2020 vision:

why you should see peak fossil fuels coming

Author: Kingsmill Bond
September 2018

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.

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About the Author

Kingsmill Bond – New Energy Strategist

Kingsmill Bond is the New Energy Strategist for Carbon Tracker, and part of the investor outreach team. His role is to communicate to investors the dramatic implications of the energy transition. He believes that this revolution is the most important driver of financial markets and geopolitics in the modern era.

Kingsmill has worked as a sell-side City equity analyst and strategist for over 20 years, including for Deutsche Bank, Troika Dialog and Citibank in London, Hong Kong and Moscow. He has written strategy on emerging markets and global themes, including the wider significance of the shale revolution. He worked for many years in Russia, which is the world's largest exporter of fossil fuels, and deeply impacted by the transition.

Kingsmill has an MA in History from Cambridge University, trained as an accountant (CIMA), and is a Chartered Financial Analyst (CFA).

Report design and typeset: Margherita Gagliardi

Key Findings

The peak in fossil fuel demand will have a dramatic impact on financial markets in the 2020s.

Technology disruption comes to energy. Digitisation allied to technology learning curves in solar PV, wind and batteries are creating disruption in energy, the world's largest sector.

Supercharged by an emerging market leapfrog. Emerging markets have all the energy demand growth and will choose renewables over fossils as their path to development. China has already overtaken the US, and India will follow.

Backed up by necessity. The need to limit carbon emissions, the desire to breathe clean air and the drive for energy independence all mean that global regulatory pressure on the fossil fuel sector will only increase.

The four phases of the energy transition. 2000-2020 has been the innovation phase; 2020-30 will be the peaking phase; 2030-50 the phase of rapid change; and 2050 onwards will be the endgame.

Investors will be impacted during the peaking phase. The 2020s will be the decade of fossil fuel demand peaks, as one bastion of fossil fuel demand after another is stormed and overwhelmed by the rising renewable tide.

Companies face disruption at the peak. Peaking demand for fossil fuels will mean falling prices, rising competition, sector disruption and stranded assets.

Incumbency and size are no protection. As every incumbent has found to their cost, markets care about growth not about size. US horse demand peaked in 1910 when cars were 3% of their number, and the demand for fossil fuel electricity generation in Europe peaked in 2007 when renewables were 3% of supply.

Risks abound. There is systemic risk to financial markets as they seek to digest vast amounts of stranded fossil assets, country risk to petrostates that fail to reinvent themselves in time, and corporate risk in sectors across the world, from drilling to diesel engines, from transport to banks.

The amounts at risk are colossal. The fossil fuel sector has built assets with a value of around $25tn, and the fossil fuel and related sectors compose up to a quarter of equity and debt markets.

We have been warned. The collapse of European electricity stocks after 2008, the bankruptcy of Peabody in 2016, the strategic U-turn of the automotive industry in 2017 and the exit of GE from the Dow Jones in 2018 are all indicators of the change.

Executive Summary

The global energy system is transitioning from a system based mainly on fossil fuels to one based mainly on renewable energy sources. The shift will involve near-term peaking of fossil fuel demand, an S curve of renewable growth, and a long-term decline in demand for fossil fuels.

The energy transition has a number of drivers, which can be described in terms of necessity, policy and technology. In turn these are driving an emerging market energy leapfrog and very rapid growth for new energy technologies.

There are two main aspects of necessity – the environment and geopolitics. Environmental drivers include the need to reduce carbon dioxide, control air pollution and address water scarcity. Geopolitical drivers include the desire to escape energy dependence, the wish for geopolitical influence, and the risk that an energy transition implies for petrostates which depend on fossil fuel rents.

The global direction of policy is clear, notwithstanding recent retrenchment in the US. Policymakers, especially in the large majority of countries that import fossil fuels, have every incentive to keep raising the regulatory pressure on fossil fuels, and will continue to do so.

Three major technologies of solar PV, wind and Lithium-ion (li-ion) batteries enjoy both rapid growth and technology-driven learning curves. For each doubling in capacity their costs have been falling at around 20%, a phenomenon that we expect to continue. In addition to this, digitisation has become a key enabler of the energy transition.

The motor of change now lies in the emerging markets, which is where all the growth in energy demand lies. Emerging markets have higher population density, more pollution, and rising energy demand. They have less fossil fuel legacy infrastructure, rising energy dependency, and are anxious to seize the opportunities of the renewables age. We believe it highly likely therefore that emerging markets will increasingly source their energy demand growth from renewable sources not from fossil fuels.

The spectacular fall in prices and the increase in flexibility provided by digitisation has driven very rapid growth (known as S curves) for the key industries of solar PV, wind, batteries and Electric Vehicles (EVs).

There are three main aspects of the energy transition: energy efficiency moderates demand growth; the decarbonisation of the electricity sector; and the electrification of energy end-use sectors.

The theory of the diffusion of innovation applies to the energy transition. As a successful new product conquers a market, it addresses new groups of people, from the innovators to the early adopters, early majority, late majority and laggards. In each country and each sector, renewables are moving along this type of trajectory.

There are thus four main phases in each part of the transition: innovation (up to around 2% penetration for new technology); peaking (at 5-10% penetration); rapid change (at 10-50% penetration); and the endgame (after 50% penetration).

The most important phase for financial markets is the peaking phase, the point at which demand for the old energy source peaks. Many standard concerns about the energy transition (such as aeroplanes, winter heat or heavy transport) are in fact phase four issues that will not hold back the transition itself.

We have seen a similar pattern in many energy transitions, from electricity, coal and cars in recent years to horses and gaslights in the past. Demand for incumbents peaks early, and investors in incumbents lose money early.

We set out a way of calculating the date of peak fossil fuel demand based on the rapid growth of solar PV and wind in the electricity sector. It requires just two assumptions – the growth rate of total energy demand and the growth rate of solar PV and wind supply. Our conclusion is that the 2020s will be the decade of peaking.

At the tipping point when total fossil fuel demand peaks in the 2020s, the challenging technologies of solar PV and wind will be around 6% of total energy supply and 14% of electricity supply.

Electricity is key to the transition. In 2017 energy to make electricity was 43% of total energy supply. Because other sectors have been electrifying, the share of electricity is growing at around 3.6 percentage points per decade. The net result of this is that energy required for electricity has made up 71% of global energy demand growth over the last 5 years.

It is key to understand the timing of the peak. The conventional bottom-up approach is less useful at times of systemic change because of modelling uncertainty, regulatory pressure and rising inter-fuel competition.

Investors face three types of risk from the energy transition – systemic, country, and stock specific.

The systemic risk to investors comes from the fact that the fossil fuel sector has $25tn of fixed assets which is increasingly vulnerable to stranding as the energy transition progresses.

Countries which are dependent on fossil fuel exports are vulnerable to the ending of the high rents of the sector. We identify 12 countries where fossil fuel rents are over 10% of GDP.

The sectors impacted by the energy transition are wide and not just limited to fossil fuel stocks. Outside the obvious areas of coal, oil and gas, they include capital goods (such as gas turbines), transport (such as coal ports) and automotive. Directly impacted sectors compose up to a quarter of equity indices. In debt markets, fossil fuel and related sectors make up nearly a quarter of the total corporate bonds followed by Fitch and a little more of the bonds covered by Bloomberg.

Index

What is the energy transition?

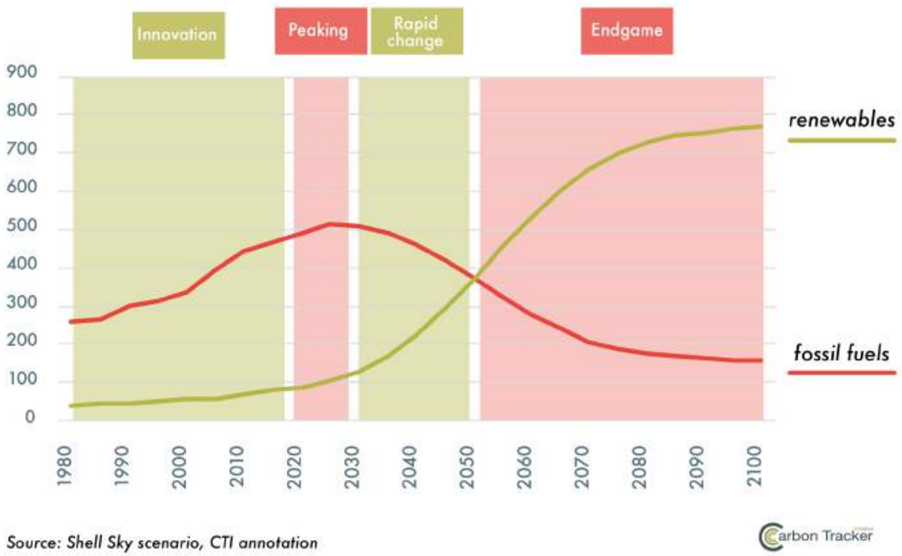
The global energy system is transitioning from a system based mainly on fossil fuels to one based mainly on renewable energy sources. The chart from Shell's Sky scenario[1] below illustrates the dynamic of this shift. The world has not seen a change of this nature since 1800 when coal rose to dominance at the expense of biomass.

There are of course many other scenarios for the future of energy, but those which seek to be Paris-compliant share the same basic structure:

- Near-term peaking of fossil fuel demand.
- An S curve of renewable growth.
- A long-term decline in demand for fossil fuels.

There are however major differences on the timing of the peak in fossil fuel demand: OPEC, the IEA[2] and BP[3] do not foresee a fossil fuel peak for another generation or more; while DNV GL[4], the respected international certification body, argues that the peak for fossil fuel demand will come in the 2020s. We address the issue of timing later in the report.

Total primary energy (EJ)



Source: Shell Sky scenario, CTI annotation

1 *Shell Sky Scenario, 2018*
2 *IEA New Policy Scenario (NPS), WEO 2017*
3 *BP Energy Outlook, 2018*
4 *Energy Transition Outlook, DNV GL, 2017*

What is driving the transition?

The energy transition has a number of drivers, as we summarise below in terms of necessity, policy and technology. In turn these are driving an emerging market energy leapfrog and very rapid growth in new energy technologies.

I. Necessity

There are two main aspects of necessity – the environment and geopolitics. Even if the main driver of the transition is now technology driving costs lower, it is important to remember that there are still fundamental forces which will encourage change in the face of very considerable inertia.

Environmental drivers include the need to reduce carbon dioxide, control air pollution and address water scarcity. In the 2017 World Energy Outlook[5] (WEO), the IEA showed that for the goals of the Paris Agreement to be achieved, carbon emissions and fossil fuel usage would need to peak immediately and fall respectively by 22% and 11% by 2030. Meanwhile, the IMF calculated that in 2015 the cost of local pollution was $2.7 trillion and of global warming was $1.3 trillion[6].

