SUSTAINABLE FINANCE PROGRAMME

SMITH SCHOOL OF ENTERPRISE AND THE ENVIRONMENT

UNIVERSITY OF OXFORD

Revolution not evolution:

Marginal change and the transformation of the fossil fuel industry

Discussion Paper

February 2017

Author: Kingsmill Bond

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Dimitri Zenghelis, Principal Research Fellow, Grantham Institute, London School of Economics

About the Author

Kingsmill Bond is a Research Affiliate at the Sustainable Finance Programme at the University of Oxford Smith School of Enterprise and the Environment. He is the new energy strategist for TS Lombard, a leading investment research company. He has worked as a City analyst and strategist for over 20 years, with a focus on emerging markets, Russia, and energy. He has been the global emerging market strategist for Deutsche Bank, global thematic strategist for Citibank, and Russia strategist for Sberbank and Troika Dialog. His focus is on the implications of the new energy revolution for financial markets.

Acknowledgements

I am particularly grateful to Ben Caldecott (University of Oxford), Lucas Kruitwagen (University of Oxford), and Elizabeth Harnett (University of Oxford) for their help and support throughout the research process.

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Table of Contents

Key Findings

Revolutionary change is about to transform the fossil fuel industry as policy-driven change moves to market-led change. Companies and investors need to abandon the false hope of slow evolutionary adjustment.

- **The hope for evolution**. The orthodox view on energy transitions argues that systemic change will take generations, implying that the energy incumbency has nothing to fear from ongoing changes to energy markets.

- **Marginal change is key**. However, what matters for companies and financial markets is marginal change, which is two orders of magnitude smaller than systemic change.

- **Change is upon us**. In 2015, solar and wind energy sources supplied only 2% of total energy but 33% of marginal energy supply. Non-fossils as a whole supplied 51% of marginal supply.

- **Growth continues apace**. The cost of electricity from solar and wind continues to fall rapidly, challenging fossil fuels in ever more locations. And falling costs drives annual growth of around 20%.

- **The emerging market leapfrog**. Led by China, the emerging markets are finding a different path to development fuelled by renewables not fossil fuels.

- **Peak fossil fuels by 2020**. Assuming global energy demand growth of 1% and solar and wind supply growth of 20%, fossil fuel demand is likely to peak by 2020.

- **Why is marginal change happening so fast**? Renewables are not the same as fossil fuels; policymakers want to reduce fossil fuel consumption; and the world has moved on from the time of the last big energy transition.

- **Expect revolution**. Once fossil fuel demand starts to fall, incumbent producers will face disruptive change as competition intensifies between fuels, prices fall, and assets become stranded.

- **The process has already started**. Investors do not need to look far to see the disruptive impact of marginal change. The coal industry saw widespread bankruptcies when demand was just 2% off its all-time peak, and the European electricity sector is undergoing radical restructuring when demand is 5% below its 2007 peak.

- **History is replete with examples of the power of marginal change**. Even when new energy technologies have been small (2-3% of supply) they have in the past caused lower volumes and prices for the incumbents. Examples from the UK include the shift from steam to electricity in the power sector after 1907 or the shift from gas to electricity in the lighting sector after 1914.

- **Investors can't wait for systemic change**. By the time the market share of new technologies had reached 25% in the UK energy transformations of the twentieth century, demand for the old technology had already been falling for 25 years.

1. What kind of change matters for investors

Orthodox thinking on the nature of change in energy systems tends to focus on the question of systemic change: how long it will take for the current fossil fuel based system providing 86% of our energy in 2015 to shift to a renewable based system which will be equally dominant. There is some debate about the hurdle rate required for the new energy source, but it is usually seen as a market share between 25% (Smil, 2016) and 50% (Grubler, Wilson, & Nemet, 2016). Strategists working for the oil industry have taken up this theme and focused on the large amount of time it takes for new technologies to take market share (Kramer & Haigh, 2009).

Systemic change is important for many reasons, above all as a tool to calculate how long it will take for the world to reduce and eliminate carbon emissions. However, systemic change is not the key issue for incumbent companies and financial markets. By the time that systemic change has happened, companies that were part of the old system have gone bust or been transformed, and long before that happens, markets anticipate and price in the change.

What matters for companies and for financial markets is marginal change (Bond, 2016c). For a company, marginal change is simply sales growth; and for financial markets marginal change acts as a signal of coming success or failure.

We can illustrate the difference between systemic and marginal change with reference to the car industry. The total car fleet is around 900 million vehicles. Annual car sales in 2015 according to Wards Auto were 83 million vehicles, with sales growth of 2 million. Electric vehicle (EV) sales in 2016 were 0.8 million, and the size of the EV fleet was just over 2 million at the end of 2016.

Systemic change is focused on questions like when will half of the car fleet be electric vehicles, or when will annual sales of EV reach 40 million. Clearly that is not going to happen for a long time.

