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New Energy
Energy demand

Analysts

Kingsmill Bond
New Energy Analyst
+44 20 3653 0634
kb@trustedsources.co.uk

For more information please contact Sales:

sales@trustedsources.co.uk
+44 20 7183 5280

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The new energy transition: History is bunk

Why change will be dramatic

The conventional lessons drawn from previous energy transitions are not applicable to the new energy revolution. This revolution will be rapid and its impact dramatic.

Renewables are different. Unlike fossil fuels, renewables are available everywhere, they are being adopted by every country, they have constantly falling costs, and they can piggy-back off existing infrastructure.

Energy demand growth is low. Global energy demand growth is only one third (1 per cent versus 3 per cent) of that in the last century. As a result, renewables find it much easier to push fossil fuels out of the energy mix.

Policy pushes change. Thanks to concerns about carbon and pollution, policymakers increasingly support new energy deployment and tax fossil fuels.

Renewable growth is unprecedented. Renewables are growing around three times faster (20 per cent a year versus 7 per cent for oil and gas) than in previous energy transitions at a comparable stage.

Incremental change is key. The orthodox view considers the wrong variables when it argues that energy change will take years to have a significant impact. Investors will focus not on a complete energy transition but on incremental change, which is much faster. In 2015 renewables made up 51 per cent of net incremental energy supply, and we calculate that by 2020 they will account for 100 per cent.

Why does this matter. Investors need to factor this transformation into their valuations of energy and related stocks – and do so right now. Incumbents will need to transform to survive, and new energy giants will rise to take their place in market indices.

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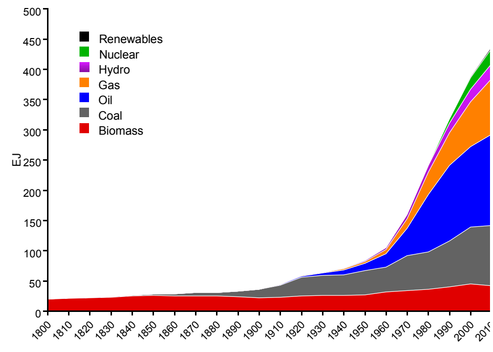
The orthodox interpretation of energy history

What energy history is

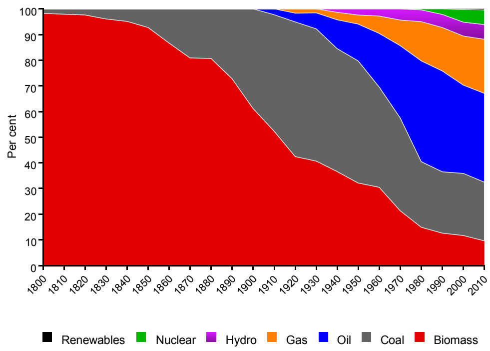
Energy history is a wide topic, so we focus on the most relevant aspects of history for financial markets. These are usually taken to be total usage of energy and the share of different fuels, as shown in Charts 1 and 2 below.

Chart 1: Global energy demand



Sources: BP and Smil.

Chart 2: Split of global energy demand



Sources: BP and Smil.

Some facts stand out from this top-level overview:

- Energy demand increased 27-fold from 1800 to 2015 to more than 400 EJ.
- Population increased sevenfold in this period, so energy demand per capita increased fourfold to 75 GJ per person in 2015.
- Almost the entire increase in supply came from fossil fuels
- There were three waves of fossil fuels (coal followed by oil and then gas) and two waves of other technologies (hydro and then nuclear).

Who interprets energy history

The group of people who interpret energy history is relatively small, given its importance. The most well-known is probably Vaclav Smil, a professor at the University of Manitoba and the author of many books on energy. Other notable writers include Ian Morris (on the wider implications of energy changes), Roger Fouquet (on the UK), Sir Michael Wrigley (on the Industrial Revolution), Paul Warde (on Europe) and Grubler and Wilson (on how to apply energy history to the present day).

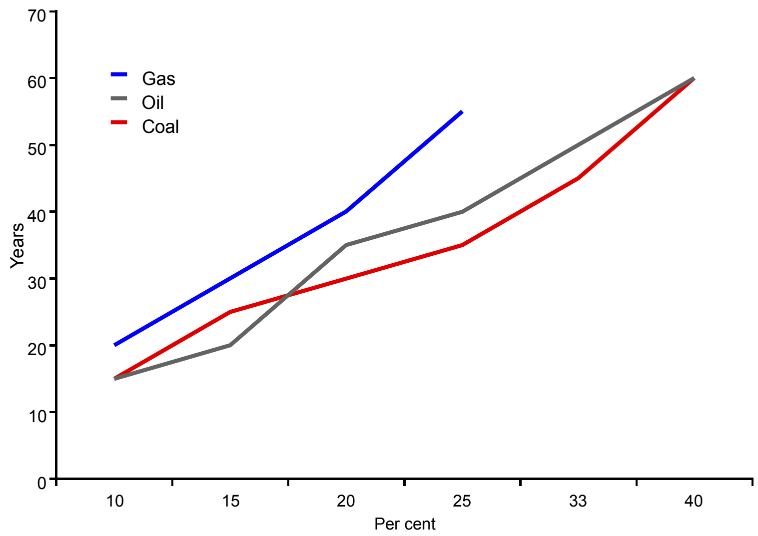
Companies such as BP and Shell tend to make good use of history, and strategists working for these companies have authored papers on the lessons of history for the modern energy sector. Examples include Christoph Ruhl of BP, who in 2012 published a paper titled “Economic development and the demand for energy: a historical perspective on the next 20 years”, and Martin Haigh of Shell, who in 2009 published “No quick switch to renewable energy”. These ideas filter into company presentations on the future of energy, such as the most recent BP review of the global energy complex.