Geopolitical drivers include the desire to escape energy import dependence, the wish for geopolitical influence, and the risk that an energy transition implies for petrostates which depend on fossil fuel rents. Further incentives for policymakers include the desire to obtain industrial leadership in the new technologies, the need to avoid wasting capital on stranded assets, and the wish to increase local employment. It is notable that most countries are importers of fossil fuels. Just eight countries have 80% of global proved oil reserves[7], and three quarters of global fossil fuel exports by value come from just ten counties with only 5% of the global population[8].

These drivers of necessity have different impacts in different locations. In the densely populated emerging markets it is local air quality and the threat of energy dependency that inspires policymakers to act. In wealthy Europe it is the desire to reduce carbon emissions. In Saudi Arabia it is the risk of the ending of fossil fuel rents. China in particular has been able to dominate the development of the new technologies and enhance its geopolitical influence.

II. Policy

There are two aspects to the policy response: from governments and from the private sector.

A number of governments across the world have for many years been seeking to reduce fossil fuel usage, encourage the growth of renewables, and make fossil fuels pay for their externalities. The Paris Agreement of December 2015 was the most visible manifestation of this. Over 190 countries[9] have submitted INDCs (Intended Nationally

5 *World Energy Outlook, IEA, 2017*
6 *How large are global energy subsidies, IMF, 2015*
7 *BP Statistical Review of World Energy, June 2018*
8 *UN Comtrade, https://comtrade.un.org/*
9 *CAIT Climate data Explorer, WRI, Open Climate Network (OCN), as of August 2018, http://cait.wri.org/indc/*

Determined Contributions) which commit them to reduce emissions in a wide variety of ways, including increasing efficiency, decarbonising their electricity sector and electrifying other sectors. Over forty countries have now committed to fully decarbonise their electricity sector by 2050 for example[10].

According to the Energy Transitions Commission[11], the pledges made in Paris will be sufficient to curtail the growth in emissions but not enough to reduce them. This has led many to be sceptical about the process. However, we believe that this misses the critical role of falling technology costs. As the costs of renewables fall below the cost of fossil fuels, the opportunity set for policymakers changes. Rather than having to subsidise renewables at high cost, they can now move to tax the fossil fuel sector for the externalities that it imposes on society.

From this perspective, the key achievement of Paris has been to set a benchmark and a mechanism to ratchet that benchmark higher. As costs fall, so policymakers will be able to do so. We believe that the global direction of policy is therefore clear, notwithstanding recent retrenchment in the US. Policy is a vital part of the energy transition. The power of the incumbents and of inertia is so considerable and time is so short that a successful transition will depend on the combination of technology and policy.

The private sector is also playing a key role in driving change. Organisations such as DivestInvest and Climate Action 100+ have mobilised significant amounts of capital in order to encourage companies to decarbonise. Companies such as Google or Apple now source all their energy from renewable sources, and are driving this commitment across their global supply chains. And the world's billionaires such as Jeff Bezos, Bill Gates and Jack Ma are funding energy research though Breakthrough Energy Ventures.

III. Technology

Three major technologies of solar PV, wind and batteries enjoy both rapid growth and technology-driven learning curves. For each doubling in capacity their costs have been falling at around 20%, a phenomenon that we expect to continue. In addition to this, digitisation has become a key enabler of the energy transition.

As we set out below, these three technologies have now reached a level at which they can compete with fossil fuels without subsidies. And this changes the environment for all energy companies.

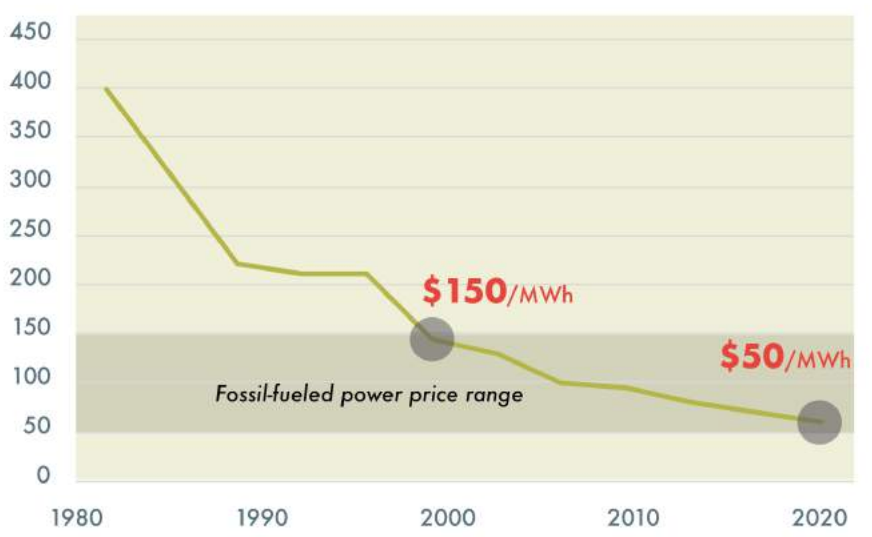
Wind

According to data from the International Renewable Energy Agency (IRENA) , the average global cost of electricity from wind has fallen from nearly $150 per MWh at the start of the century to under $60 today. In optimal locations such as the Great Plains in the US, the price has fallen to as low as $30 per MWh[12], and at the end of 2017, Excel in Colorado received a bid for wind plus battery storage at a headline price of $21 per MWh. The comparable price of electricity from fossil fuels is $50 to $150.

According to Bloomberg New Energy Finance (BNEF)[13], the onshore wind industry enjoys a technology learning curve of 19%, and the offshore industry a learning curve of 16%.

10 REN21. Renewables Global Status Report 2018
11 Pathways from Paris, Energy Transition Commission, 2016
12 Levelised cost of energy, Version 11.0, Lazard, 2017
13 New Energy Outlook, Bloomberg New Energy Finance, 2018

Wind costs ($/MWh, global average)



Source: IRENA

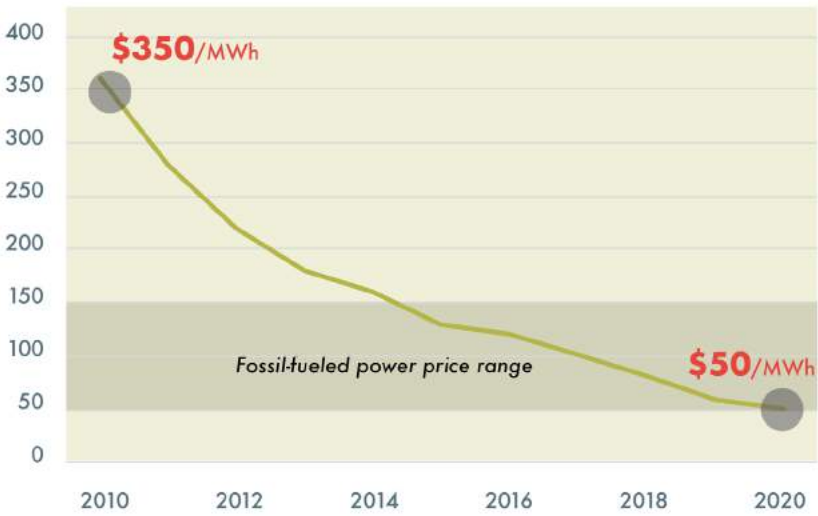
Solar PV

The average global cost of solar PV electricity has fallen from $350 per MWh in 2010 to $80 in 2018, with auction results indicating it will fall to $50 by 2020. In certain locations such as the Middle East and India the cost has fallen still lower than this. In October 2017, Acme solar PV won a bid for the Bhadla solar park in Rajasthan at $36 per MWh. In May 2018, Masdar officially launched the phase 3 of the MBR Solar Park near Dubai, with a cost of $30 per MWh. According to BNEF, the price of solar panels is likely to fall by over 20% this year to 24 cents per Watt of capacity, and the panel industry is on a learning curve of 29%.

IRENA notes that renewables will be cheaper than fossil fuels in every major region of the world by 2020[14]. In the US the cost of electricity produced from new solar PV and wind installations is now below the cost of electricity produced from most new fossil fuel stations. Lazard has been producing data on the levelised cost of energy (LCOE) for the US for many years and their analysis is widely followed. In their most recent analysis for November 2017[15], they showed that the US cost of electricity from wind was in a range of $30-60 per MWh, from solar PV $46-53, from gas $42-78, and from coal $60 -143.

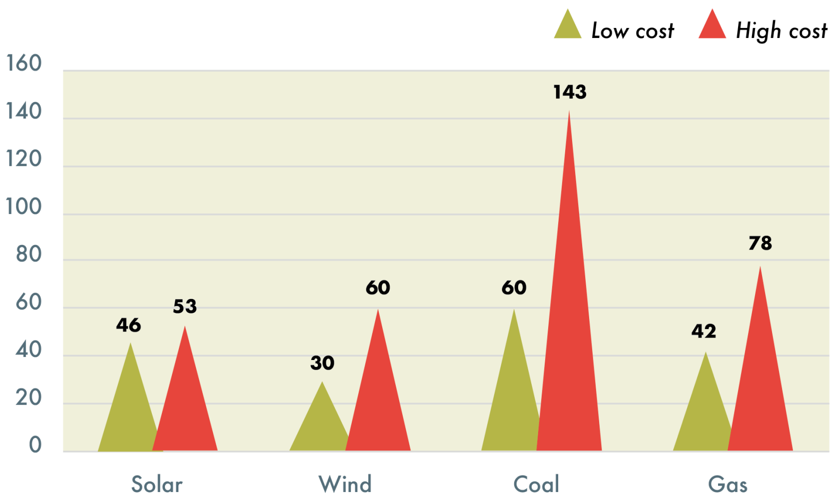
14 *Cost of Renewables 2017, IRENA*
15 *Levelised cost of energy, Version 11.0, Lazard, 2017*

Solar PV electricity costs ($/MWh, global average)



Source: IRENA

US levelised cost of electricity (LCOE, $/MWh)



Source: Lazard

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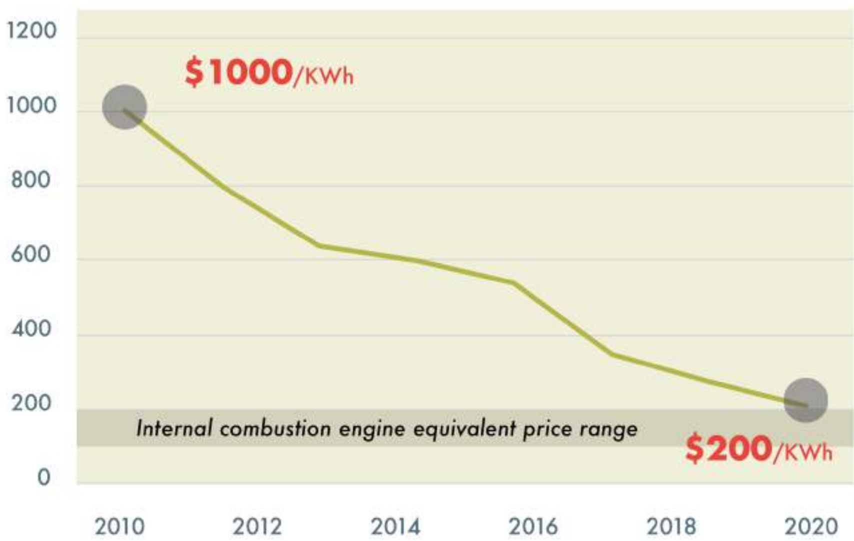
Batteries
Lithium-ion battery costs have now fallen to under $200 per KWh of capacity, with the price of the Tesla battery pack understood to be around $150 per KWh. Battery costs are widely expected to reach $100 per KWh in the early 2020s, a level at which EVs will be comparable with conventional cars on purchase. The industry enjoys an 18% technology learning curve according to BNEF, and prices have been falling at 21% a year since 2010.

