oil companies, such as BP and Shell, are beginning to reduce their capital expenditure on fossil fuels and increasing allocations into renewables. Most car companies have already decided to pivot into electric vehicles. And 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 Mark Carney.[46]

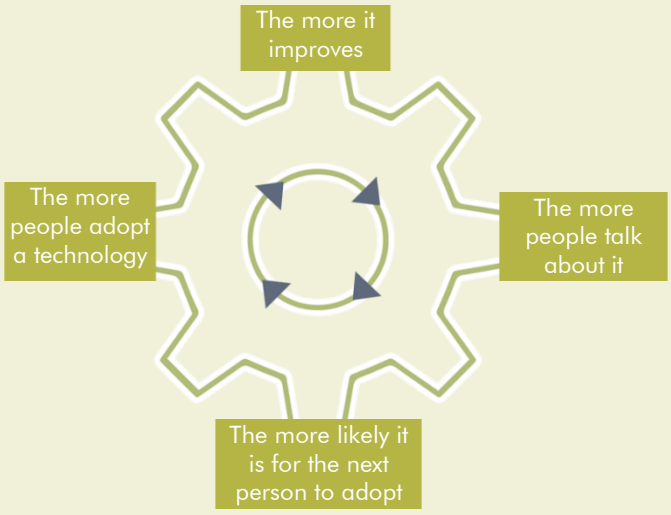
[44] *Source: The Innovator's Dilemma, Christensen, 1997*
[45] *Source: Can a virus and viral ideas speed the world's journey beyond fossil fuels?,* Lovins & Bond, *2021*
[46] *Source: Breaking the tragedy of the horizon, Carney, 2015*

5. Society

5.1 Green diffusion: a virtuous spiral

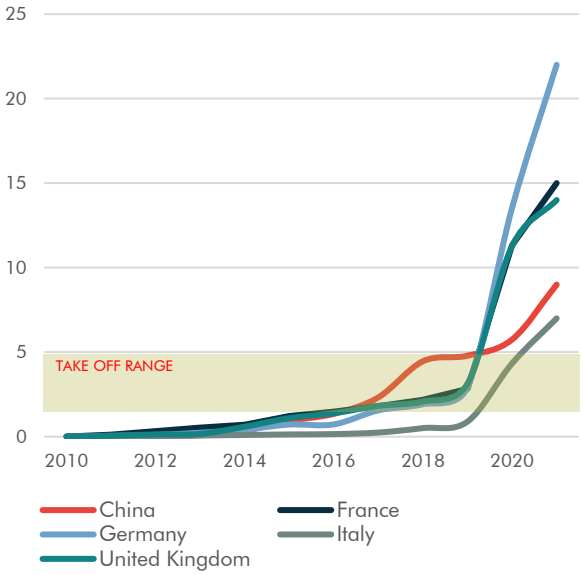
THE LOOP: IN THEORY

Humans copying their neighbours and peers is as empirically sound as it is intuitive – a phenomenon referred to as social contagion. 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, famously popularised by Everett Rogers.[47] Furthermore, the more people who buy a technology, the more it surfs its learning curve and the more complementary infrastructure is built around it.



THE LOOP: IN MOTION

5.1 THE S-CURVE: EV SHARE OF CAR SALES



Source: IEA, Rystad

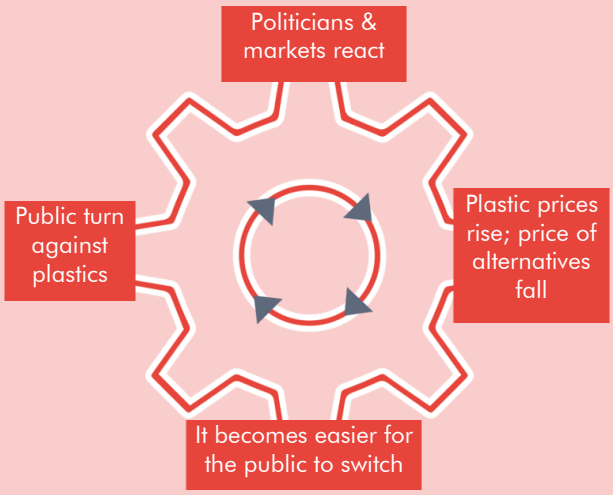
The adoption of electric vehicles is proving to be a classic illustration of the S-curve. As more people buy EVs, so more charging stations are built (a 'network effect') and so more adopt. And as more adopt, so more people see and talk about them and adoption rises. Public opinion and social movements are subject to the same kind of positive feedback[48] – observe the growth curve of Fridays for Future.[49] And as these pro-environmental values spread, this is changing the payoff for businesses and policy makers to turn green. And as there are more and better green options (politicians or products), so more of the public turns green.