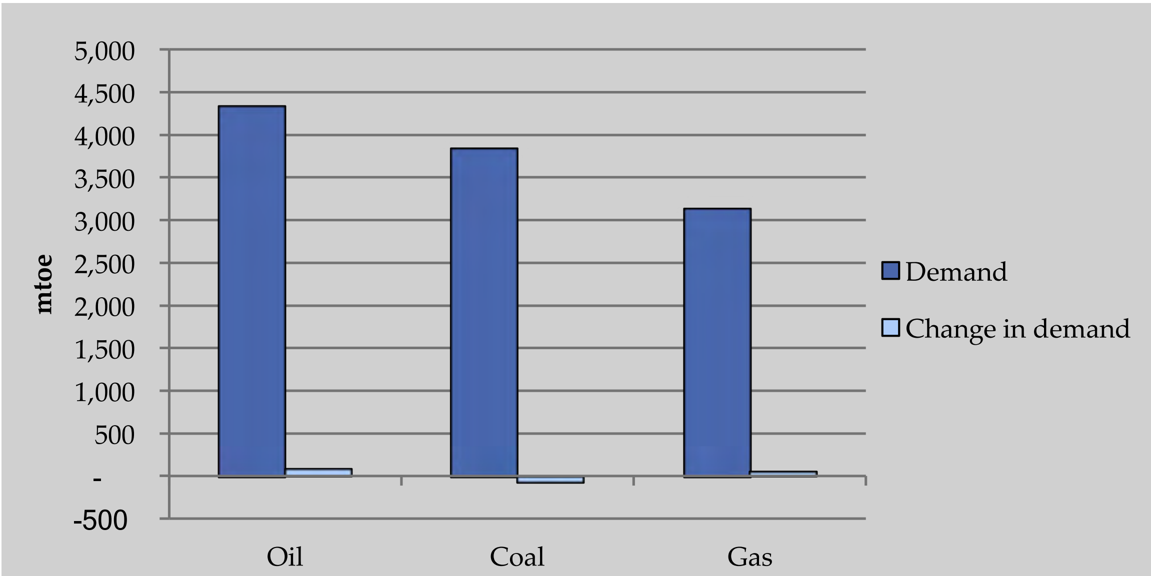
Marginal change for the car industry focuses on the 2 million vehicles: which company can take a share of the 2 million vehicle growth. Change here clearly can happen much sooner. Incremental EV sales in 2016 were 0.3 million, and at current growth rates, electric vehicles will supply all incremental car demand in 5 years (Bond, 2017). At this stage the market share of EV would be under 10% and they would make up just 3% of the global fleet.

Meanwhile, we do not see automotive manufactures sitting on their laurels and not worrying about the fact that it will take decades for electric vehicles to replace the internal combustion engine. In 2016, when EV were less than 1% of total sales, a large number of automotive manufacturers, from BMW to Ford, made announcements about a major strategic shift into EV.

1.1 What are the hurdle rates for significance

As an illustration of the wide difference between systemic and marginal change, we summarise below the demand and growth in demand for coal, oil and gas in 2015.

Figure 1. Demand and change in demand 2015 (mtoe)



Source: BP (2016)

The conclusion is obvious – the hurdle rate for the significance of marginal change is about two orders of magnitude lower than that of systemic change.

Total demand for energy in 2015 was 13,147 mtoe according to BP (2016), and energy demand growth was 127 mtoe. We believe that disruption for incumbents will occur when the 127 mtoe come from non-fossil sources, not when 13,147 mtoe are replaced.

2. When will marginal change strike

A lot of the debates about change in the energy sector are vulnerable to the criticism that any given example is specific not systemic. In order to get round this issue, we make the argument about marginal change with regard to the entire energy sector.

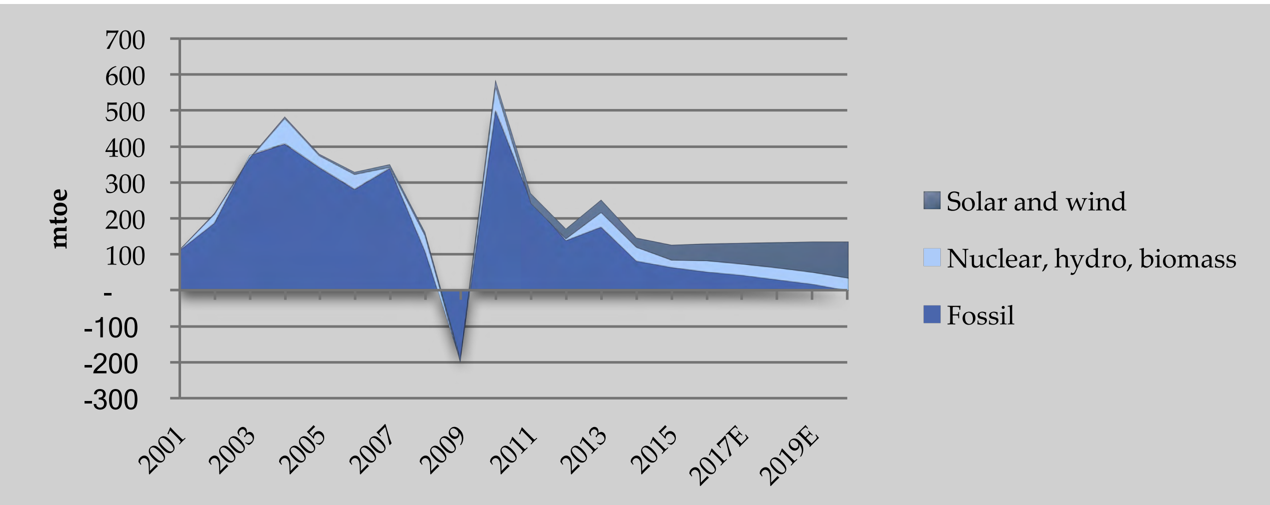
Most energy analysts have grown accustomed to modelling the energy world in great detail and from the bottom up. Kerosene demand from Kenya, palm oil supply from Indonesia, EV deployment in California, they all take their place in models of breath-taking complexity. This type of analysis is excellent for short-term developments or for understanding what happens if one energy source is taken offline, but it is unsuited for modelling long-term energy changes, and wholly inappropriate for handling systemic change. As a result, consensus has an impressive track record of missing systemic changes, from the fall in oil demand in the OECD to the growth of US shale production or the spectacular increase of wind and solar capacity.