The li-ion battery is a key technology which is necessary for the success of EVs, and a helpful tool for the increase in the share of solar PV and wind in grid infrastructure. At $100 per KWh, the starter price of an EV is comparable with that of a conventional car, although of course its fuel and running costs are much lower.

Digitisation
As analysed in detail by the IEA[16], digitisation is taking place in many areas of the energy sector, taking advantage of cheap sensors, cloud storage and distributed energy management systems. The increasing digitisation of electricity and transport is a key facilitator of rising penetration levels of renewable electricity and EVs, and digitisation is a vital tool in increasing efficiency and reducing waste. In Norway, electric vehicles are starting to act as backup storage for the grid, and in China there are more than 430 million smart meters to add flexibility to the grid.

Counter-arguments
There are of course arguments which maintain that solar PV and wind are more expensive than they appear because of intermittency, connection costs, and so on.

Li-ion battery costs ($/KWh, global average)



Source: BNEF

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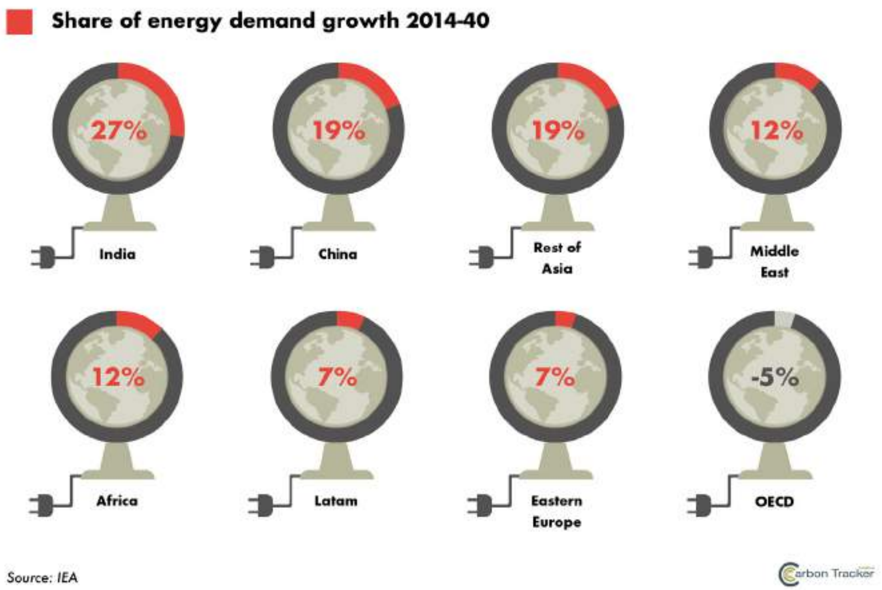
16 IEA Digitisation and energy, 2017

However, these arguments are increasingly out of date because of the rapid technology learning curves that distinguish renewables, and the fact that large amounts of storage are not required at the levels of penetration (under 15% of global supply) sufficient to drive fossil fuel peak demand.

There are further arguments which maintain that even if the LCOE of renewables is lower than that of fossil fuel generation, the operating costs of existing fossil fuel plants are lower than those of new renewable plants. There are two responses to this. The first is that we are looking specifically at the moment when the growth in fossil fuel demand stops. So, by definition, we are only interested in new demand, which on the whole requires new capacity. The second argument, made by Carbon Tracker in '*No Country for Coal Gen*'[17] and '*Lignite of the Living Dead*'[18], is that the costs of solar PV and wind could over the next few year start to fall below the operating costs of fossil fuel plants.

IV. The emerging market leapfrog

The energy transition is a messy affair, especially in developed markets which have to contend with legacy subsidy regimes and falling energy demand. The motor of change now lies in the emerging markets, which is where all the growth in energy demand lies. For example, the IEA predicts[19] that 27% of energy demand growth in the next 25 years will come from India and 19% from China.



17 Carbon Tracker Report, No Country for Coal Gen, 2017, https://www.carbontracker.org/reports/no-country-for-coal-gen-below-2c-and-regulatory-risk-for-us-coal-power-owners/
18 Carbon Tracker Report, Lignite of the Living Dead 2017, https://www.carbontracker.org/reports/lignite-living-dead/
19 World Energy Outlook, IEA, 2016

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Developing markets have higher population density, more pollution, and rising energy demand. They have less fossil fuel legacy infrastructure, rising energy dependency, and are anxious to seize the opportunities of the renewables age. We believe it highly likely therefore that emerging markets will source their energy demand growth from renewable sources not from fossil fuels. A popular recent example of such a shift is how large numbers of people in developing markets moved from no phones to mobile phones without the intermediary stage of fixed line telephony.

In 2015, developing markets overtook developed markets as the largest source of capital expenditure on renewables. And in 2017, developing markets spent $177bn on renewable technologies, 1.7 times the spending of the developed markets[20].

China overtook the US as the world's largest deployer of solar PV and wind capacity in 2012, and electric cars in 2016. In 2017, China had 164 GW of wind capacity, 1.9 times that of the US; 131 GW of solar PV capacity, 2.6 times that of the US; and 1.3 million EVs, 1.6 times that of the US.

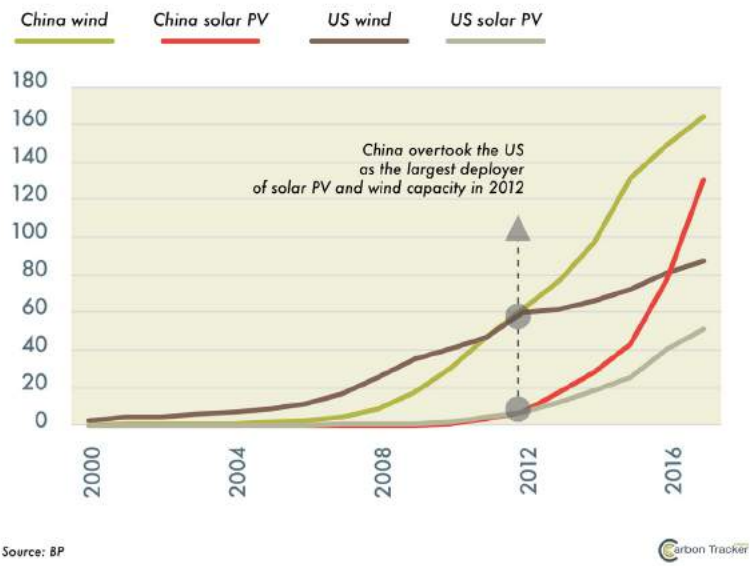
China is far ahead of the US and other countries in terms of other key new energy technologies such as electric bikes, electric buses, smart meters or high voltage direct current (HVDC) lines. Moreover, China has already emerged as the world's largest producer and exporter of the key renewable technologies, giving the country significant industrial advantage and the capacity for greater geopolitical influence.

Capital expenditure on renewables ($bn)

Source: BNEF

20 *Global trends in renewable energy investment, BNEF, 2018*

US and China solar PV and wind deployment (GW)



Source: BP

Meanwhile, India has just increased its 2022 target level of renewable energy deployment from 175 GW (a level which once seemed far beyond reach) to 228 GW.

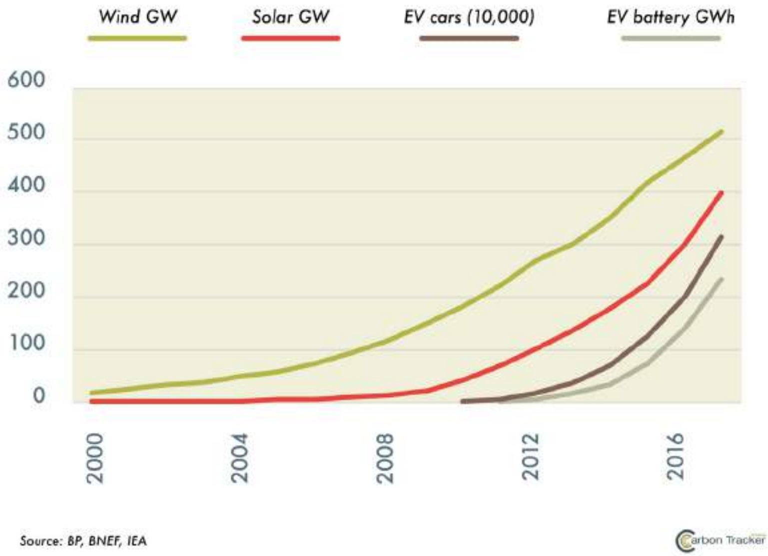
Over the last 12 months the cost of solar PV electricity in India has fallen to a level ($36 per MWh) well below that of new coal-fired power stations. India also has ambitions for all new car sales to be electric by 2030.

V. S curves of growth

The spectacular fall in prices has created rapid global growth curves (known as S curves) for the three core growth industries of solar PV, wind and batteries. At the end of 2017, the world had 400 GW of solar PV capacity[21], 515 GW of wind capacity, 234 GWh of lithium-ion transport battery capacity[22], and 3.1 million EVs[23].

Whilst this report is not focussed on specific forecasts, it is nevertheless interesting to note that organisations such as BNEF or DNV GL expect these S curves of growth to continue. BNEF forecasts a 30-fold increase in EVs to 2030 to over 100 million cars, and a nearly five-fold increase in electricity provision from solar PV and wind to 7,400 TWh in 2030.

Deployment of key renewable technologies



Source: BP, BNEF, IEA

21 Source: BP
22 Source: BNEF
23 Source: IEA

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Mechanics of the transition

There are three ways in which the energy transition works its way into the energy system: energy efficiency moderates demand growth; the decarbonisation of the electricity sector; and the electrification of end-use sectors.