The orthodox historical interpretation

The primary lesson drawn from history by the orthodox view is that energy systems change very slowly. This is used to imply that change will be slow and incremental in the future too.

Vaclav Smil, for example, demonstrates that it takes a long time for each new energy source to reach different shares in the global energy mix. He presents data showing how long it takes for each new fuel to reach certain shares of the global energy mix, starting from a 10 per cent share. Coal and oil both took 60 years for example to get to 40 per cent of the global energy mix.

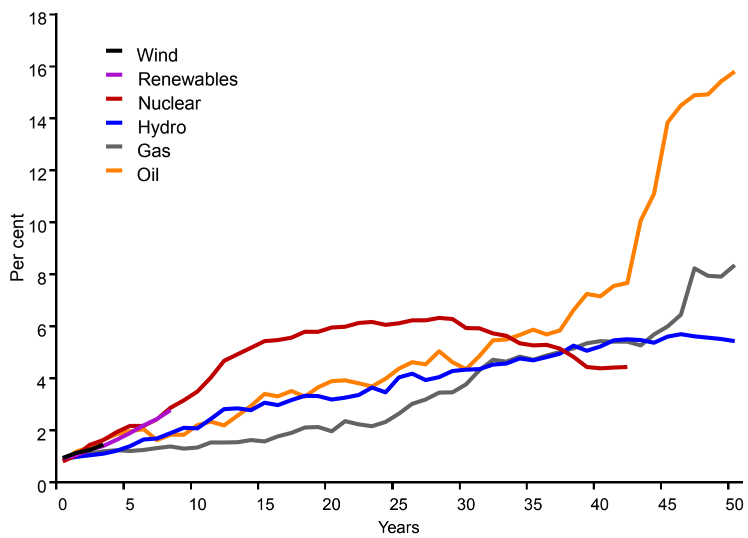
Chart 3: Time taken to reach a given share in the global energy supply mix



Sources: Vaclav Smil, Energy Transitions, 2010.

In their 2015 energy sector review (which came out in June 2016), BP kindly provides a chart showing that it has taken on average 30 years for a new energy technology to increase its market share from 1 per cent to 5 per cent.

Chart 4: Share of global energy mix versus time taken to get there



Source: BP.

Martin Haigh of Shell, in an excellent article in Nature in 2009 called "No quick switch to low carbon energy," argued for the existence of two empirical laws of energy history:

- New energy technologies require a few decades of exponential growth to become material (defined as around 1 per cent of global energy);
- Growth slows down once a new technology secures a 1 per cent share.

The drivers of the laws are identified as the time and money it takes to build out new technologies, along with the existence of long-lived existing energy capital stock and the high costs of new technologies, among other factors.

Why the orthodox view does not apply to the future

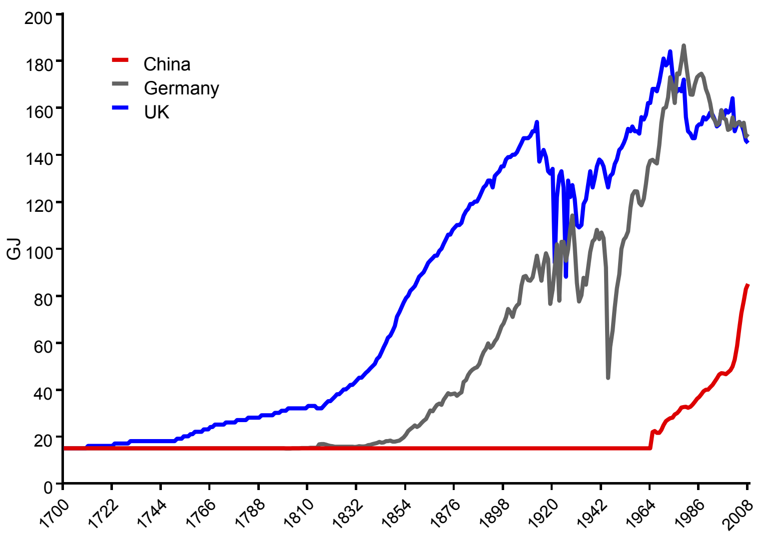
These views are eloquently argued, based on data that come from years of hard work and show a deep understanding of the past. However, we do not believe that they are relevant to the new energy revolution for the reasons we set out below.

Global data from the past are not relevant for the present

One reason why the sources of global energy changed so slowly in the past is that most countries were not changing at all. The country where change took place first (the UK) was relatively small, and giant countries like China and India acted as a brake on global data throughout the 19th century because they were not changing at all.

It is possible to illustrate this by looking at energy use per capita in each country. Energy usage in China and India remained essentially flat until the middle of the 20th century, leaving most of the growth to come from Europe and the US.

Chart 5: Energy use per person per annum



Sources: Fouquet, Warde, BP, TSRP estimates.

The point is that it is inappropriate to take the slowness of past changes as an indication of the pace of growth in the future. At present, all countries – not just a handful of small states – are embracing renewables.

Energy demand growth is much lower

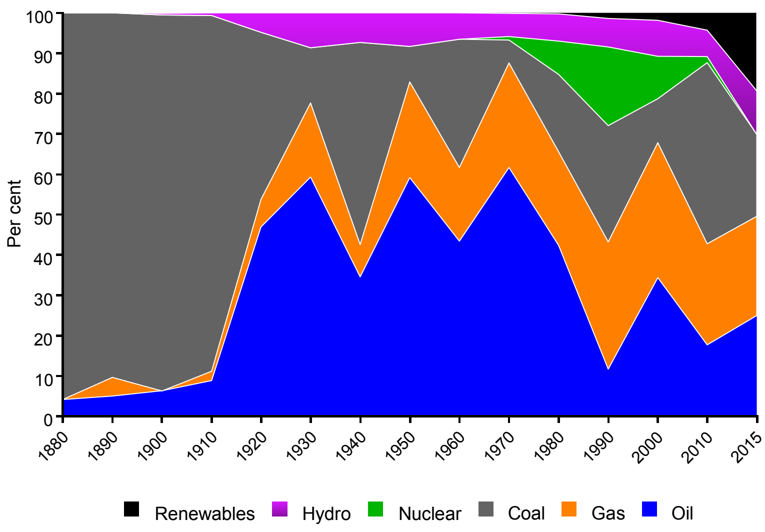
In the 20th century, global energy demand growth averaged 3 per cent a year, and in the mid-century it rose to as high as 5 per cent a year as the larger countries started to increase energy demand. We show below the average annualized energy demand growth in each decade in order to smooth out annual fluctuations.