We seek therefore to model top-down. We split the energy world into two – fossil fuels, which we see as the incumbents; and non-fossils. We then split non-fossils into two parts – fast growing – solar and wind, which we see as the challengers; and slow-growing, which are hydro, nuclear and biomass. We then model total demand growth against the supply growth of non-fossils. Fossil fuels are the balancing factor. Our key assumptions as laid out in more detail in a recent piece (Bond, 2016b) are:

- Total demand growth. We assume that total energy demand growth runs at 1% a year until 2020. In 2015 it was 0.9%. The IEA in WEO (2016b) assumes a long term energy demand growth rate of 1% in large part because of ongoing efficiency gains.
- Solar and wind electricity supply growth. We assume 20% growth a year for the next five years, in line with growth rates over the last few years and at the top end of the growth rates predicted by the Global Wind Energy Council (GWEC) and Solar Power Europe (SPE).
- Supply growth of hydro, nuclear and biomass. This is a variable in much less dispute as these technologies are established and slow growing. We assume continuity of around 2% growth a year.

With these assumptions, non-fossil sources will make up all marginal supply of energy by 2020. We call this the tipping point.

Figure 2. Marginal supply of energy (mtoe)



Source: BP, TSRP estimates

Clearly, reality will not be so simple as our model. Energy demand growth might be higher (or lower) than we assume, and solar and wind supply may grow faster or slower than we assume. We show therefore the timing of the tipping point with different assumptions for these two variables. For example, if solar and wind growth were to be 15% per annum and global energy demand growth were 1%, then the tipping point would be 2024 instead of 2020.

Table 1. The timing of the tipping point

	Global energy demand growth			
Solar and wind growth rate	**0.50%**	**1%**	**1.50%**	**2%**
5%	2033	2065	2091	2118
10%	2021	2032	2040	2046
15%	2017	2024	2028	2032
20%	2017	2020	2024	2026
25%	2017	2019	2021	2023

Source: TSRP estimates

2.1 Why does peak fossil fuel demand matter

The fossil fuel industry has enjoyed almost uninterrupted growth for two centuries; even at the peak of its deployment, in 1985, nuclear energy made up only 28% of incremental energy supply. The assumption of ever-rising growth is deeply ingrained into the fossil fuel operating model as a result. A shift from growth to decline would therefore be likely to leave the industry with stranded assets that cannot be monetised.

And as the industry awakens to this new reality, we would expect a surge of production as companies race to sell their fossil fuels while they still can.

Moreover, as the industry is obliged to compete for demand (rather than the more recent environment of users having to compete for supply), it is bound to change in ways that are hard to forecast in detail. Cost cutting, innovation, shifting into new markets, all this and more can be expected. Examples of changes that we have already seen include the decision by Saudi Arabia to build a solar PV industry to reduce its summer oil burn, the replacement of kerosene with solar as a lighting source in Africa, the reduction in growth in the petrostates, or the attempt by the gas industry to substitute oil in heavy transportation. In addition to this, energy demand from the energy sector itself is likely to be weaker.

The peaking of total fossil fuel demand implies that there will be many separate peaks in demand for fossil fuels by product and by region. These peaks will take place both before and after the central peak. The following changes are therefore best seen as harbingers of a wider transformation: the peaking of demand for energy in the OECD in 2007; the peaking of demand for fossil fuels for electricity generation in Europe in 2008; the peaking of global coal demand in 2014; and the peaking of global per capita fossil fuel demand in 2015.

3. Have we seen this before

We set out below a number of examples where marginal change has had a devastating impact on incumbent producers. It is not the purpose of this note to set out a unified theorem on energy systems, so we accept that our examples are anecdotal. Nonetheless, we believe that they are relevant examples as they involve more than a simple change in end use.

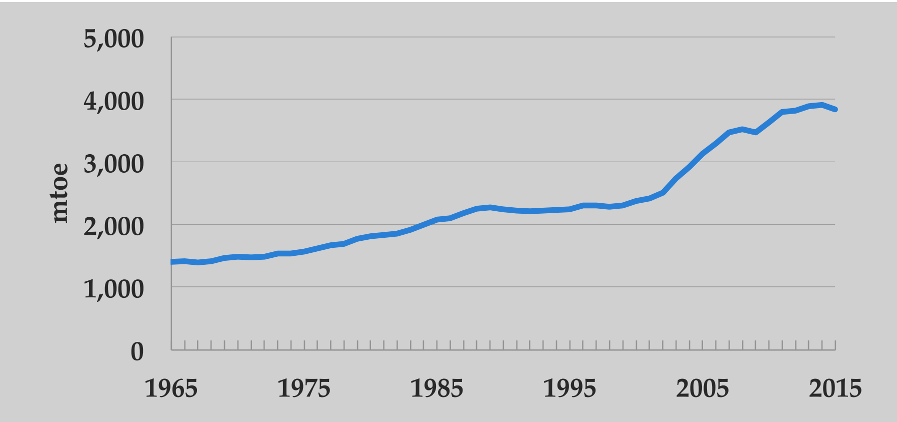
3.1 In recent times

We highlight two recent examples of rapid marginal change in the energy sector – global coal and European electricity. We believe that these are examples of the type of change that is likely to sweep across the global energy sector over the next few years.