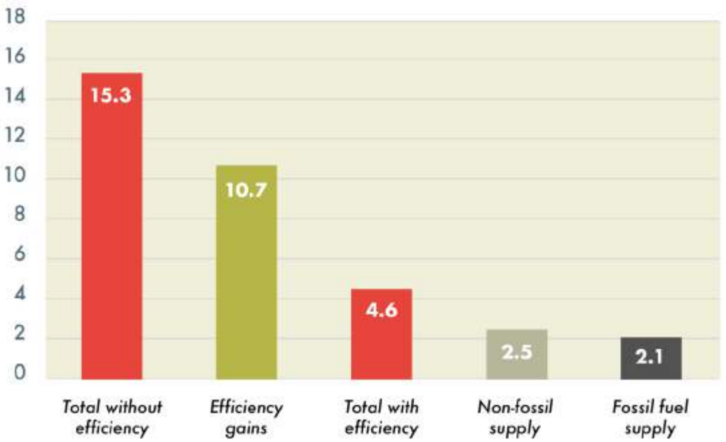
V. Energy efficiency

In the twentieth century the average annual growth rate of energy demand was around 3% comparable with the growth rate of global GDP. A focus on efficiency in recent years has broken this link, and annual efficiency gains are now running at around 2%.

The implication of this is very important. As energy demand is now growing at between 1-2% a year, the amount of renewable energy required in order to create a peak in fossil fuel demand is up to three times lower.

We illustrate this by showing global energy demand growth in 2015 with and without efficiency gains.

Energy demand growth 2015 (EJ)



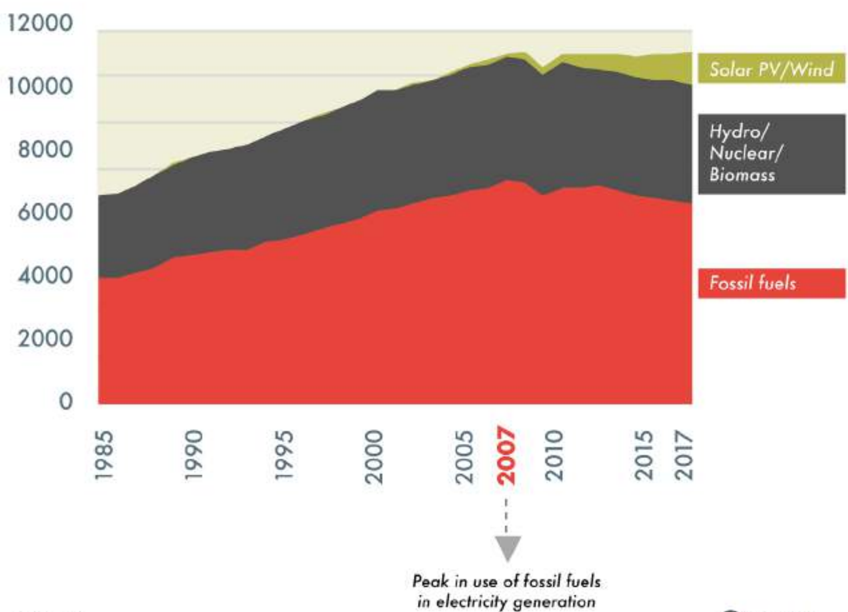
Source: Energy Efficiency Report, IEA, 2016, BP

II. Decarbonisation of the electricity sector

The rapid growth of solar PV and wind is providing the necessary momentum to decarbonise the electricity sector. An illustration of this is the fact that the use of fossil fuels in electricity generation peaked across the OECD in 2007. At this point, solar PV and wind were only 1% of the electricity mix. As they continued to grow in an environment of stagnant total growth, so demand for fossil fuels in electricity fell.

A similar story is taking place at a global level. In 2017 solar PV and wind were 6% of global electricity supply, but 45% of the growth in supply. As we examine in the section on timing, we expect global demand for thermal electricity to peak in the 2020s.

OECD electricity generation (TWh)



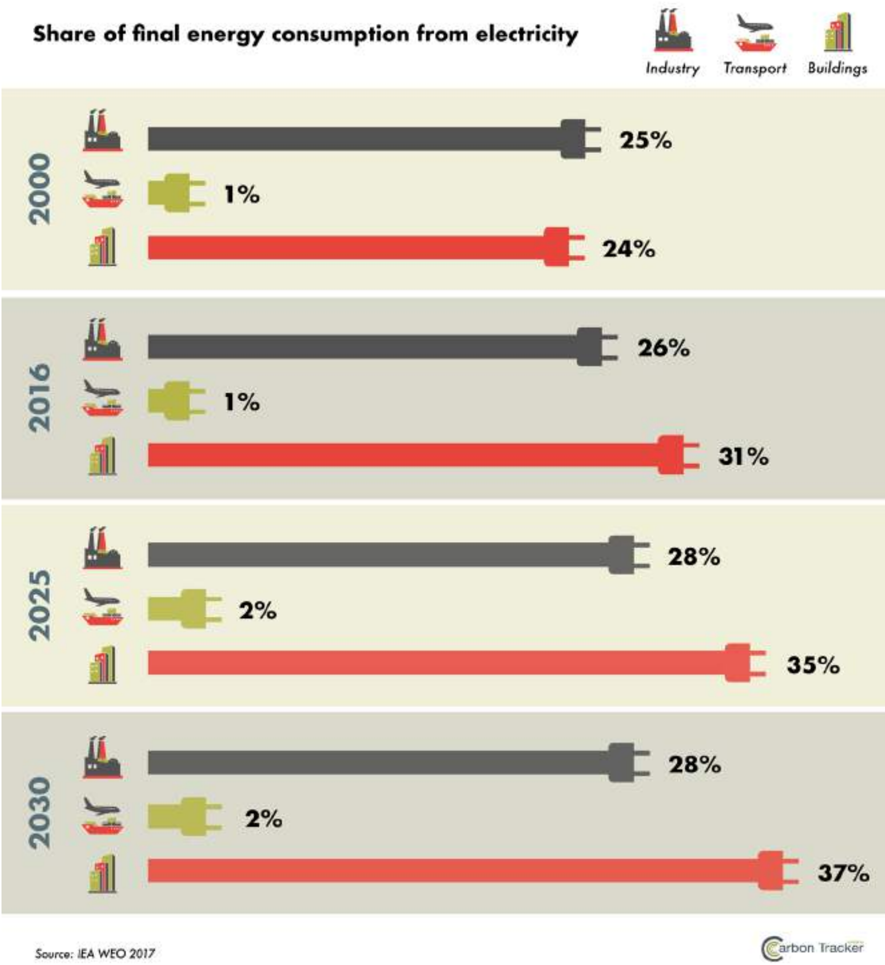
Source: BP

III. Electrification of other end-use sectors

The third step in the transition is the electrification of end-use sectors such as transport, buildings, and industry.

This process has of course already begun. According to the IEA, the share of final energy consumption from electricity in 2016 was 31% in buildings, 26% in industry and 1% in transport. This share has been rising over time, and is expected to continue to rise.

The tools to achieve the transition vary. In the building sector, heat pumps, solar thermal and district heating are all growing. In the industry sector, renewables and electricity are starting to provide low temperature heat. And in the transport sector, the very high-profile success of EVs is providing new sources of competition for light vehicles.



Phases of the energy transition

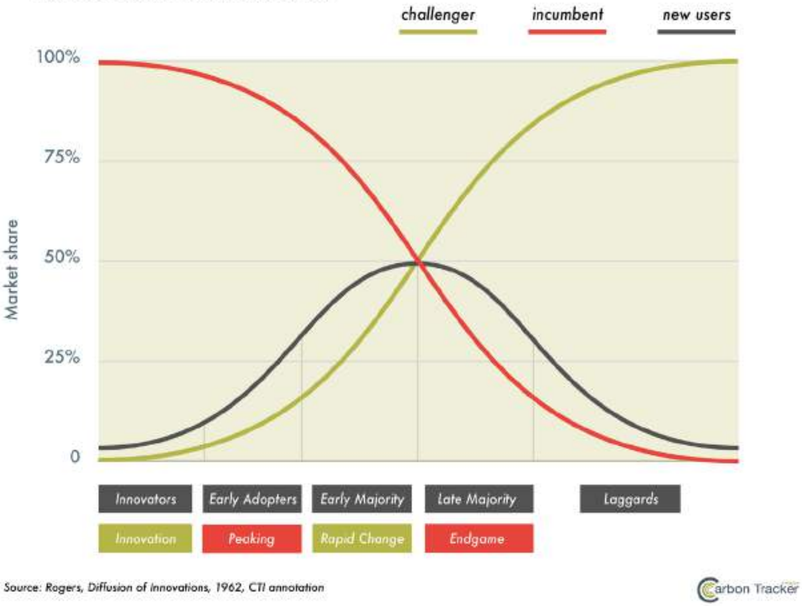
The energy transition is happening in each sector and each country in phases. We describe the phases in general terms before looking at how they play out by sector and country and then considering the big picture.

I. The key phases of change

The theory of the diffusion of innovation[24] is one that is widely understood. As a successful new product conquers a market, it addresses new groups of people, from the innovators to the early adopters, early majority, late majority, and laggards.

This is a useful framework within which to consider the energy transition. In each country and each sector (with some notable exceptions of course), renewables and electricity are moving along this type of trajectory. We show the framework for the shift in the chart below. In addition to the share of demand coming from new users, we also show the market share of the challenger technology and of the incumbent.

Diffusion of innovation framework



Source: Rogers, Diffusion of Innovations, 1962, CTI annotation

24 *Rogers, Diffusion of Innovations, 1962*

When seen from this perspective there are four main phases of change.

Phase 1 - Innovation

The market share of the challenging technology rises to around 2.5% as the demand of the innovators are addressed and various niches conquered. In this phase the challenger is small, niche and expensive. It requires governmental support, and it tends to be dismissed by incumbents. This describes the solar PV and wind sector in Europe a decade ago, the global EV sector until a couple of years ago, or the solar PV and wind sector in parts of SE Asia today.

Phase 2 - Peaking

Early adopters take up the new technology and the market share rises to double digits. Towards the end of the period, the challenger starts to compete with the incumbent on price, and is able to take all the growth in demand. Demand peaks for the incumbent. This tends to happen when the challenger is 5-10% of the total supply and the peak can be surprisingly rapid. The peaking period is typically the moment when the impact is felt in financial markets.

Phase 3 - Rapid change

The early majority starts to use the new technology. The challenger grows rapidly and the incumbent declines. This is where there is typically significant destabilisation of the business model of incumbents. It is important to note that this takes place when the incumbent is still much larger than the challenger. The process can take place over decades. This describes where the European electricity sector is today. And where demand for conventional cars will be after around 2023.