Chart 6: Global annual energy demand growth

Sources: BP, Smil.

As a result of the very high level of growth in energy demand, new energy sources were supplemental to existing supply. Prior to 1870, coal made up the bulk of incremental supply; but even as oil and then gas entered into the supply mix, coal continued to add to it throughout the 20th century. It is important to note for example that even in the decade of its most significant growth (1980-1990), nuclear energy made up just 19 per cent of incremental energy supply.

Chart 7: Split of incremental energy supply by decade



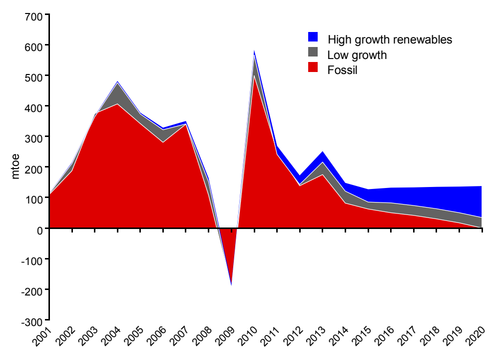
Source: BP.

Present energy demand growth is, however, much lower. In 2015 it was 0.9 per cent, and the IEA estimates a future annual growth rate of just 1 per cent.

This total growth difference is of very great significance because it becomes much easier for renewables to make up all incremental energy supply when demand is growing slowly. For example, global energy demand in 2015 was just over 13 billion tonnes of oil equivalent (toe). Growth of 3 per cent, as we saw in the last century, would imply demand growth of 500 mtoe. Growth of just 1 per cent (or less) that we expect, means incremental demand of just 130 mtoe.

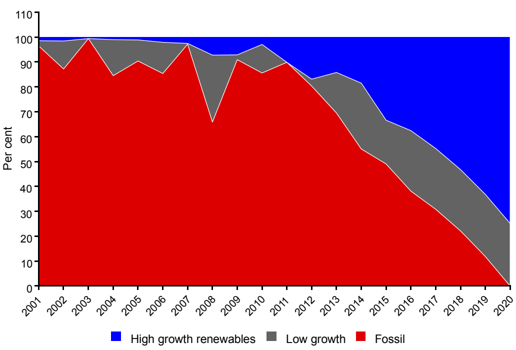
As we noted in our 20 April 2016 paper Fossil fuels – the beginning of the end, renewables and nuclear already made up 51 per cent of the increase in global energy supply in 2015, and we believe that they will make up all incremental energy supply by 2020.

Chart 8: Incremental energy supply



Sources: BP, TSRP estimates.

Chart 9: Split of incremental supply



Sources: BP, TSRP estimates.

Tipping points matter

One of the primary arguments of energy historians is that energy systems change only slowly. Energy requires infrastructure, which, once built, locks in particular types of energy. One example would be coal-fired electricity generating stations; another would be the national grid, which transports that electricity; and a third would be petrol cars, which use oil for transportation. It is impossible to imagine that all this energy infrastructure could be replaced rapidly.

We do not dispute that both legacy infrastructure and legacy energy supply will continue to be used for decades yet to come. However, we believe that investors and financial markets should not – and will not – focus on total demand; rather, they will focus on the change in demand or even the change in the change in demand. In other words, attention will be focused not on the actual but on the first or second derivative. Demand for petrol will be around for decades to come; the real issue is when that demand will peak.

Below we illustrate the importance of the change in demand rather than total demand with regard to electricity and cars. The argument can even be stretched to geopolitics.

The conclusion is that the impact on the corporate world will be felt long before there is a wholesale change to the system. Thus investors should not rely on the phlegmatic approach of historians who tell them not to worry about change.

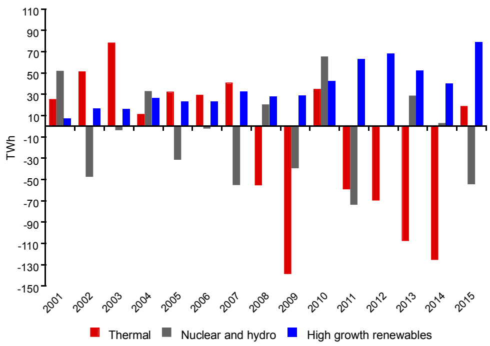
The example of electricity

In 2007 European electricity demand was 3,400 TWh. Average annual growth since 2000 had been 1.6 per cent and renewables ex hydro accounted for just 6 per cent of total supply. The consensus view was that demand would continue to rise and that it was necessary to build new thermal capacity to meet it. Tens of billions of Euros were spent accordingly to build new gas generation stations.

Two developments emerged to shake the industry out of its complacency:

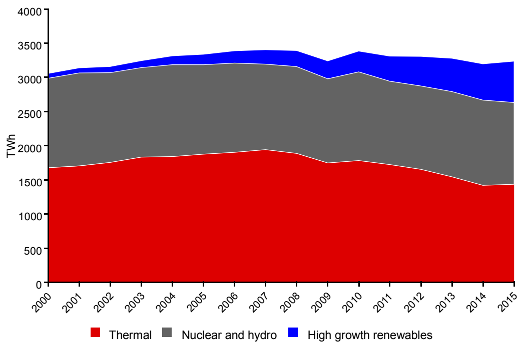
- Demand began to fall after the financial crisis – on average by 0.6 per cent a year;
- Renewables (which had been growing at 18 per cent a year) continued to grow – on average by 14 per cent a year.