3.1.1 Coal

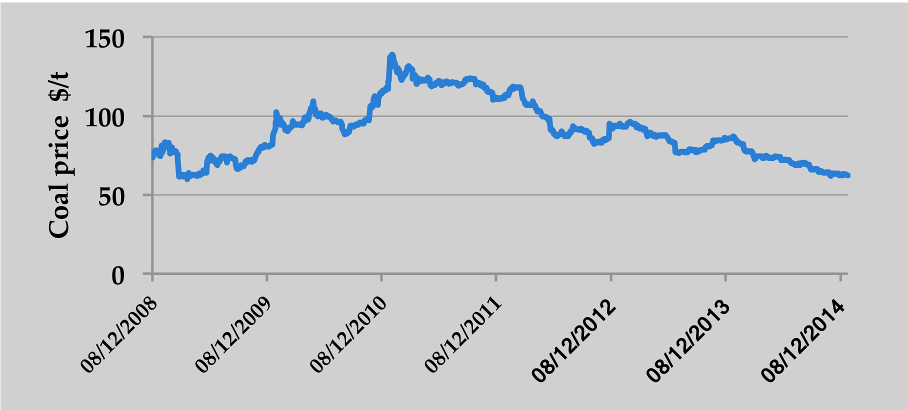
As soon as demand stopped rising rapidly (and even before demand fell), coal prices started to fall. And coal equities anticipated the fall in coal prices by around six months. It is notable that a number of well-known coal companies filed for bankruptcy in 2016 when coal demand was just 2% below record highs.

Figure 3. Coal demand mtoe



Source: BP (2016)

Figure 4. Coal price $/t Newcastle



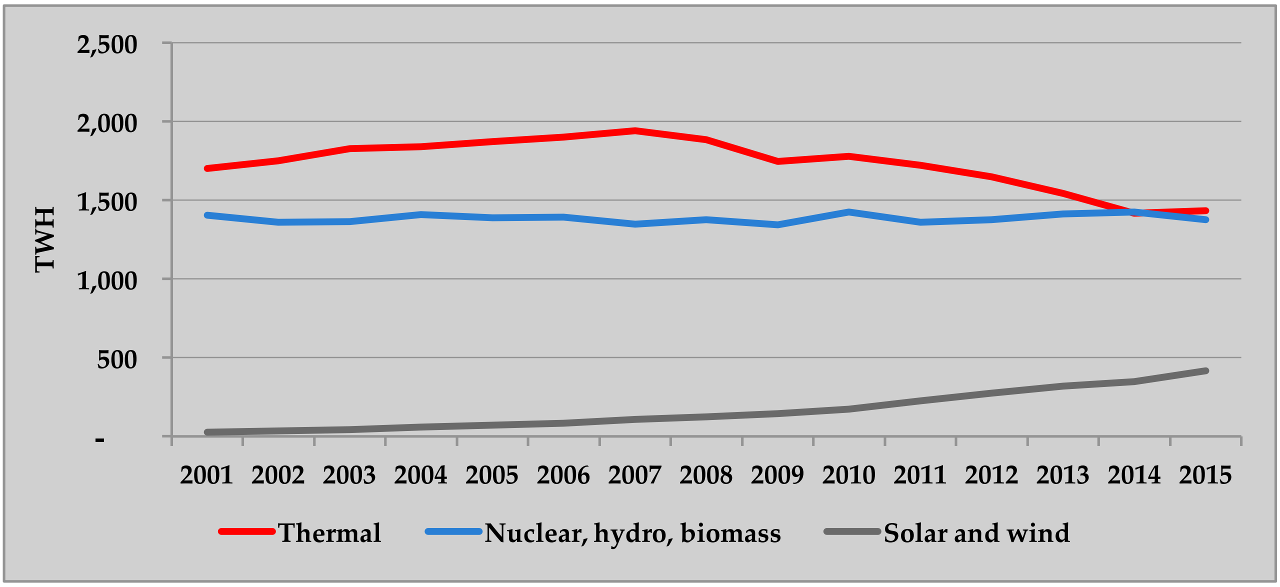
Source: Bloomberg

3.1.2 European electricity

For many years, the business model of the European electricity sector was to produce increasing amounts of electricity from fossil fuels to meet ever-growing demand. However, two developments challenged this cosy world after 2007: electricity demand stopped rising, and renewable supply carried on growing.

Fossil fuel-based generators were squeezed in the middle, facing rising competition and falling demand for their products. Electricity prices peaked in mid-2008 and equity prices peaked some six to nine months before this. Eight years later, the industry leaders are undergoing radical restructuring, even though total demand is just 5% off its peak.

Figure 5. European electricity supply by source TWh



Source: BP (2016)

3.2 Marginal change in the twentieth century

Roger Fouquet's excellent book Heat, Power and Light provides data for the UK market in the four main sectors of heat, light, transport and power, as the coal based energy systems of the nineteenth century were transformed into the oil, gas and electricity systems of the twentieth (Fouquet, 2009).