[47] *Source: The Diffusion of Innovations, Rogers, 1962*
[48] *Source: The S-curve of cultural change, Fischer, 2014*
[49] *Source: The global climate movement is growing at a faster and faster rate, Climate Interactive, 2019*

5.2 Fossil support: a vicious spiral

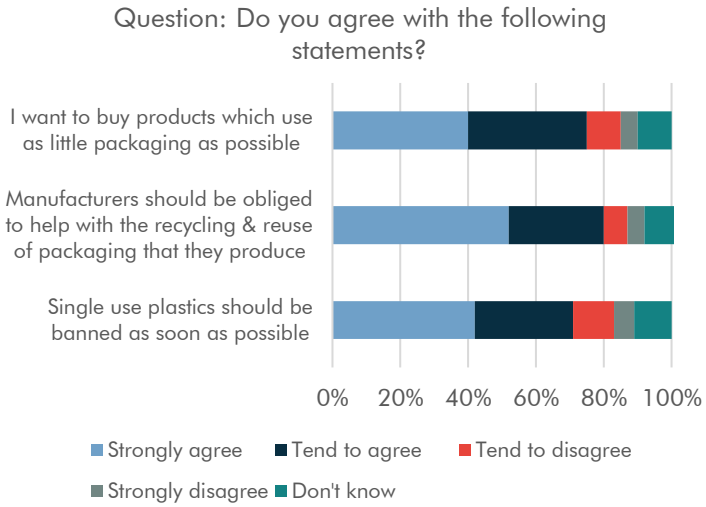
THE LOOP: IN THEORY

Changing social norms can put something out of fashion as quickly as in. This is playing out as more of the public turns against fossil fuels and plastics. As more of the public turn against them, so markets and policy react. And as markets and policy react, awareness rises, alternatives improve and the prices of the old can rise (through falling demand or policy), thereby reducing public support.



THE LOOP: IN MOTION

5.2 PLASTICS LOSING PUBLIC SUPPORT



Source: IPSOS; Note: 19,515 online adults surveyed across 28 countries. Fieldwork dates: July 26th – Aug. 9th, 2019

Plastic is a good example of this. IPSOS polling finds that between 70% and 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. Policy can reinforce behaviour change, as observed with the UK plastic bag charge that saw plastic bag sales fall by 95% since 2015.[50] Plastics demand falling in the future is significant for the oil industry with plastics being the largest source of forecasted growth.[51]

[50] *Source: UK Government, 10p plastic bag charge press release, 2021*
[51] *Source: The Future's Not in Plastics, Carbon Tracker, 2020*

6. Politics

6.1 Green political capital: a virtuous spiral

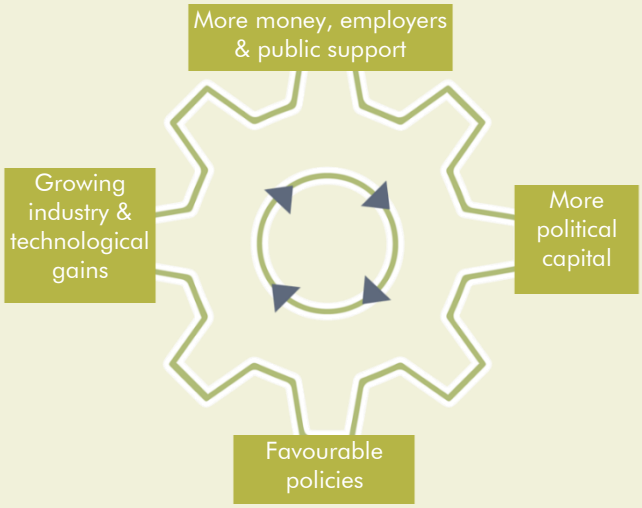
THE LOOP: IN THEORY

The political capital of the new green system is in an upward spiral.