Phase 4 - Endgame

Where the late majority shifts. The challenging technology reaches more than half the supply mix and starts to push out the incumbent from the remaining niches. This is where leaders such as Demark are today in their electricity sector and where Norway is about to reach in its car sector. It is clear that the world as a whole is a very long way away from the energy endgame.

Historians and incumbents have tended to focus on the problems to be faced during the last of these phases, in this case the point when renewables become larger than fossil fuels. However, the financial consequences will be felt long before this final phase. For example, during the last energy transition from biomass to coal after 1800, coal only overtook biomass as a share of total energy provision in 1905. And yet the consequences of the shift to coal were a dominant feature of the century before this.

It is often argued that there are certain apparently insoluble areas of fossil fuel demand, the existence of which means that there will be no energy transition. Examples include winter heat, airplane fuel, heavy transport and various industrial processes. However, these should be seen as phase 4 problems, which will be solved long into the energy transition and after all of the (many) easier to solve issues have been addressed.

II. Country sequencing

There is a clear sequencing of the transition by region and country. We believe that the best way to think of the energy transition is to consider each sector in each country advancing along the diffusion of innovation path.

For example, in the electricity sector, specific European countries such as Denmark or Germany have taken the lead. Demark has now entered phase 4, where over 50% of its electricity comes from solar PV and wind, and it is facing complex endgame issues. Germany and the EU are in phase 3, where fossil fuel demand has entered into decline and the electricity sector is restructuring. China is now in phase 2, where demand for fossil fuels is about to peak. And Africa and the CIS are still in phase 1 where the technology is being tested and costs are falling from relatively high levels.

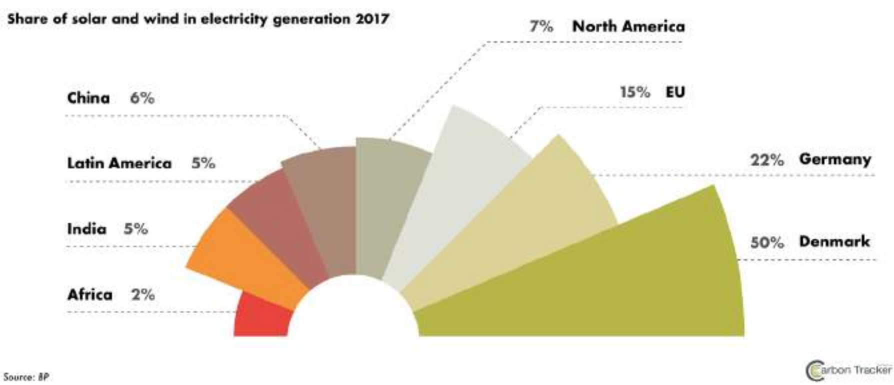
III. Sector sequencing

The first sector to make the transition from fossil fuels to renewables will be the electricity sector.

Thereafter, the transition is progressing in other sectors though electrification and the advance of other renewable technologies. At present, the shift is most advanced in the buildings sector, followed by industry and then transport.

It is important to realise that each sector of end-demand has sub-sectors which are easier and harder to solve. So for example, in the transport sector, it is difficult to provide clean energy solutions for heavy transportation, but increasingly easy to do so for cars. And as the car drives down the cost of batteries and increases global expertise, so the technology will spread to the trucking sector. We already see this process taking place, with electric vehicles spreading faster in the last mile and delivery truck segments than in heavy trucking.

In a similar way, there are certain industrial processes which are more easy to shift to renewable sources, as detailed by the IEA in its report on renewable energy for industry[25]. Low-temperature process heat, efficiency gains and the use of bioenergy are all examples of this.



25 *Renewable Energy for Industry, IEA, 2017*

IV. Overall sequencing

Each country and technology has its own sequence. However, when they are all added up it is possible to come up with a rough global framework for the transition as we set out below. Once more we use the Shell Sky scenario for ease of presentation.

We can identify four main periods:

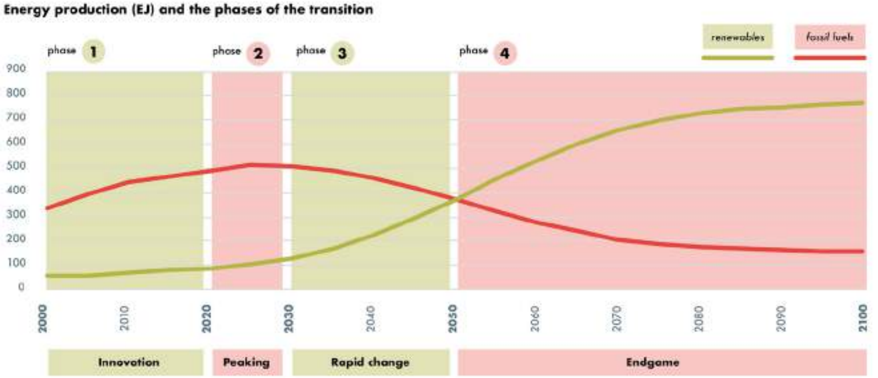
- **2000-2020 – Innovation**
Renewables are growing and some sectors and countries are already seeing peaking. However, renewables are not yet big enough in aggregate to supply all incremental energy demand.

- **2020-30 – Peaking**
Renewables become large enough to supply all incremental demand. Fossil fuel demand peaks and starts to fall. Most of the fossil fuel industry still expects a return to the cyclicality of past decades.

- **2030-50 – Rapid change**
The reality of declining fossil fuel demand is now clear, and this is a golden period of demand growth for the renewable sector.

- **2050-2100 – Endgame**
Renewables finally overtake fossil fuels to provide more than 50% of energy. At this stage, some of the more intractable sectors of fossil fuel demand will need to be addressed.

Energy production (EJ) and the phases of the transition



Source: Shell Sky Scenario, CTI

Investors will be impacted at the peak

Incumbents are typically impacted during the peaking phase because it is then that demand for their products peaks.

I. What happens at the peak?

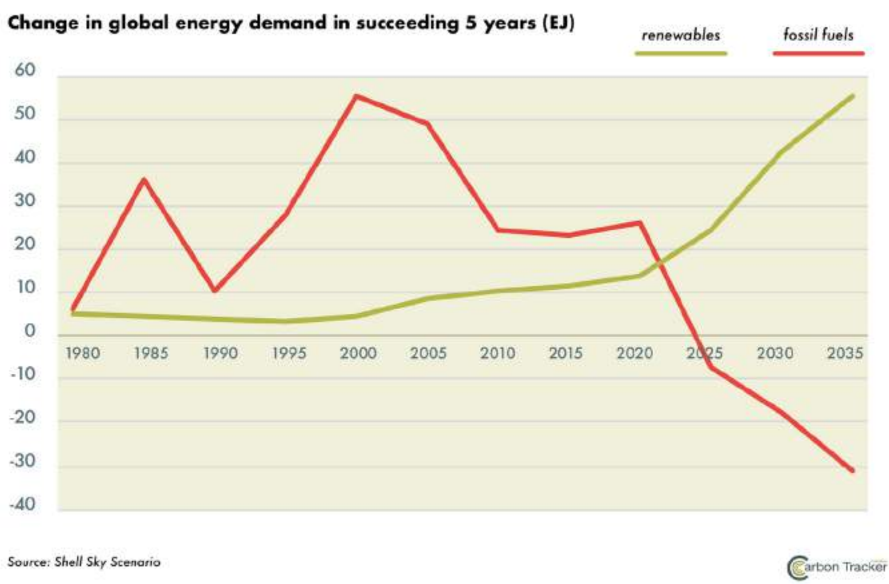
We showed earlier the data from Shell Sky scenario on the total size of fossil fuels and renewables. From the perspective of an incumbent producer, the key issue is not total demand but change in demand. When we look at the same data from the perspective of change in demand, a very different picture emerges. After 2025, fossil fuel demand is already falling.

At the moment when growth turns to decline, there are usually four factors that impact companies: new entrants, lower prices, stranded assets, and sector disruption.

New entrants
The providers of the new technology are usually new entrants, which are attracted by the high levels of growth and low barriers to entry. New entrants imply more competition, which is likely to drive down returns for the incumbents.

Lower prices
The challenging technologies of solar PV, wind and batteries are on established learning curves, so the price of the energy they produce falls every year. In order to compete, fossil fuel companies will have to be able to match these prices. So fossil fuel prices will trend downwards over time.

Stranded assets
As new competition challenges established incumbents, so the assets and the technology of the incumbents starts to become stranded. For example, coal-fired



and gas-fired power generation capacity in Europe and parts of the US is already being closed down because it is uneconomic, and in the last 12 months, the building of 100 GW of coal-fired power generation plants has been stopped in China.

Sector disruption

The consequence of more competition and falling prices is sector disruption. We should then expect a major reallocation of capital, bankruptcy of companies that are unprepared, and sector restructuring as those who prepared for the shift take over the assets of those that did not.

II. When are investors impacted?

Investors anticipate, so they will typically react even before companies see peak demand. As we show below, this is what happened recently in the coal and European electricity sector transitions.

We believe that investors will start to react faster as the energy transition works its way through the world's capital markets. As each sector is impacted, it become easier for the market to anticipate something similar happening to the next sector.

III. Examples of energy transitions

We set out below some examples of energy transitions and how they impacted demand and investors. We use both examples from the present such as coal, electricity and automotive, as well as examples from the past such as the switch from horses to cars or gas lighting to electricity. They show a similar pattern whereby incumbents are impacted right at the start of the transition, as demand peaks.

Coal

Global coal demand peaked in 2014. The share price of Peabody peaked in 2011 at the point when rapid growth slowed down, and within two years of the coal demand peak, in 2016, Peabody filed for bankruptcy.

The peaking of global coal demand was little anticipated by the industry, which believed that coal demand growth would continue as India and other emerging markets replaced China as the driver of demand. As a result, companies built capacity for demand that never materialised. And the overcapacity caused price falls, which in turn caused bankruptcy or significant share price falls in a number of major coal companies.

Electricity in Europe

In 2007, the electricity industry in Europe expected demand to continue to rise and did not see renewables as a threat. Renewables were just 3% of total supply and at the time it appeared that they could not be incorporated into the grid in major size. After the financial crisis, efficiency gains rose to higher than GDP growth, meaning falling demand. And renewables kept on growing, pushing fossil fuels out of the generation mix. Meanwhile new engineers and new thinking kept on pushing back the boundaries of what level of intermittent renewables was possible.

Demand for thermal electricity peaked in 2007. Shortly before that we saw a peak in the share price of RWE, the largest electricity company in Europe at the time.