Whilst Fouquet focuses in his book on the considerable length of time required for systemic change, a very different picture emerges if one looks at marginal change.

- Demand for the old technology started to fall when the new technology was still a small part of the energy system. In the case of the power sector, electricity was just 3% of the total supply at the moment of peak demand for steam. In the transport sector, coal demand peaked when oil supply was just 2% of the total.

- Demand for the old technology started to fall even when the average price of the new technology was higher. This probably reflects the important role of niche adopters and the fact that even when average prices may be higher, there will be specific areas of demand where they are lower. This is a very salient point today at a time of much dispute about renewable costs.

- Prices for the old technology started to fall as soon as volume fell.
- By the time the new technology was 25% of the total supply (the low end definition for systemic change according to Benjamin Sovacool (2016)), demand for the old technology had been falling for 25 years.

Table 2. Change in the UK energy system

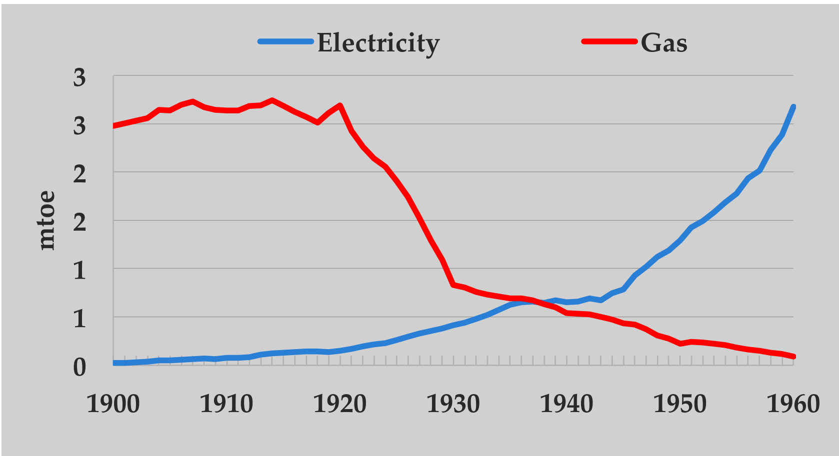
Area	Energy Source		Date of peak 'old' demand	Market share at peak demand	
	Old	New		Old	New
Power	Steam	Electricity	1907	84%	3%
Transport	Coal	Oil	1913	94%	2%
Light	Gas	Electricity	1914	69%	3%
Heat	Coal	Gas	1940	88%	6%

Source: Fouquet (2009)

3.2.1 Light

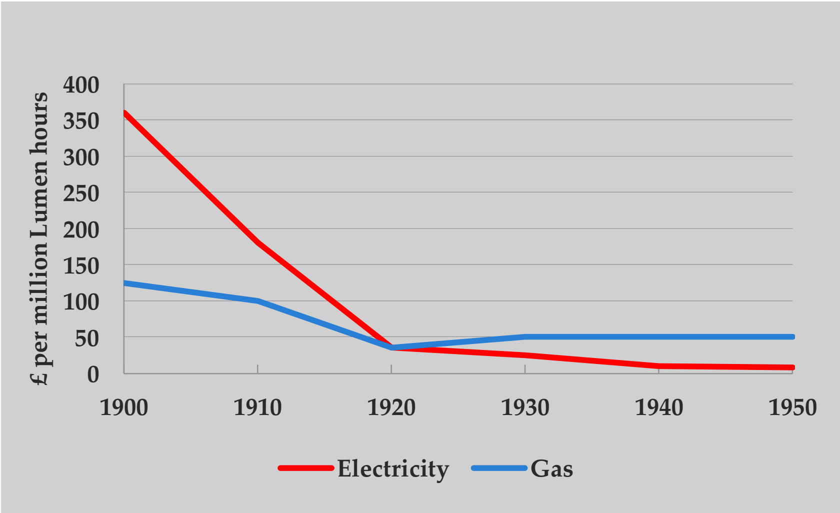
We show below a little more detail on prices and volumes for the provision of lighting in the UK, as the system moved from gas lighting to electricity in the early years of the twentieth century. As the provision of electricity grew, so gas demand stopped growing after around 1907, and gas demand peaked when electricity was just 3% of the total supply in 1914. Demand for electricity rose even thought its average price was higher than that for gas. Meanwhile, gas prices started to fall, and efficiency to rise after 1900, in a classic example of the 'sailing ship effect'. Gas was able to maintain roughly flat demand until 1920, when the average price of electricity fell below that of gas. After that, demand for gas rapidly fell.

Figure 7. Energy consumption for lighting in UK mtoe



Source: Fouquet (2009)

Figure 8. Price of lighting in UK



Source: Fouquet (2009)

4. Why is marginal change so soon

We summarise below why we believe that marginal change will take place rapidly. At heart we are simply seeking to explain and justify two numbers – 1% global energy demand growth, and 20% solar and wind electricity supply growth. We considered this at length in a piece published in September 2016 – The new energy transition – history is bunk (Bond, 2016d).

We do not believe that the assumption of 20% growth for solar and wind electricity supply is unreasonable. If solar and wind capacity installation were to remain constant at 2016 levels of 132 GW a year, then global supply to 2020 would grow at a compound annual growth rate of around 14%. However, as we set out below, there are plenty of reasons to believe that installation levels will continue to grow, driven by emerging market demand and led by China (Bond, 2016a).