As the industry grows, so too does its political clout. It has more jobs, more money, more public support and thus more lobbying power.

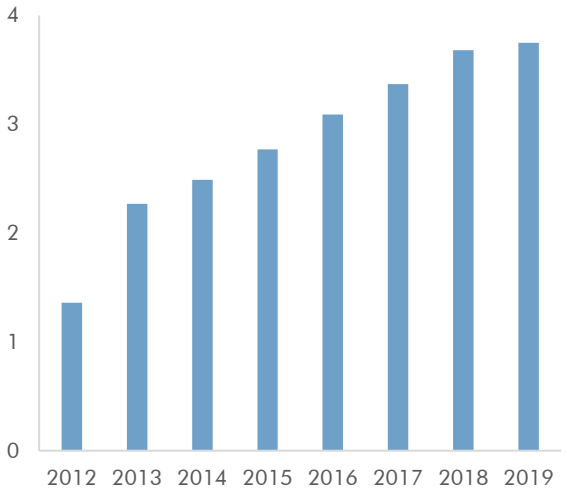
As technological gains ease the politics of the energy transition, the political narrative is flipping from pain to gain. And as politicians realise that the industries of the future are green, [52] so they too focus on where opportunities lie.

As the world warms and its effects become increasingly visible, public pressure is growing, as seen in Greta Thunberg and the Fridays for Future movement.



THE LOOP: IN MOTION

6.1 SOLAR JOBS, MILLIONS



Source: IRENA

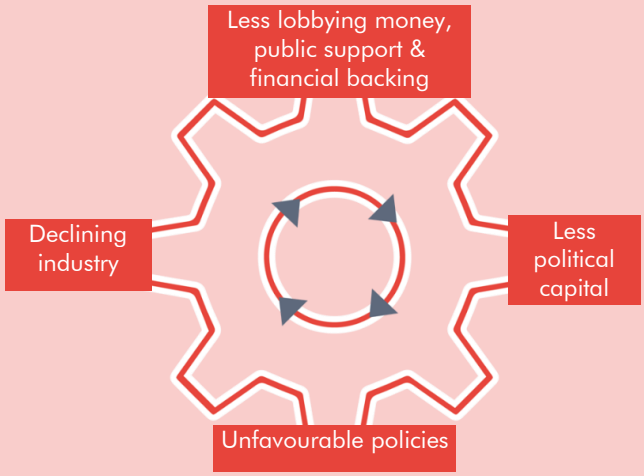
Renewable energy jobs are rising as a function of deployment and in many regions now outnumber those in fossil fuels.[53] This shift in employment is happening fast given renewable energy's growth and higher jobs/kWh than fossil fuels.[54] Meanwhile, the Climate Strikes are one of the largest social movements in history, reporting strikes in over 150 countries.[55] And as the movement continues to grow, so too does their presence in boardrooms, courtrooms and parliaments. Country by country, the green coalition is beginning to outmuscle the fossil fuel coalition at the same time as the economics of clean gets ever more attractive. The implication is the inevitability of an ever more aggressive policy response.