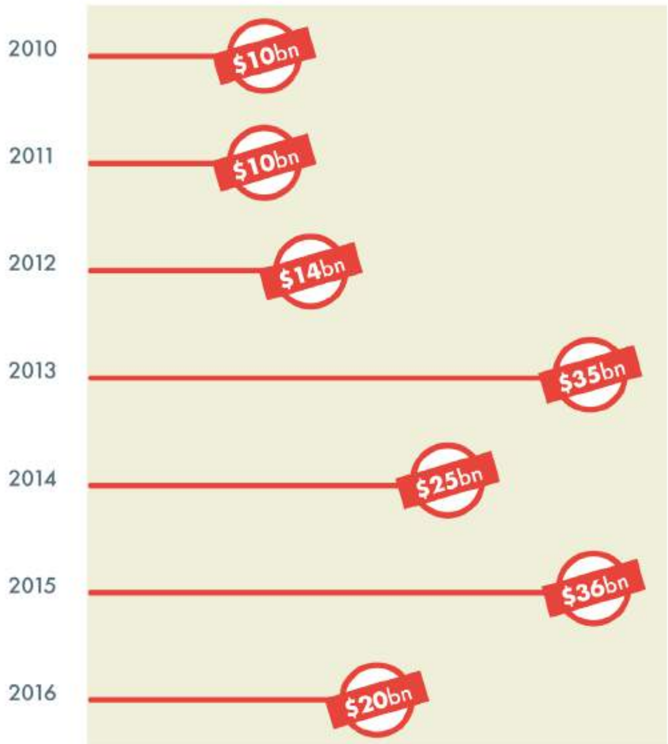
As renewables took market share in a market with falling demand, wholesale prices fell, and the impact on the industry was dramatic. $150bn of assets were written down , and the capitalisation of the sector fell very significantly.

RWE share price

Source: Bloomberg

Carbon Tracker

European electricity sector write-downs ($bn)



Source: IEA

Carbon Tracker

The car sector

The oil sector widely dismissed the threat of EV, arguing as late as in 2017 that they were a drop in the ocean of cars. In 2017, EV sales were a mere 1.1 million out of total car sales of 85 million, and the total EV fleet size was 3 million, out of 800 million cars.

However, that was not the perspective of the car sector. In 2017, EVs supplied 22% of the growth in total car sales, and the car sector worked out that EV would take all growth in car demand by the early 2020s.

The result was a spectacular shift in strategy by most of the world's leading car companies in 2016-17, as they refocussed on EVs. According to Reuters, the world's leading automotive companies had committed $90bn to EV strategies by January 2018.

If we take BNEF data, incremental sales of EVs will be higher than that of internal combustion engines (ICE) by 2020, and by 2023 ICE sales will already be falling. Such is the speed of marginal change.

Source: BNEF

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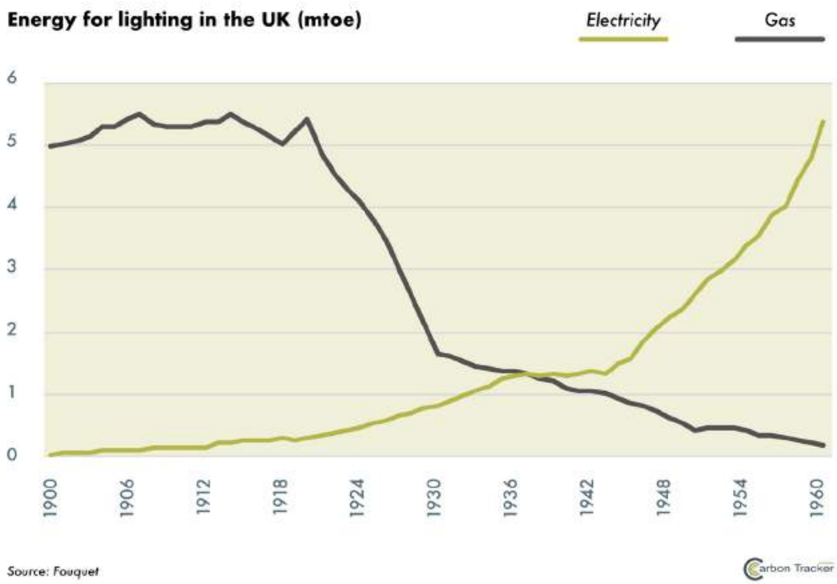
The UK lighting transition – gas lamps to electricity

Previous energy transitions have been characterised by a similar picture. Challenger technologies such as electricity or cars have arisen to dethrone incumbent technologies such as gas lighting or horses.

Incumbents have typically seen demand peak when the challenger was still small – around 2-3% of total sales. When lighting in the UK shifted from gas lamps to electricity, demand for gas for lighting peaked in 1907, at the point when electricity was just 2% of total lighting supply. Demand for gas held up for about a decade, but then collapsed as soon as the average price of electricity fell below that of gas in 1920. It is also interesting to note that it was only in 1938 that demand for electricity overtook that for gas; an incumbent gas lighting company that waited until 1938 to change its strategy would have been far too late[26].

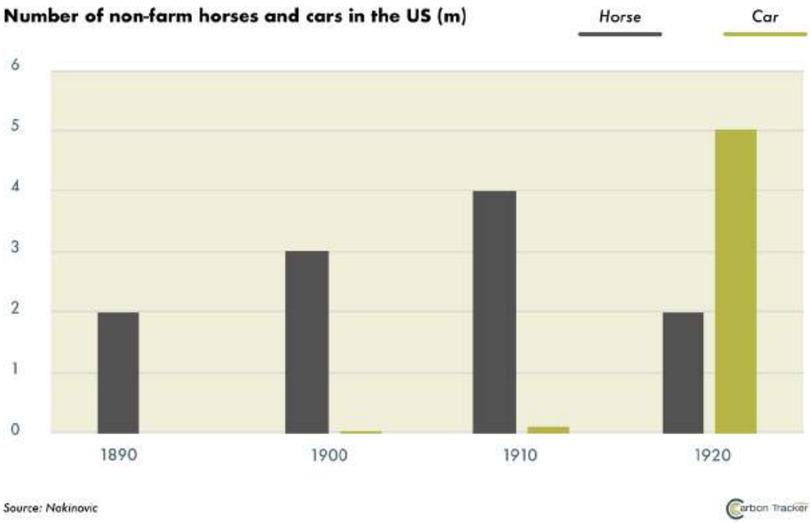


26 *Roger Fouquet. Heat, power and light*

The US transport transition. Horses to cars

In the famous transition from horses to cars, the number of non-farm horses in the US peaked in 1910 at 4 million when there were only 100,000 cars. Cars were thus just 3% of the number of their competitor.

It is also interesting to note that horses stayed on in certain transport niches where cars were not powerful enough to compete at the start. For example, pack horses survived for a number of years for the transport of heavy goods.



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Fossil fuel demand will peak in the 2020s

Most analysis of the future of fossil fuels seeks to make a detailed calculation of energy demand by country and product far into the future. It requires a huge number of assumptions, and not surprisingly there is considerable disagreement.

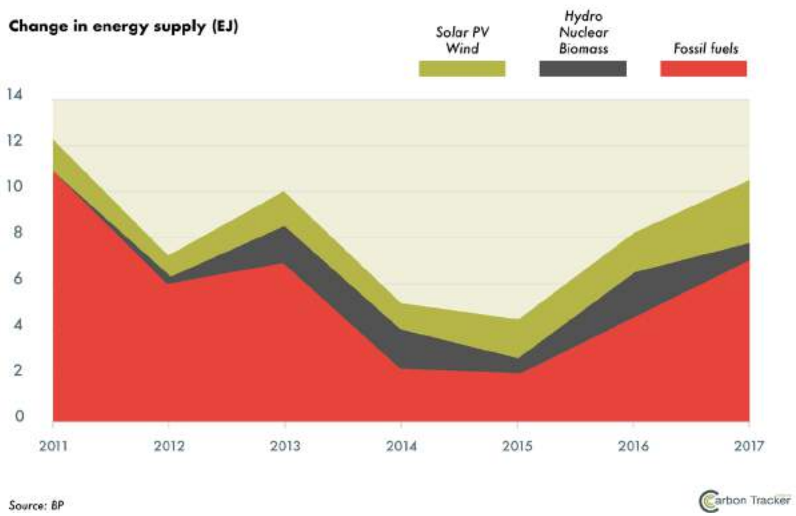
However, we are asking a much simpler question: when will fossil fuel demand peak? Because the peak of fossil fuel demand is in the near future, this question requires far fewer assumptions. Given that we are in a time of disruptive change in the energy sector, the smaller the number of assumptions the better.

We set out below a way of calculating the date of peak fossil fuel demand based on the rapid growth of solar PV and wind in the electricity sector. It requires just two primary assumptions – the growth rate of total energy demand and the growth rate of solar PV and wind. Our conclusion is that the 2020s will be the peaking decade.

I. How to divide energy supply

It is possible to split energy supply into three parts.

- **Slow-growing non-fossil technologies** like nuclear, hydro and biomass. These are mature technologies with established growth rates of around 2% a year.
- **The fast-growing new technologies of solar PV and wind**. As we have seen, these are characterised by S curves of growth, and in 2017 electricity generation from these sources grew at 22%.
- **Fossil fuels**. These are best seen as the residual source of energy supply. The fuel that you use when you don't have enough of the alternatives.



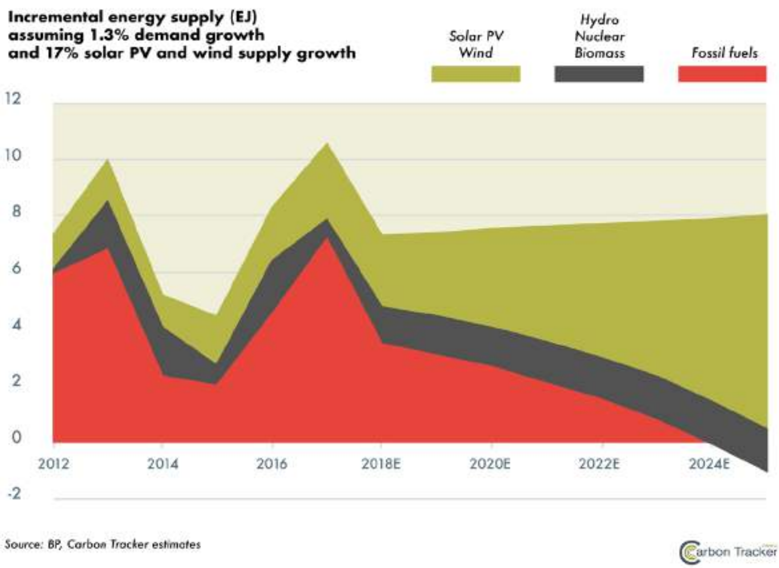
In the energy supply split, solar PV and wind are tiny – at just 3% of the total in 2017. However, when it comes to the change in energy supply, they are much larger because of their very rapid growth. In 2017, solar PV and wind supplied a quarter of the growth in total energy supply.