We separate our argument into four parts – renewables are not the same as fossil fuels; policymakers want to reduce fossil fuel consumption; solar and wind costs have reached parity with fossil fuels; and the world has changed since the last energy transition.

4.1 Renewables are not fossils

It might seem rather obvious to say that renewable energy (defined here as solar and wind) has dramatically different characteristics to fossil based energy. Nonetheless this is a point worth making because much of the literature on energy transitions seeks to identify laws of energy history based on a small number of mainly fossil fuel based transitions.

- Renewables are everywhere, fossils are in a limited number of locations. As renewable costs fall, it is as if every country in the world woke up one bright morning to find that it had a North Sea at its disposal. The implications of this fact alone are very significant. The academic literature, as summarised and analysed by Benjamin Sovacool (2016) is very clear that individual countries can change their energy systems quite rapidly. It is also axiomatic that counties exploit local energy resources rapidly.

- Renewables are a technology, fossils are extraction. Renewables have a cost learning curve of up to 20% for every doubling in capacity, and get cheaper the more you produce. In contrast fossil fuels tend to get more expensive the more you produce, because you extract the easily accessible reserves first. Renewables are already cheaper than fossil fuels today in many countries, and over time their cost advantage is likely to increase.

- Renewables are scalable, fossils are monolithic. Renewables can be deployed everywhere, from the roof of a house in Bangladesh to the deserts of Spain, and are able to work at every scale. Fossils require huge capex, and every project is different.

- Renewables have strong policy support; fossils are under increasing policy pressure as detailed below.

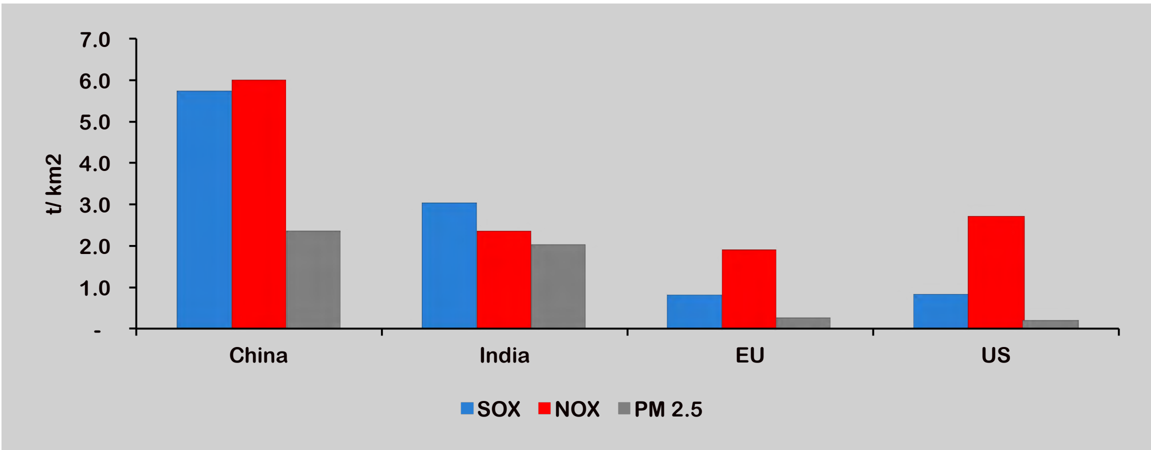
- Renewables need less infrastructure. Whilst we have not carried out a detailed comparison of the total infrastructure requirements of fossil fuels versus renewables, it is clear that there are many locations where renewables simply will not need so much infrastructure as fossils. Instead of incurring the expense of oil wells, refineries, pipelines and grids, a village in Ghana can simply buy a solar panel and a battery to obtain electricity. Moreover, in many developed markets, renewables can be added to existing systems. An electric vehicle needs a plug, whilst a century ago a petrol car needed not just a petrol station but an entire road network.

4.2 Policymakers want to reduce fossil fuel consumption

There are three main factors which encourage policymakers to reduce fossil fuel consumption: local pollution; energy security; and climate change.

- Local pollution. According to the World Bank (2016), air pollution, mainly caused by the energy sector, is now the fourth largest killer in the world, responsible for 10% of all deaths, or 5.5 million deaths a year. The smog infested cities of India and China simply cannot endure dramatically higher levels of energy consumption. One illustration of this is to consider the levels of pollution per square km in the areas in which the bulk of the population lives.

Figure 9. Pollution t/ km2 in areas of primary habitation



Source: IEA, WHO, TSRP estimates

- Energy security. Although the US is now energy self-sufficient, most countries are not. Europe, China and India are already major energy importers, and the energy dependency of China and India is only expected to grow as their energy usage increases.