[52] *The tools to help policy makers seize their country-specific potential are also dramatically improving, see: The Green Transition Navigator, Andres & Mealy, 2021*
[53] *Source: Renewable energy and jobs,* IRENA, *2020*
[54] *Source: ibid*
[55] *Source: Fridaysforfuture.org, accessed: July 2021*

6.2 Fossil political capital: a vicious spiral

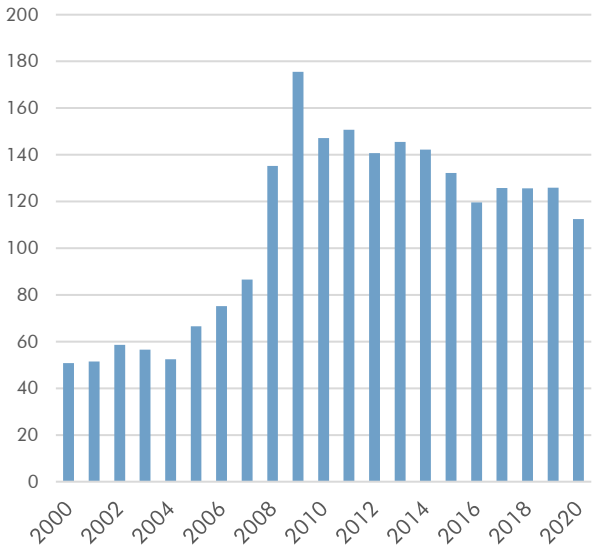
THE LOOP: IN THEORY

Despite the historic political influence of the fossil fuel industry, it is now in a downward spiral. As profits fall and doubts set in about their future relevance, so wanes their ability to lobby for change. Meanwhile, as public pressure is getting increasingly directed at the fossil fuel majors, the licence (social *and* legal) of a fossil future is being increasingly challenged. The combination means less power, credibility and policy support.



THE LOOP: IN MOTION

6.2 OIL & GAS LOBBYING IN THE USA, $M



Source: Open Secrets

According to OpenSecrets, the oil sector's lobbying capex peaked in 2009 and is down by 36%. Legal risks are also rising as the number of cases grows and the science of attribution improves.[56] Over 1,000 climate change-related cases have been brought forward in the last six years, reflecting climate change rising up the public agenda.[57,58] Meanwhile, Europe is proposing a carbon border tax (a process that could set off a carbon pricing domino effect)[59] and the global share of emissions under a carbon tax has increased from 5% to 22% in the last decade.[60]

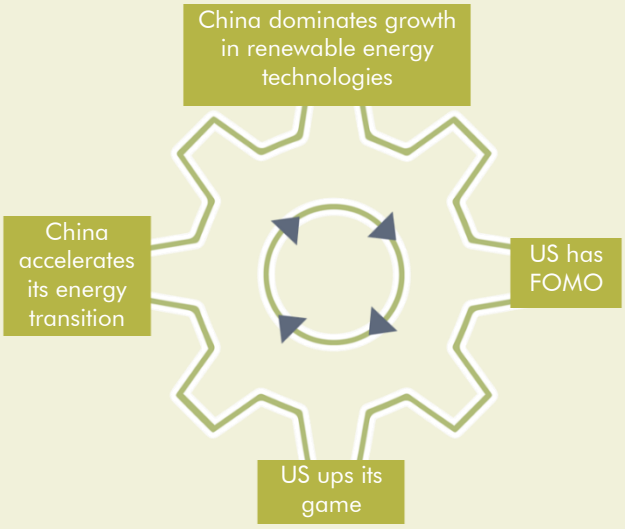
[56] *Source: Filling the evidentiary gap in climate litigation,* Stuart-Smith et al, *2021*
[57] *Source: Global trends in climate litigation,* Setzer & Higham, 2021
[58] *This is a loop of its own: successful climate-related cases beget more cases, lawyers and changes in public opinion.*
[59] *Faced with a carbon border, the exporting country has an incentive to create a domestic carbon price. This is explored in Sensitive intervention points to achieve net-zero emissions, Hepburn et al, 2020*
[60] *Source: State & Trends of Carbon Pricing, World Bank, 2021*