II. How to project energy supply

When projecting global future energy supply, there are then two key variables:

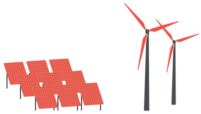
- **The growth rate of global energy demand.** In 2017 this was 2.1%[27], the highest it has been since 2011, in part thanks to cyclical factors. Over the last five years it has averaged 1.4%. The IEA forecasts a long-term growth rate of 1% in its NPS scenario.
- **The growth rate of solar PV and wind supply.** As we have seen, both industries are on well-established S curves of growth. The maths of S curves is simply that percentage growth rates are maintained at high but falling levels over time. Over the last decade the growth rate of solar PV and wind has fallen from 29% in 2007 to 22% in 2017.

If we make assumptions for these two factors, it is possible to calculate the date at which fossil fuel demand peaks. We illustrate this below, assuming total energy demand growth of 1.3% (assuming a slight fall from the 5-year average) and solar PV and wind supply growth of 17% (assuming a continued S curve of supply growth, with growth ratees falling over time from the current level of 22%). The date of peak fossil fuel demand is then 2023.



27 BP, 2018

Year of peak fossil fuel demand



Solar PV and wind supply growth	*Global energy demand growth from 2018*: 1%	1.5%	2%
10%	2029	2037	2043
15%	2022	2027	2030
20%	2020	2023	2025

Source: Carbon Tracker assumptions

Clearly, our view of 1.3% energy demand growth and 17% solar PV and wind supply growth is open to question. We show therefore the date of peak fossil fuel demand using a range of assumptions for energy demand growth and solar PV and wind supply. The most plausible scenarios are for a global growth rate of energy demand of 1-1.5% and solar PV and wind supply growth of 15-20%. This gives a range of 2020 to 2027 for the date of peak fossil fuel demand.

Under the most likely scenarios demand for fossil fuels will peak in the 2020s. For this reason, we believe that the 2020s should be called the peaking decade.

III. How large will solar PV and wind be in the global energy mix at peak fossil demand

At the tipping point when total fossil fuel demand peaks, the challenging technologies of solar PV and wind will be 6% of total energy supply, as we show in the chart below.

This implies that solar PV and wind would be 14% of global electricity supply. 14% penetration of solar PV and wind is far below the levels of penetration of solar PV and wind already achieved in many countries in Europe, and also below the level of penetration (around 20%) at which the IEA believes it will be necessary to have a significant amount of storage backup for renewables.

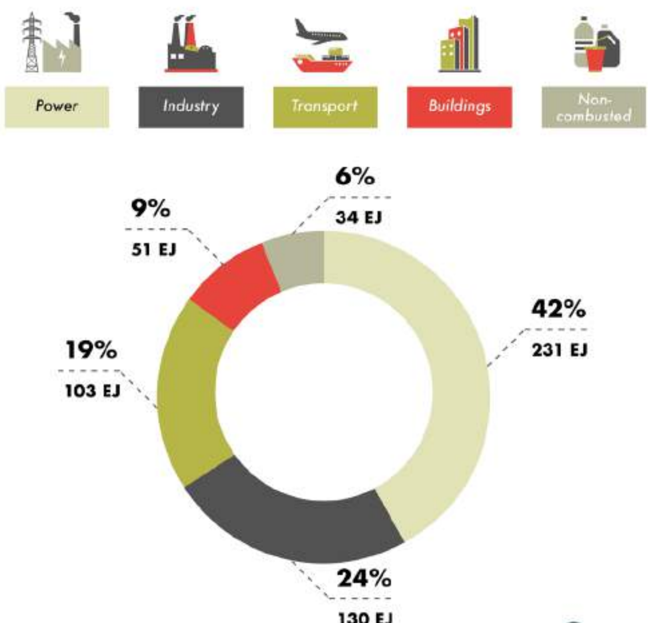
IV. Why is electricity so important

We set out below why we believe electricity is key to the energy transition, and then examine the main counterargument that electricity is only a small part of the story.

The primacy of electricity in the energy transition

According to BP data, in 2015 energy to make electricity was 42% of total energy supply.

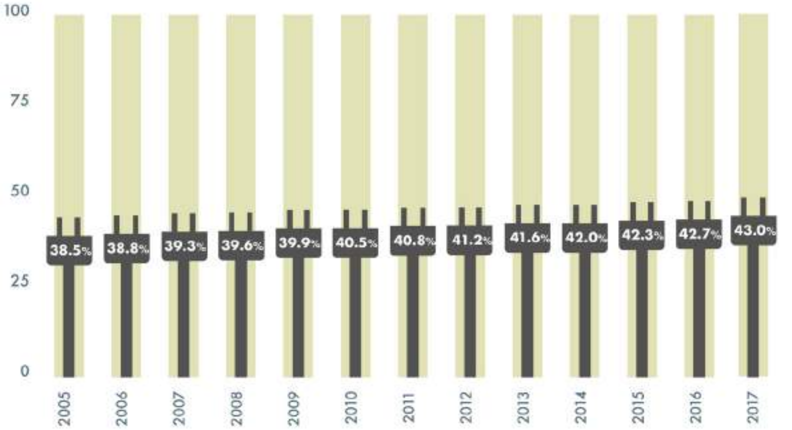
Energy demand by sector, 2015 (EJ)



Source: BP

Carbon Tracker

Share of electricity in total energy demand



Source: BP

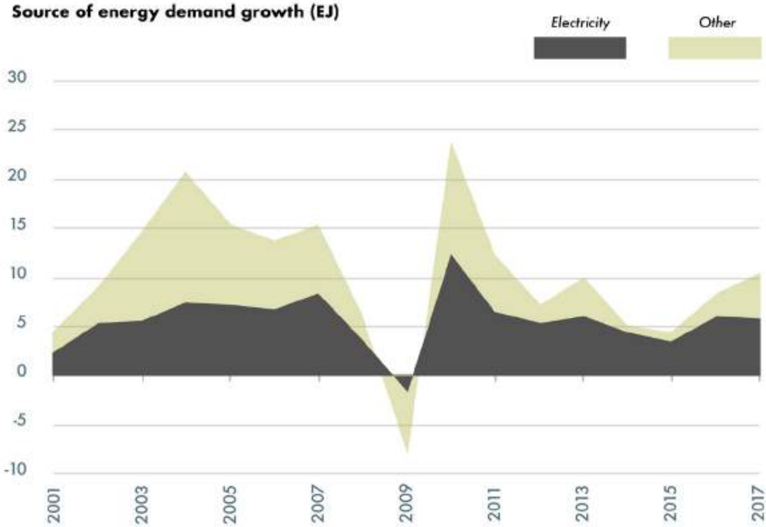
Carbon Tracker

And because other sectors have been electrifying, the share of electricity in total demand for energy is growing at around 3.6 percentage points per decade.

The net result of this is that demand for electricity has made up 71% of global energy demand growth over the last 5 years.

The implication is that the transition of the electricity sector is key. Once fossil fuels start to be pushed out of electricity supply, we will be very close to peak demand for fossil fuels in total.

Source of energy demand growth (EJ)



Source: BP, CTI estimates

Carbon Tracker

The counterargument

It is often argued that electricity is not especially significant because it is only 20% of end demand.

In part the gap between the two perspectives is because we are looking at the change in demand rather than total demand.

However, there is also fundamental debate in the energy industry[28] about how to compare the energy from solar PV and wind with the energy in fossil fuels. It is hard to compare electricity from solar PV and wind, which is a high quality energy carrier with the primary energy sources of coal or oil which are lower quality energy that lose around two thirds of their energy on conversion to electricity or transport.

When looking at the electricity sector there is no difficulty in comparison. The issue arises when looking at the total amount of energy, measured in million tonnes of oil equivalent (mtoe) or Joules. Without going into excessive detail, the IEA counts one Joule of solar electricity at the same value as 1 Joule of oil. BP takes account of the (unavoidable) thermal losses on conversion, and as a result the size of its solar PV electricity measured in mtoe is about three times larger than that of the IEA. We simply take the pragmatic view that if one KWh of solar PV replaces 3 KWh of raw coal, then the BP approach is a more accurate reflection of reality.

At low levels of solar PV and wind supply, this was not a very important issue. However, as the penetration rises and as we look at marginal change, it becomes vital to understand the speed of change.

28 See for example 'Is peak energy coming soon' DNV GL 2017 or Energy Klima. Erik Sauar. 2017

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Why the peak in fossil fuel demand is key?

It is often argued that it is necessary to analyse each country, area of end-demand and area of supply in order to build up an accurate picture of the energy transition. We explain below why we believe that this is neither possible nor helpful when taking a long-term view. Our approach is to understand the timing of the peak of fossil fuel demand and then to think through the consequences of the peak.

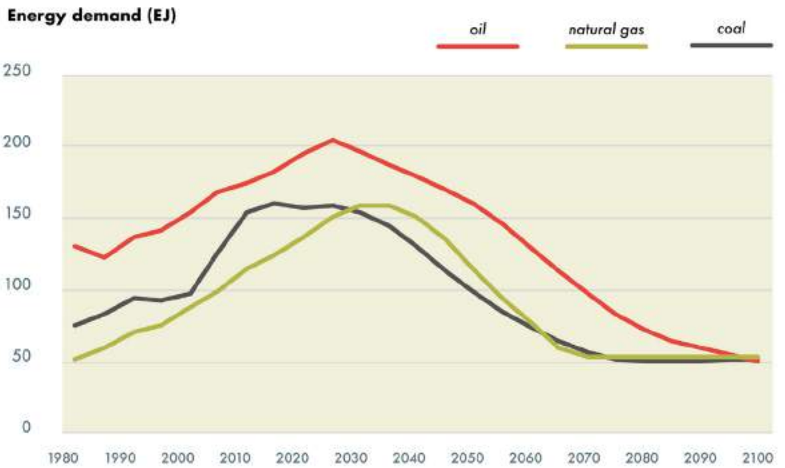
I. Modelling uncertainty

In a world with perfect data and without a technology disruption, bottom-up detail is the best solution. However, in a world which is undergoing technology disruption and where we do not know in detail how the future will play out, it is more accurate to model the big picture.

II. All fossil demand peaks in any event

If there is peak demand for fossil fuels in total, then there will be peak demand for each of the three key fossil fuels within a few years of the total peak. The best illustration of this is to show the detail by fuel in the Shell Sky scenario.

On close examination, it is possible to see that coal, oil and gas all peak at different times. Coal in 2015, oil in 2025 and gas in 2035. But each of them peaks and then declines.