Chart 10: Change in EU electricity supply



Source: BP.

Chart 11: EU electricity supply



Sources: BP, TSRP estimates.

The consequences for the industry have been dramatic. Dozens of thermal plants have been closed down, billions of Euros have been written off, and companies across the sector have split into smaller entities.

And yet the orthodox historian reviewing the numbers would say that the share of renewables simply rose from 6 per cent to 19 per cent and the share of thermal fell from 57 per cent to 44 per cent, while remaining the largest energy source.

The point is simply that what seem to be small changes from a distance have, in fact, a huge impact on the ground.

The example of the car

It is also possible to illustrate this distinction nicely with the example of the car. According to the International Organisation of Motor Vehicle Manufacturers (OICA) there were 907 million passenger cars in use at the end of 2014; sales of passenger cars were 66 million units in 2015, and annual car sales growth in the three years to 2015 averaged 3%.

Meanwhile, according to the IEA, there were 1.25 million electric vehicles at the end of 2015, and 2015 sales were 0.5 million electric vehicles. Under the most optimistic scenarios, electric car sales could be 7 million units annually by 2020 and there could be a total of 20 million electric vehicles on the road by then.

The conventional approach is to argue that electric vehicles are only 0.1% of the global car fleet today, and will still be less than 2% of the fleet in 2020. The conclusion drawn is that the electric car will have little impact on the industry for many years to come.

However, this is not how things will look in the car market. If total car demand growth is 3 per cent, annual incremental sales are around 2 million. So even today, electric vehicles account for a quarter of incremental car demand. If new EV sales are indeed 7 million by 2020, then demand for petrol cars will already be falling. Such a development would certainly have a disruptive impact on the industry.

Meanwhile, the issue for the oil industry is not how long it will take to replace the entire fleet but how long it will take for electric vehicles to reduce global oil demand growth to zero. In its New Policies Scenario, the IEA forecasts global oil demand growth out to 2040 at 0.6% a year, an increase of 0.6 mbpd every year. Annual EV sales would need to be around 25 million units in order to replace this level of demand. At 50% annual growth rates, this is possible by 2024; at 30% growth rates, it would take until 2029.

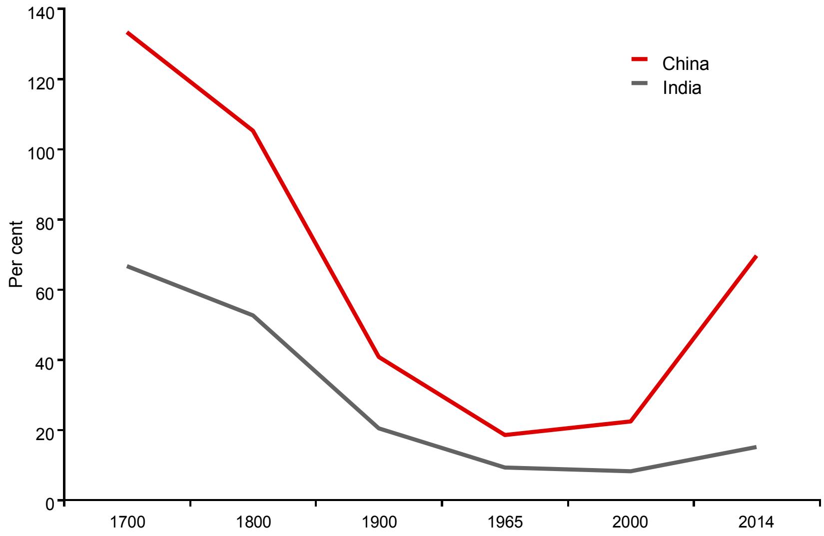
And because financial markets anticipate, investors will be selling shares in the most impacted companies well before the final changes are entered into global databases.

Energy change in history

Another example of the power of incremental change can be seen with reference to geopolitics. Smil notes that it was not until 1920 that coal overtook biomass as the primary source of energy. Again, the implication is that energy changes are slow and steady as well as later than is generally assumed. And the argument is that this will be the case once again.

However, long before 1920, this energy shift had had massive geopolitical consequences. We leave it to historians focused on the 19th century to establish the exact role played by energy in the rise of Europe to global hegemony, but the exploitation of new energy sources certainly played a key role in making possible that change. Below we show the relative energy capture per person in China and India as a percentage of that in Europe. Europe's moment of hegemony was brief and is rapidly being lost.

Chart 12: Energy capture per person in India and China as percentage of that in Europe



Sources: BP, TSRP estimates.

Renewables are not the same as other energy sources

As we have seen, it is often argued that there are empirical laws that govern changes in energy systems. The assumptions are that there are huge similarities between coal, oil, gas, hydro, nuclear and renewables, and that the history of slow change in these sectors is one which will apply to renewables. However, we believe that renewables are sufficiently different from all previous energy sources to render this assumption incorrect. They are available everywhere, they are adopted everywhere, they have falling costs, and they can utilise existing infrastructure.

Universal availability

Wind and solar are, of course, available everywhere. Some places may be sunnier or windier than others, but every country has access to renewable energy resources. As costs keep falling and technology improving, the amount of renewable energy that can be accessed in a commercial manner continues to rise.

By contrast, coal can be found only in a limited number of places and oil and gas in an even smaller number of locations. And once the easy and cheap fossil fuels have been used, they are gone forever. Hydro is available only where there are mountains, while nuclear requires water and a lot of technology expertise. Biomass needs land and, in any event, is an extremely inefficient way to make energy from sunlight.