7. Geopolitics

7.1 The race to power: a virtuous spiral

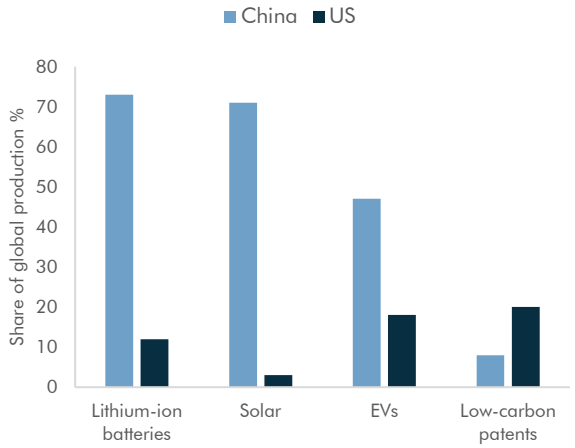
THE LOOP: IN THEORY

Geopolitical competition is spurring technological progress forward. The most consequential case of this race is between China and the US.[61] Both have their eyes on the prize of technological leadership in the energy economy of tomorrow and the geopolitical power that comes with it. And where the motivation is not influence, it is energy independence and the economic and geopolitical benefits that come with that. 80% of people live in counties that import fossil fuels, so most of the world has a strong incentive to shift to domestic renewable energy.



THE LOOP: IN MOTION

7.1 GEOPOLITICAL POWER OF TOMORROW: MADE IN CHINA



Notes: Lithium-ion batteries is the share of manufacturing capacity in 2019 (BNEF); Solar is the production share of modules in 2019 (IEA PVPS); Patents is the share of production between 2010-19 (EPA); EVs is the share of production between 2010-19 (ICCT)

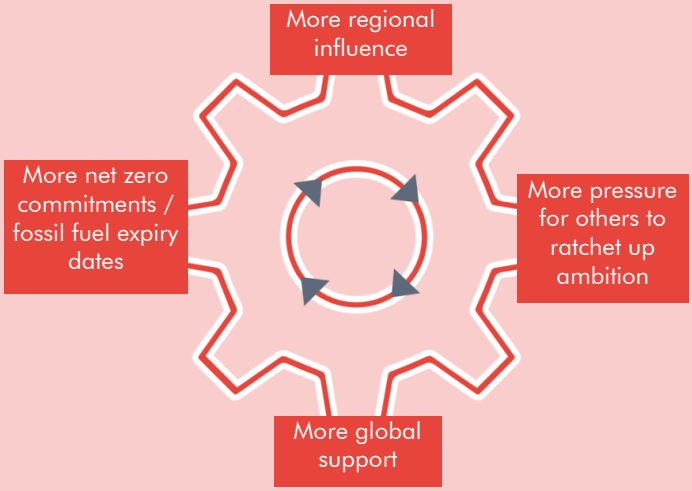
China is far ahead of the US (and the rest of the world) in the production of batteries, solar and electric vehicles but the US leads China when it comes to low carbon patents. The Biden Presidency is seeking to close this gap and regain geopolitical leadership. The US is pushing the Build Back Better World (B3W) infrastructure plans of the G7 as a counterweight to China's Belt and Road Initiative (BRI). In the same vein as countries were able to play off the US and the USSR in The Cold War, so they will be able to get support for renewable deployment. And nor is the race reserved to China and the US, as many geographies (such as India and Europe) seek the international competitiveness that comes with leading the world into the green digital age.

[61] *Source: Sino-US competition is good for climate change efforts, Foreign Policy, 2021*

7.2 The race to zero: a (virtuous) vicious spiral

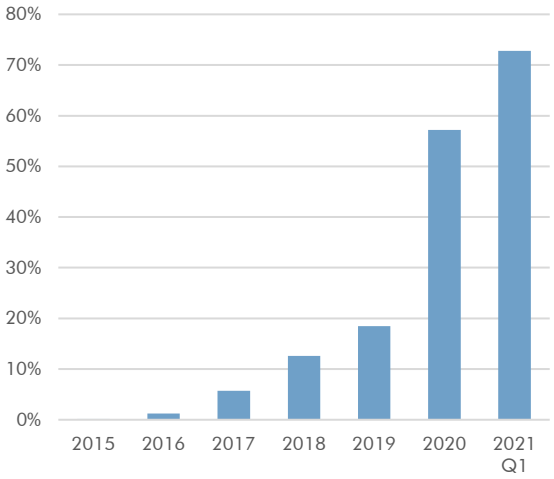
THE LOOP: IN THEORY

The race to net zero emissions is equally the race out of fossil fuels as climate commitments breed more commitments. When your neighbour makes a net zero target or puts an official expiry date on coal or petrol cars, you are encouraged to copy. And as more of your neighbours reap the rewards of clean air, local production, new jobs and energy independence, there is more pressure for you to follow suit.