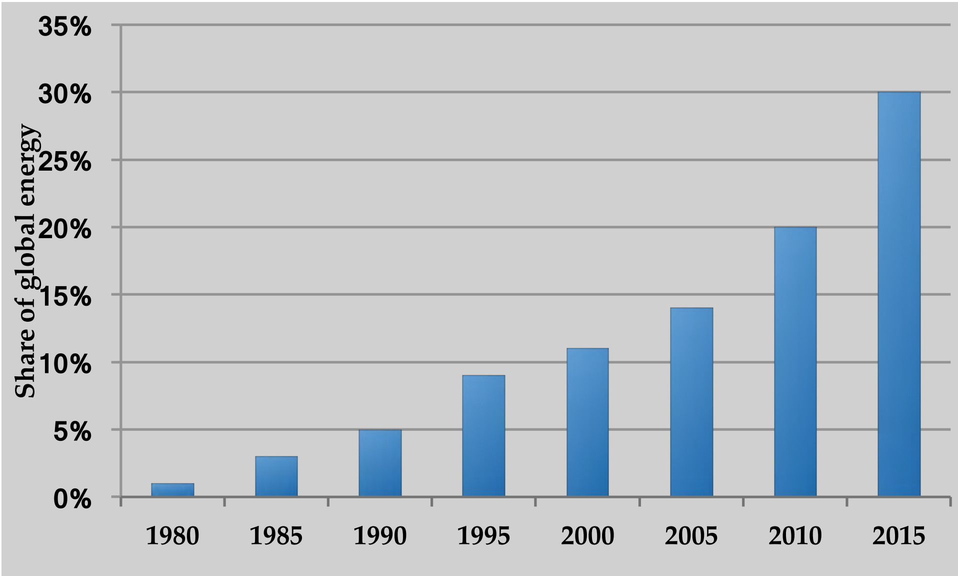
- Climate change. At COP21 in Paris in 2015, the countries of the world agreed to reduce the production of greenhouse gases to net zero in the second half of the century. As many commentators have noted before, this implies that carbon dioxide production will need shortly to fall, and that as a result policymakers will be actively seeking to reduce demand for fossil fuels.

In light of the recent US election result, it is worth noting that each country is of course different. The US is nearly energy self-sufficient, has relatively low population density and a large constituency that is indifferent to climate change. However, the rising powers of China and India have major issues with energy security and local pollution, and Europe is especially concerned about climate change.

As a result, in many locations, policymakers are focused on making renewable technologies work as they seek to mitigate climate change and to limit local pollution, as noted by Kern and Rogge (Kern & Rogge, 2016). This means that renewables can continue to expect favourable treatment at the same time as fossils can expect rising taxation.

We have seen rising regulatory pressure on car efficiency as a result of these factors. The most comprehensive statistic, produced by the IEA, is the amount of energy production that is subject to efficiency regimes.

Figure 10. Share of global energy under mandatory efficiency regimes

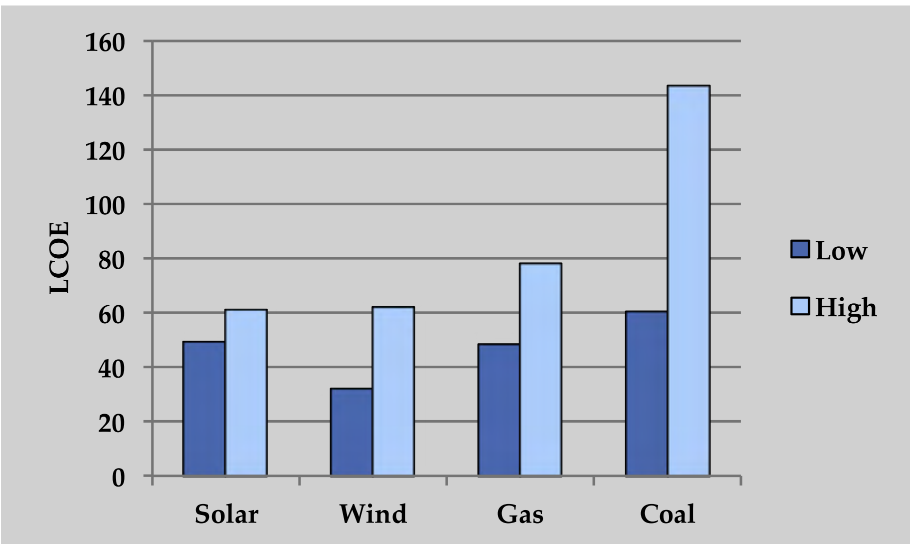


Source: IEA (2016a)

4.3 Costs are comparable

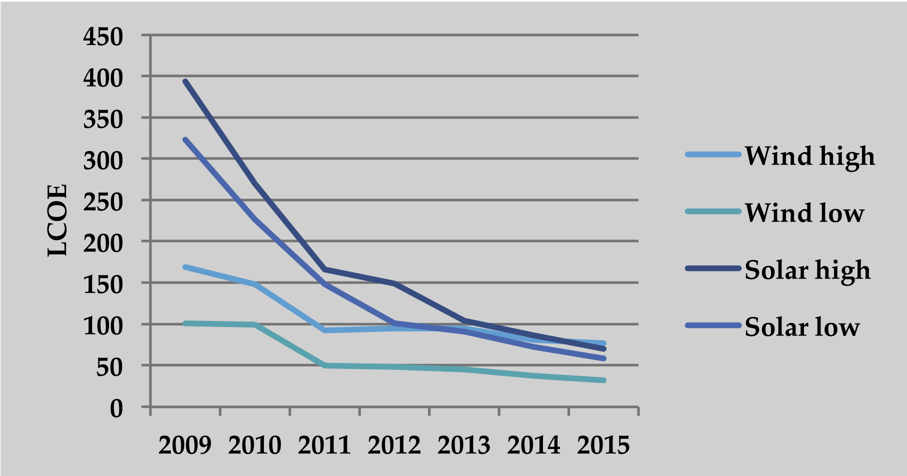
The costs of solar and wind have fallen to levels where, in the right locations, they are comparable to or lower than the costs of fossil fuel based electricity, without subsidies. This observation is much disputed, in part because each country is different. By way of illustration of the point, we therefore show data below from the well-know Lazard LCOE analysis for the US from December 2016 to show the price range of different technologies for the provision of electricity. The cost of solar and wind is now in the range of $30-60 per MWh, whilst gas is $50-80, and coal is $60-140 per MWh.