Universal adoption

The world has moved on since the slow diffusion of technology in the pre-internet era.

For example, it took three centuries for the coal revolution to spread round the world. The use of coal surpassed that of biomass in the UK in 1680, in

Germany in 1862 and the US in 1895. That development occurred at the global level around 1920. It was only around 1970 that coal overtook biomass as a source of energy in China and in the 1990s in India.

However, today the situation is very different. Innovations in one country can be copied almost immediately in every other country. The innovators in rich countries have a special interest in ensuring take-up in poorer countries because the production of carbon in any location is equally conducive to global warming. As a result, many programmes have been launched to implement renewable technology globally – a good example being German support for clean energy in India.

Wind and solar are now being exploited in every major country in the world. Above all, they are being used by the large countries, such as China or India, where energy demand is rising.

Falling costs

Solar and wind generation are technologies and, as such, are subject to constantly falling costs. Many analysts have pointed to the existence of a 20 per cent learning curve in solar panels and an 8 per cent one in wind turbines. The more solar energy produced, the cheaper it becomes.

By contrast, other energy technologies have not been subject to constant falls in costs, notwithstanding recent price moves. The price of nuclear energy is as high today as it was 30 years ago. The price of coal, according to Doyne Farmer, a professor at Oxford University, exhibits the characteristics of a random walk but does not fall over time. The price of oil and gas fluctuates wildly but does not fall on a consistent basis; indeed, oil is the only commodity of note whose real price did not fall in the 20th century. And, of course, the more accessible fossil fuels will be extracted first, so the more extracted, the higher the costs.

Infrastructure is reusable

Previous energy revolutions required the construction of huge amounts of infrastructure – railways, roads, electric grids, power stations, petrochemical plants, pipelines and so on.

Renewables, too, require new infrastructure (solar panels, grid connections for offshore wind, EV charging points) but are able to piggyback to a large extent on existing infrastructure. Home solar panels combined with batteries do not need a grid. Electric cars can use the existing electric grid and existing road infrastructure. Solar panels can use some of the existing grid infrastructure. Artificial liquid fuels or hydrogen can to a degree use the existing hydrocarbon transportation infrastructure.

This seemingly theoretical point has practical implications as it means that renewable technology can be deployed much more rapidly than other energy technologies that require huge infrastructure buildouts. As a result, governments are consistently surprised by the speed of take-up of solar panels as soon as they become cheap enough to deploy. A consumer today can buy an electric car and plug it immediately into his/her home socket and drive it on existing roads. He/she can buy a solar panel and put it on his/her roof and use the electricity immediately without waiting for a grid connection.

Policy is supportive of renewables

Energy transitions in the past had some government involvement, but we believe that this is far less significant than the desire of many governments in the modern world to reduce fossil fuel demand. Every major government in the world signed up in Paris last December to a protocol committing them to take action to reduce the growth of carbon dioxide production and to achieve a carbon-free world by 2100. Europe, for its part, wants to reduce its carbon production by 80 per cent by 2050 and has set targets for every country to reduce the share of fossil fuels in the energy mix to specific levels by 2020. Moreover, as we showed in our 11 July 2016 note China – leader of the new energy future – the link between energy technology and hegemony is likely to mean that the world's leading countries embrace renewables for geopolitical reasons.

At the same time, most major countries are very concerned about outdoor air pollution, and are taking steps to reduce it by restricting energy demand growth and fossil fuel usage.

Renewables are growing faster

The BP and Shell view

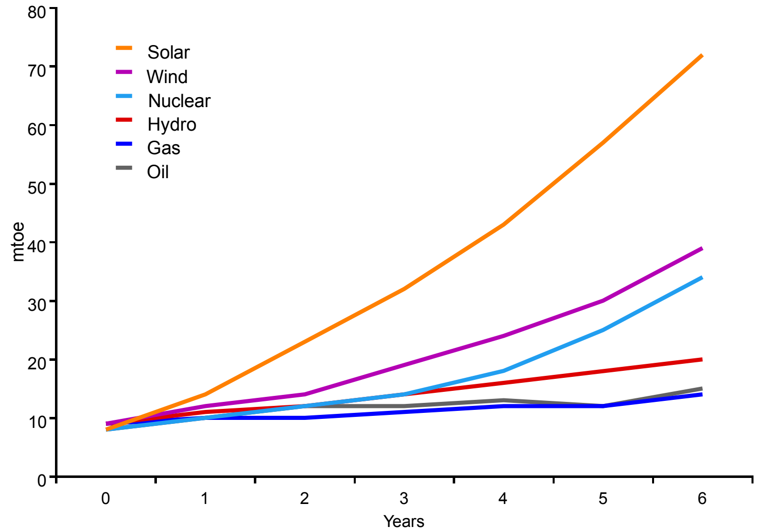
The argument of BP and Shell is that renewables are growing no faster than other new energy technologies at a similar stage of growth. The argument is based on the growth rate after those technologies have reached a significant share of global energy supply, which is defined as 1 per cent. However, we believe that this methodology itself is flawed for the following reasons:

- As noted above, the global growth rate of energy demand is much lower today than in the past and new supplies can therefore have a major impact on incremental supply at a much lower share. Thus it is more appropriate to look at total incremental supply than at the share of supply.
- BP methodology mixes slow-growing geothermal and biomass with fast-growing solar and wind – presumably in part because solar is still below the 1 per cent threshold and wind reached it only recently.

What is happening

While there is no perfect way to analyse this issue, we offer an alternative approach to looking at the data in order to determine how rapidly energy production grew after a threshold level was reached. We take 10 mtoe as a threshold because this is a number large enough to be meaningful (total Irish demand for energy, for example, is 15 mtoe) and data over a sufficient number of years are available.