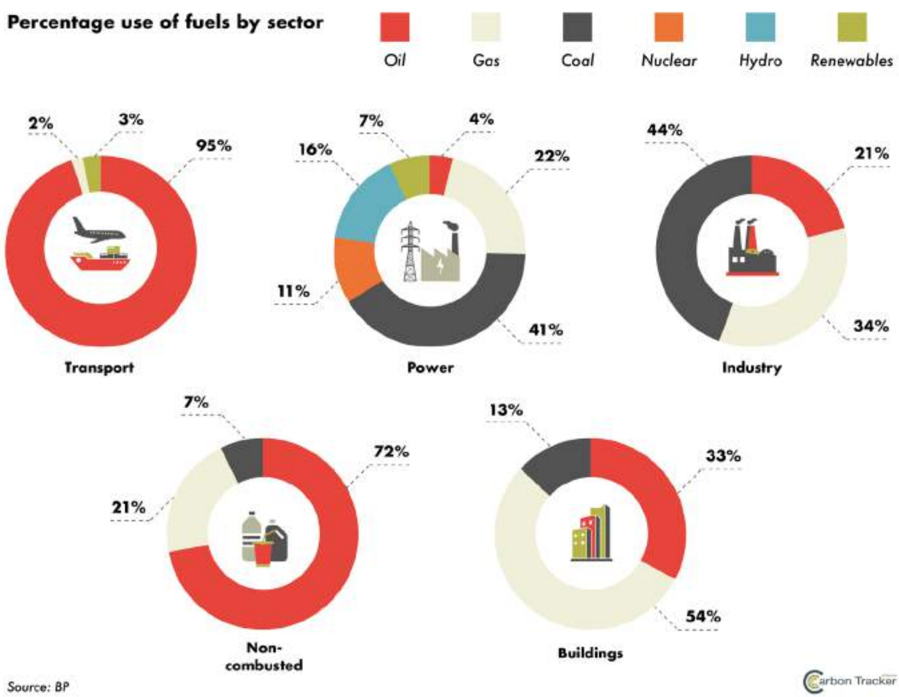
Source: Shell Sky Scenario

III. Fossil fuels compete directly with renewables and with each other

Fossil fuels compete directly with renewables and each other across the energy sector. Competition is most fierce in the electricity sector, and is now set to intensify in the transport sector thanks to the fall in battery prices. Much technology innovation is taking place in order to increase fungibility between the fuels. For example, there is potential for hydrogen produced from the electrolysis of water to replace gas in heating or as a source of interseasonal storage.

IV. The rising regulatory burden will impact all fossil fuels

Although some fossil fuels are less pollutive than others, the desire to reduce pollution, carbon emissions and energy dependency applies to all of them. They will all therefore face increasingly stringent regulation.



How much money is at risk?

Investors face three types of risk from the energy transition – systemic, country, and stock specific.

I. Systemic risk

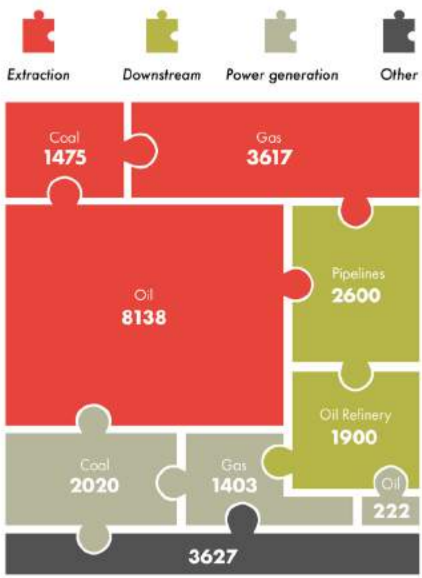
The systemic risk to investors comes from the fact that the fossil fuel sector has very large amounts of assets which will become stranded as the energy transition progresses.

The process is simple economics. As the costs of renewables fall, so high cost and early stage fossil fuel assets become redundant. Examples include gas-fired power generation in Europe, gas turbine makers such as GE, or builders of diesel engine factories.

As the cost of renewables fall further, they reach a level called by BNEF 'the second tipping point' at which the cost of renewable electricity is cheaper than the variable cost of fossil fuels. At this stage it makes sense to close down existing and functioning fossil fuel plants. This is the situation today for parts of the European thermal generation sector.

The reason why this is a systemic risk is because the fossil fuel sector has the largest built asset infrastructure in the world, with an estimated build cost of $25 trillion according to Shell. We detail below a rough approximation of the largest components of this infrastructure, based on standard build costs.

Fossil fuel infrastructure value ($bn)

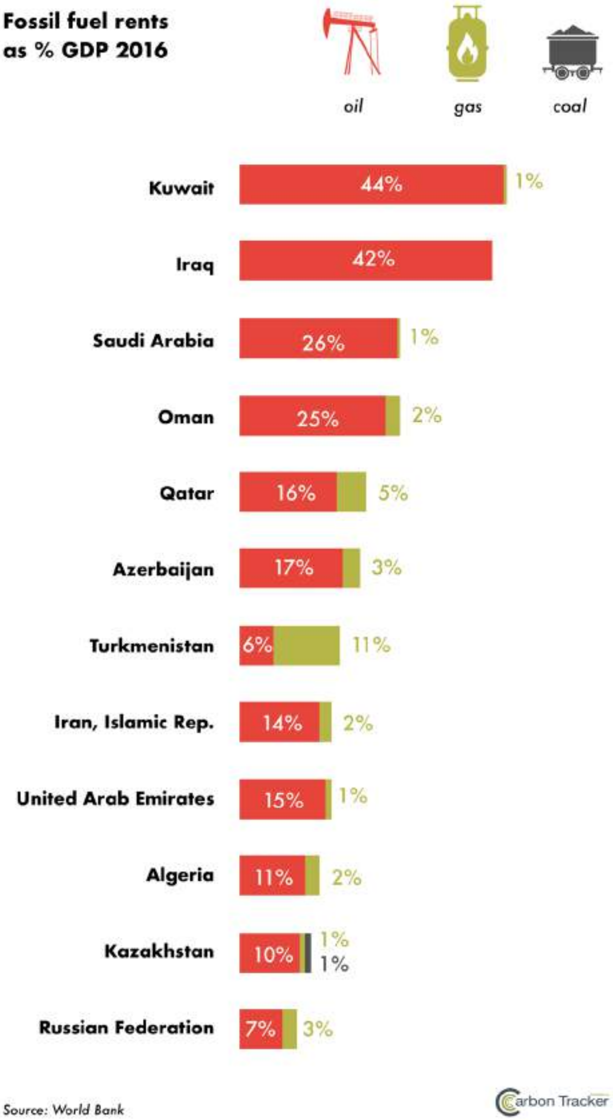


Source: Carbon Tracker

II. Country risk

Countries which are dependent on fossil fuel exports are vulnerable to the ending of rents. We summarise below the world's leading countries in terms of fossil fuel rents as a share of GDP.

On the other side of the equation, lower middle-income countries with large fossil fuel imports (such as Pakistan or India) will enjoy a major boost to their current account as they are able to increase domestic production of energy and to curtain energy imports.



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III. Company risk

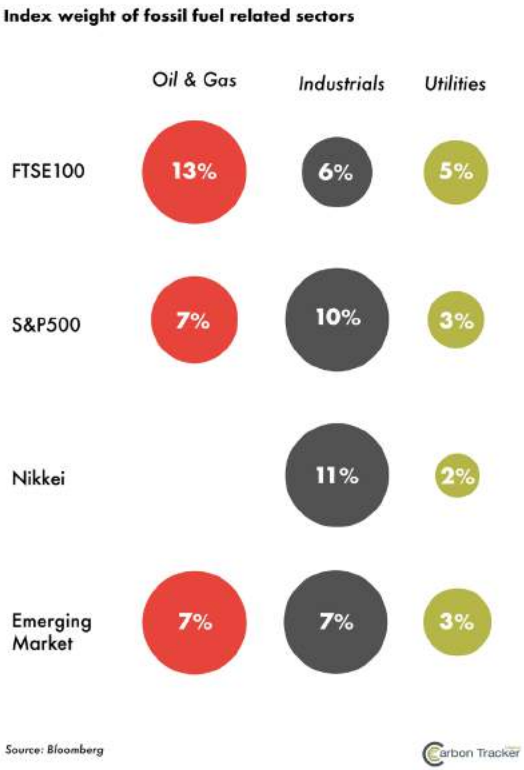
Companies can of course transition, as Orsted (formerly Danish Oil and Natural Gas) has done. However, entire sectors will struggle to transition from one environment to another. They can expect price declines, greater competition, restructuring, stranded assets and market derating.

Companies already impacted
The energy transition has already had an impact on a number of major fossil fuel companies. Although there are clearly other factors impacting share prices, there has been significant underperformance in recent years from companies such as RWE, Peabody, or GE.

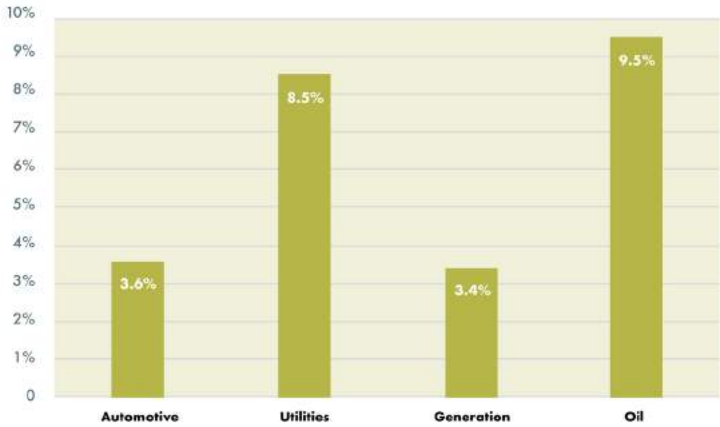
How big are impacted sectors
The sectors impacted by the energy transition are wide and not just limited to fossil fuel stocks. Outside the obvious areas of coal, oil and gas, they include capital goods (such as gas turbines), transport (such as coal ports) and automotive.

There will also be impacts on sectors such as banking and on domestic stocks in petrostates. Other vulnerable sectors may turn out to be biomass and fertilizers, which were part of the last attempt to find cheaper alternatives to fossil fuels but which will increasingly be superceded by solar PV and wind.

Directly impacted sectors compose up to a quarter of equity indices



Share of global corporate bonds in impacted sectors



Source: *Fitch*

In debt markets, fossil fuel and related sectors make up nearly a quarter of the total corporate bonds followed by Fitch, and a little more of the bonds covered by Bloomberg.

Which areas are most vulnerable

We set out some of the greatest areas of vulnerability.

- Regulation. Sectors which are subject to stringent regulation. Such as European electricity
- Demand growth. Areas where demand growth is weak. Such as OECD fossil fuel demand.
- Capital goods. Providers of capital goods such as companies building diesel engines or oil platforms or gas turbines.
- High cost. Sectors at the top end of the cost curve such as LNG or Arctic oil.
- Highly pollutive. Sectors such as coal or tar sands.

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