Figure 11. LCOE of electricity in the US 2016



Source: Lazard (2016)

Figure 12. LCOE of wind and solar over time



Source: Lazard (2016)

The price of wind has been falling at 14% a year, and solar at 24% a year since 2009.

It is of course possible to dispute many aspects of these cost structures. LCOE is not the best available costing tool, Lazard leaves out integration costs, it costs more to replace existing systems than to build new ones, and so on. On the other side of the debate, Lazard uses a relatively high cost of capital (12%) and does not account for the costs of fossil fuel pollution or climate change.

However, many of these concerns about the cost comparability of renewables melt away when faced with technologies where costs continue to fall so relentlessly. The International Renewables Agency, IRENA, has written many excellent reports on solar and wind cost structures. In a recent note, The Power to Change (IRENA, 2016), they argue that solar costs could fall a further 59% by 2025 and wind by 26%. This implies solar costs falling by 9% and wind by 3% a year, far less than in recent years.

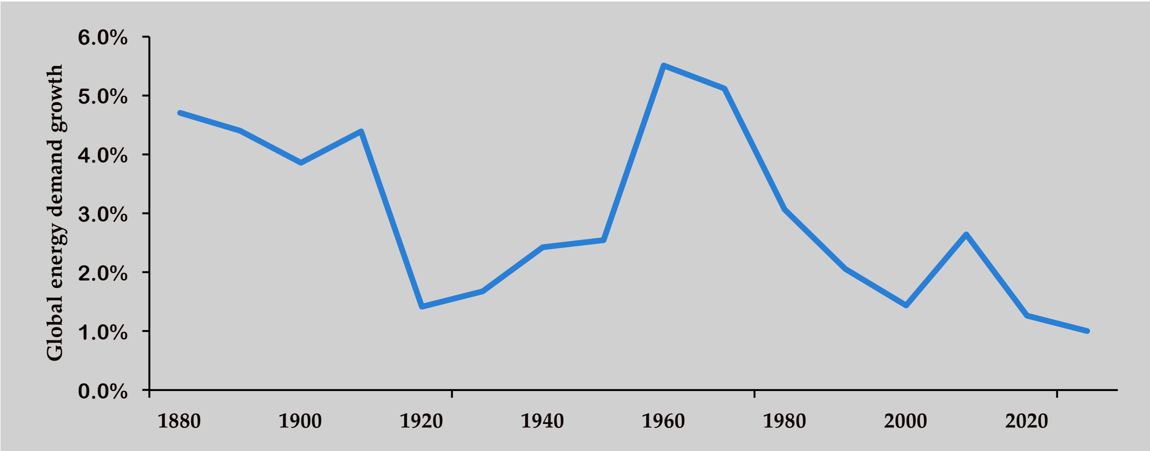
Two further points can be made. First, that there are many specific examples of solar and wind electricity generation at less than $50 per MWh, in countries from Morocco to Chile to the US. Moreover, as we noted in our review of the switch from gas to electricity in the UK lighting sector, demand for the old technology can stop rising long before the average cost of the new technology is cheaper.

4.4 The world has changed

A large part of the argument for slow change makes reference to historical examples of slow systemic change. Change was relatively slow in the past because major countries such as China or India did not adopt new energy technologies at scale until the mid twentieth century and because it took time for technology to move around the world. However, this is an inappropriate framework for the modern world because renewables technology is available to all countries, and most countries are seeking to reduce their fossil fuel footprint.

In addition to this, global energy demand growth is not so high as once it was. In the twentieth century annual global energy demand growth was 3%. The current IEA forecast is for future annual demand growth of just 1%. The hurdle for renewables to have an impact is thus three times lower.

Figure 13. Annualised global energy demand growth



Source: BP (2016), IEA (2016b)

Apart from policy-driven efficiency, mentioned above, drivers of this include:

- Demand saturation in rich countries. Energy demand has been falling across the OECD since the 2008 financial crisis.

- The passing of the inflection point in China. Energy demand tends to rise rapidly from low levels before tailing off. Energy demand per capita in China is now approaching European levels, so growth can be expected to be much lower.

- Lower global population growth. Annual population growth in the last century was 1.3% per annum, and is expected by the UN to fall to around 1% by 2030 and below 0.5% in the second half of the century.

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PROGRAMME

Smith School of Enterprise and the Environment
University of Oxford
South Parks Road
Oxford, OX1 3QY
United Kingdom

E enquiries@smithschool.ox.ac.uk
T +44 (0)1865 614942
F +44 (0)1865 614960
www.smithschool.ox.ac.uk/research/stranded-assets/

SMITH SCHOOL OF ENTERPRISE AND THE ENVIRONMENT

UNIVERSITY OF OXFORD