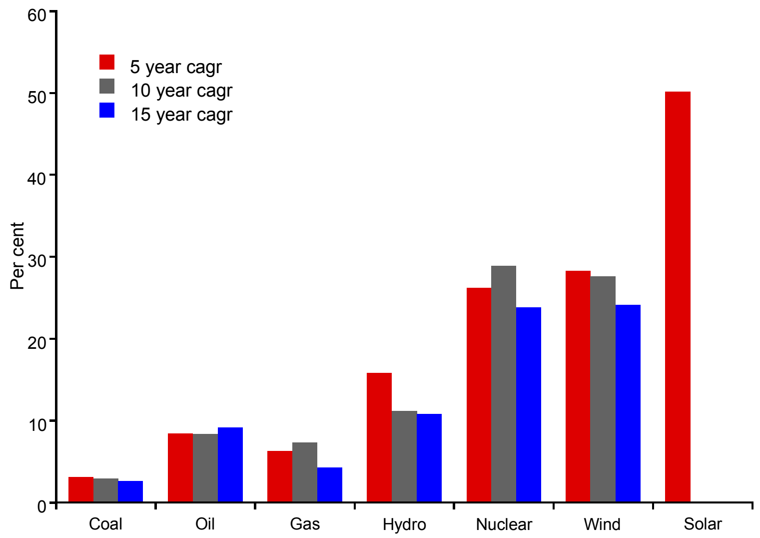
Chart 13: Energy production after reaching the 10 mtoe threshold



Sources: BP, Smil, TSRP estimates.

The conclusion is that the growth rates of renewables today are much higher than those of fossil fuels after they reached the threshold of 10 mtoe. Coal supply, which after 1800 grew at just 2-3 per cent a year, changed the world and ushered in the modern era. Oil and gas supply grew at rates of 7% in the decades after they reached 10 mtoe of production. Wind has been growing at more than 20 per cent a year and solar has been doubling every two years since reaching production levels of 10 mtoe.

Chart 14: CAGR after reaching the 10 mtoe threshold



Sources: BP, Smil, TSRP estimates.

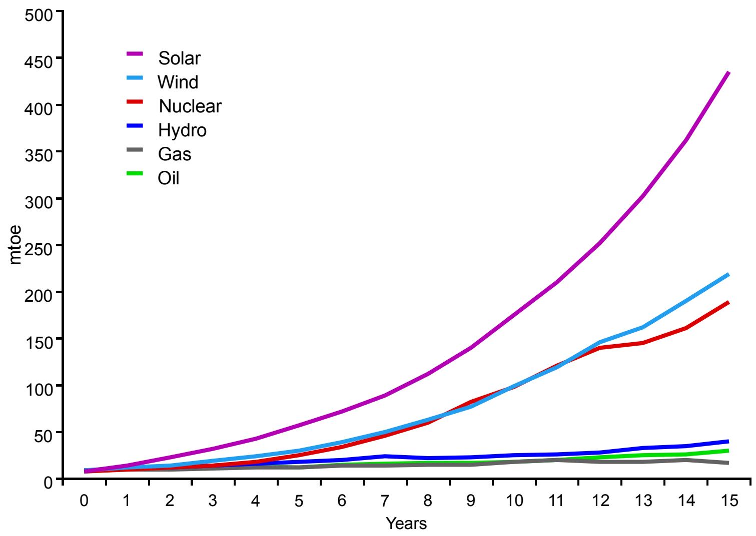
One obvious objection to this way of looking at the data is that a larger number should be taken to indicate maturity – say, 100 mtoe or a 1 per cent global market share. However, solar has not yet reached this level.

These different approaches could be reconciled by looking at the share of incremental energy that comes from new technologies. As we noted above, the peak of incremental energy supply from nuclear (in the 1980s) was just 19 per cent, while solar and wind already accounted for 33 per cent of incremental energy supply in 2015.

In any event, playing around with numbers is unlikely to help the debate much; the key point is that solar and wind will continue to witness falling costs and rising take-up and are likely to continue to grow rapidly.

We show below how solar would look if it maintained growth rates of 25 per cent a year to 2020 and 20 per cent a year to 2025. The point here is not so much to make concrete forecasts as to show that the kind of growth we are seeing in solar is far beyond anything that the fossil fuel industry has seen.

Chart 15: Energy production after reaching the 10 mtoe threshold (with solar extrapolated)



Sources: BP, Smil, TSRP estimates.

Why would growth slow

The other point often made by the oil sector is that solar and wind supply must inevitably slow. In part this is because of the law of large numbers and the fact that renewables are intermittent; but, above all, the argument seems to be that the costs are too high.

The law of large numbers is a valid point, and percentage growth rates will certainly slow over time. However, there is a difference between a slowdown in growth and a collapse in growth. And we can see no reason why growth would collapse.

To reiterate the reasons why we expect renewables growth to remain high:

- Costs keep falling
- The resource is available everywhere
- Governments want to use renewables
- Renewables are or soon will be cheaper than new fossil fuels in most locations
- Growth can easily continue until fossil fuels are pushed out of incremental supply; only then would it need (in theory) to slow down.

- Provided the economics are favourable, there is no shortage of finance available to pay for the new infrastructure in a world of very low yields
- The world is still a long way from saturation point

Renewables are nimble

It is also argued that energy changes are slow because they require so much money and expertise. But there is a difference between a nuclear power station, which takes years to build and costs billions, and a solar panel on a householder's roof, which costs a few thousand dollars and can be put up over a weekend.

The nimbleness of renewables means that innovation can be faster and implies once again that costs can continue to fall.