THE LOOP: IN MOTION

7.2 % OF CO_2 EMISSIONS COVERED BY NET ZERO TARGETS



Source: IEA

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%. First comes the spread of distant targets, then comes the spread of interim and specific targets. This is happening with coal: Indonesia and Malaysia recently set no new coal targets, South Korea and Japan governments have committed to stop funding coal overseas.[62] Meanwhile, China's BRI is leaving coal behind and embracing green technology.[63] Given increasing financial[64] and political pressure, coal strongholds are shrinking.

[62] *Source: South Korea and Japan Will End Overseas Coal Financing. Will China Catch Up?,* WRI, *2021*
[63] *Source: Coal phase-out in the BRI, Green BRI, 2021. Of the 52 coal-fired power plants approved since 2014, only 1 is in operation and 33 have already been cancelled or shelved.*
[64] *Source: Powering Down Coal, Carbon Tracker, 2021*

What next? A tale of tipping points

> *When conditions are right such (positive) feedback can cause major cascades to wash across the system.*
>
> *—John Miller & Scott Page*

Tipping points cascade. As one is breached, the likelihood of surpassing the next rises.[65] Therein lies the final feedback loop: tipping points beget tipping points.

Economics. One technology's economic tipping point (price parity) brings forward the next technology's tipping point. For example, the economic tipping point in clean electricity is an accelerator to the equivalent in green hydrogen, itself an accelerator for tipping points in the economics of clean aviation, shipping and steel and so on.[66] Similarly, one geography's economic tipping point is the acceleration of the next country's: technologies do not care where in the world their learning curves are ridden. Falling costs then drive peaks.

Peaks. The energy transition is sequenced by peaks: coal (2014), internal combustion engine (2018), fossil fuel electricity (likely 2018), oil (likely 2019) and then come trucks, shipping, aviation, gas, plastics and so on.[67] Each peak is a catalyst for the next, as the perceptions and technologies driving each are tightly interconnected.

Finance. With peaks can come financial bandwagon effects – or Minsky Moments.[68] Financial markets move in packs, particularly when it comes to technological revolutions. This will be a frenzy, as greed turns green and fear drops fossil fuels.

Climate. Very soon come dangerous climate tipping points that bring with them more social tipping points and then political change. Climate chaos is *highly* non-linear due to the positive feedback loops at play in the Earth's systems.[69] That means so too is the human cost of this damage. But perhaps even more discontinuous and abrupt is the perception of these human costs.

Perceptions. Perceptions and norms underpin politics and markets, and as more social tipping points are breached, the direction politics and markets are already moving in further accelerates.

Policy. With each day that passes, the incentive for policy makers to act on the climate strengthens; meanwhile the sensitivity of the fossil fuel system to policy change heightens.

Stranded assets. At times of deep and rapid societal change, the gap between values and value is financial risk: a stranding paradigm brings vast stranded assets.

Quite how fast this will unfold is not yet clear. Incumbents will sweat their assets; old thinking, poor risk management and institutional inertia will persist, and the deeper paradigm shift will largely occur along generational lines. But, if the history of technological revolutions teaches us one thing, it is the speed at which change can occur once an interconnected set of positive feedback loops dominate the behaviour of a system.

Of course 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. But, that is a story for another decade. A story to be told in a world transformed.

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[65] *Source: Tipping positive change,* Lenton, *2020; Upward-scaling tipping cascades to meet climate goals,* Lenton & Sharpe, *2020*
[66] *Source: The Paris Effect,* SYSTEMIQ, *2020*
[67] *Source: 2020 Vision, Carbon Tracker, 2018*
[68] *As referred to by Mark Carney in Breaking the Tragedy of the Horizon, 2015*
[69] *Source: See for example, Climate tipping points – too risky to bet against,* Lenton et al, *2019*

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