Other ways of looking at energy history

Individual countries change fast

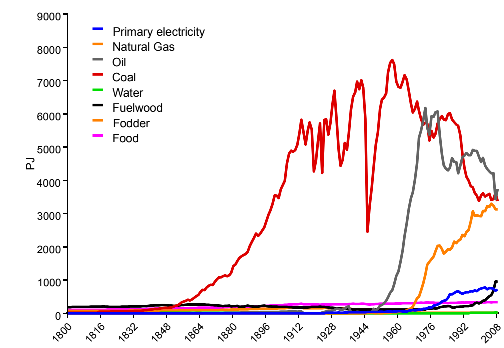
We have seen that global change has been slow; however, change in individual countries can be quite rapid. Below we demonstrate this for Germany, the US and China. In a world of universal renewables availability, we believe that global demand in the future will look a lot more like country demand in the past than like global demand in the past.

Germany

Germany was able to change its energy mix with remarkable speed:

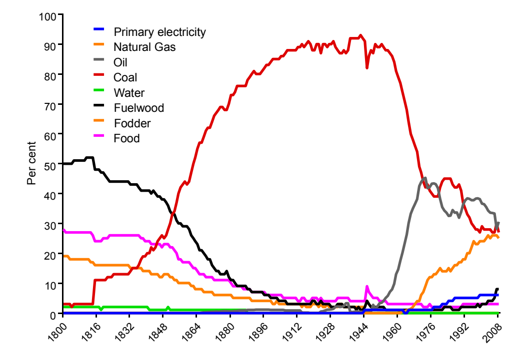
- Coal went from 3 per cent of the mix in 1814 to half the total energy mix in 1862
- Oil went from 1 per cent of the size of coal in 1947 to larger than coal by 1972 (that is, just 25 years later)
- Coal demand halved in the decades after 1950

Chart 16: German energy demand



Source: Energyhistory.org.

Chart 17: German energy share

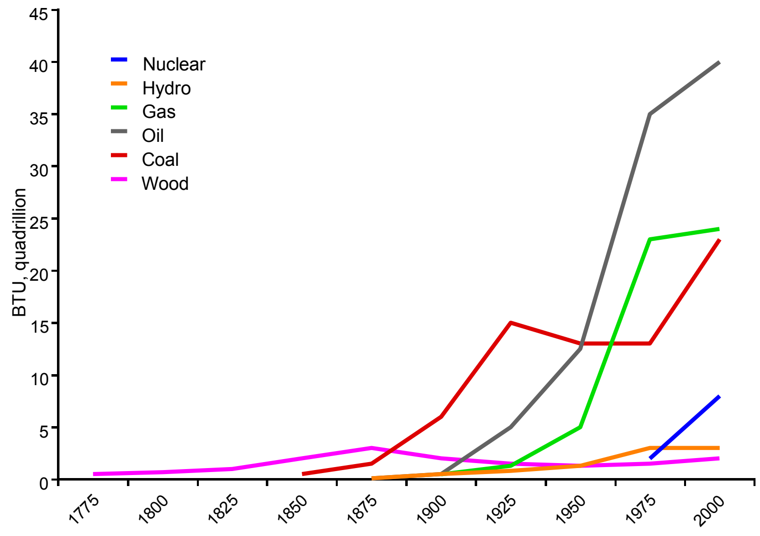


Source: Energyhistory.org.

US

The US adopted coal and then oil and then gas with speed, and we reproduce the EIA data on this below.

Chart 18: History of energy consumption in the US

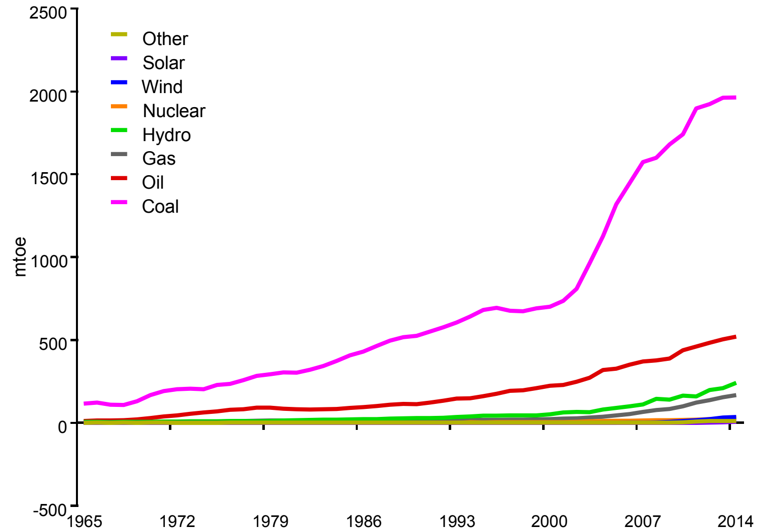


Source: EIA.

China

China adopted coal quickly: in 1965 total coal usage was under 200 million tonnes; by 1990 it exceeded 500 million tonnes; and by 2014 it had reached 2 billion tonnes.

Chart 19: Chinese energy demand



Source: BP.

In the case of individual countries around the world, factors that encourage more rapid change include:

- Large domestic resources: all countries have their own massive domestic renewable resources.
- Energy import dependency: most countries have a high energy import dependency that they would like to escape.
- Small size: smaller countries find it quicker to enact rapid change. Here again, renewables are interesting as they are available in every region of a country; and across the world, some regions within countries are changing much faster than others.

Countries learn from the past

To state the obvious, people tend to learn from the leaders. It took the UK 200 years (1500-1700) to move from low levels of coal usage to coal supplying half the total, while it took Germany 50 years (1812-1862), the US 30 years (1855-1885) and China around 25 years (1960-1985).

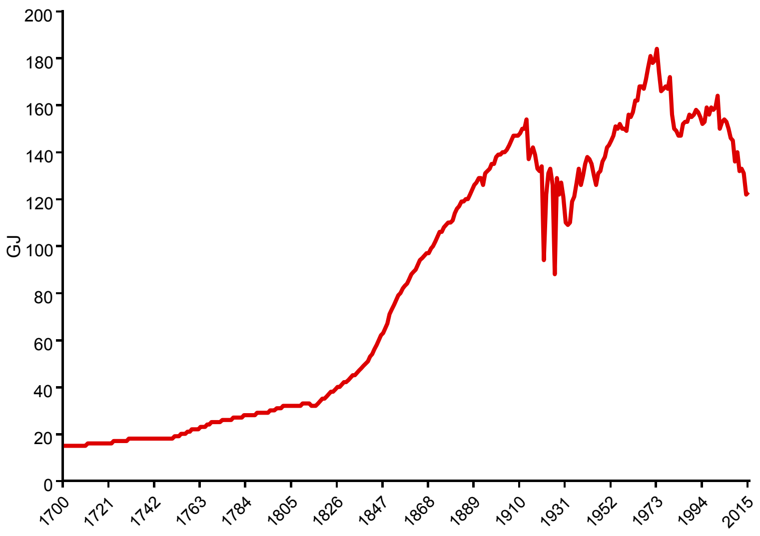
The implication is that the slow and costly learning curve for renewables pioneered by Denmark and Germany, simply does not have to be repeated elsewhere.

Demand peaks and then declines

There appears to be a fairly consistent pattern of energy demand associated with the transition from organic to fossil fuels. Energy demand rose rapidly from low (subsistence) levels before peaking and then declining. Decline kicks in as soon as efficiency gains overtake GDP growth.

According to data from Fouquet, UK energy demand per capita today is lower than in was in the 1880s.

Chart 20: UK energy use per person per annum



Sources: Fouquet, BP.

Thus, it is incorrect to believe that (at current pricing levels) energy demand will rise over time. There are perhaps some limits to the amount of energy we can or will consume.

The global energy demand picture therefore becomes much more nuanced. Rather than a uniform picture of constantly rising demand, there is a series of rising and falling demand charts dependent on country.

Cost is key

To state the obvious, lower costs will always win out in the end. We make this point simply to counter the scepticism of those who argue that new energy technologies will not succeed because of the cost of the infrastructure.

Lower costs have tended to allow new technologies to succeed, even if there is infrastructure to be built. Examples include gas lighting, electricity, railways and cars.

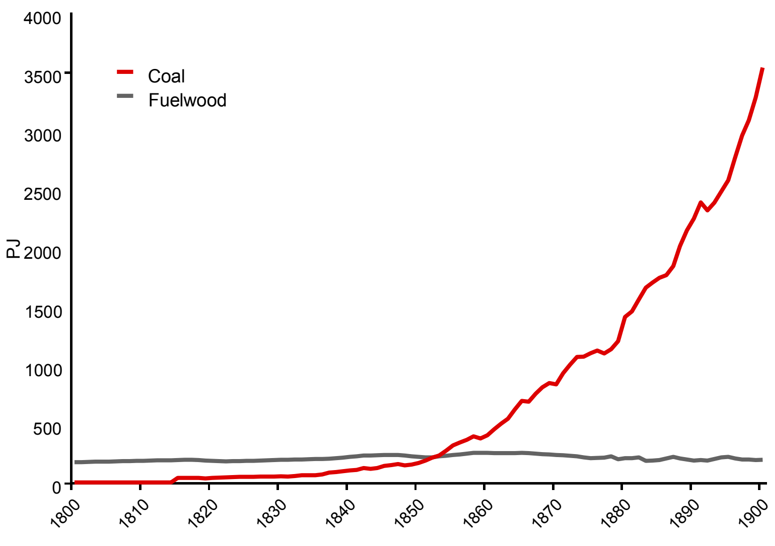
Old energy sources soon stop growing

An often overlooked aspect of the data – but one central to our argument – is that new energy sources rapidly destroy demand growth in old energy sources. It is true that it takes a long time for the old energy sources to be phased out completely, but it is also true that new energy has tended to have a massive impact on marginal change. We include a number of examples of this phenomenon below. This is not a particularly scientific selection, and there is another debate about what is the most comparable transition to the renewables revolution. However, we cite the following simply to show that there are many examples of new energy sources rapidly rendering old resources either stagnant or redundant.

Coal replacing wood

When coal was introduced in Germany, demand for wood stagnated and then fell.

Chart 21: German demand for coal and wood



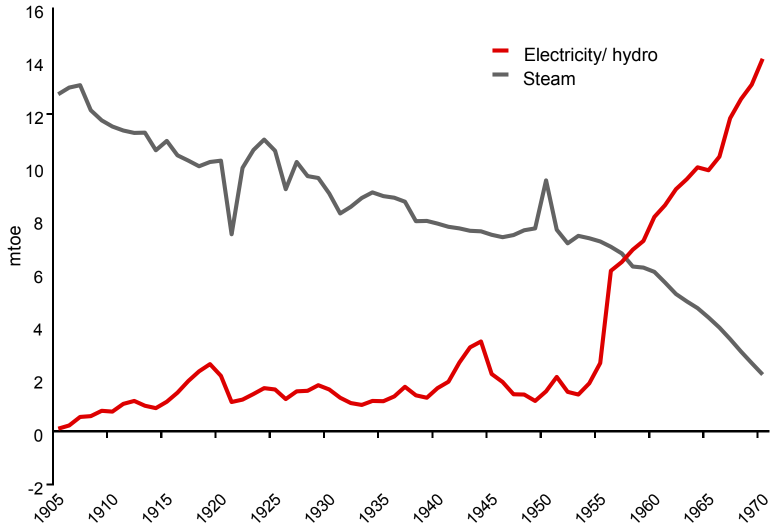
Source: Energyhistory.org.

In the US, demand for wood initially continued to rise as coal demand rose, but by 1875, when wood was still much larger as a fuel source than coal, demand had already peaked and started to fall.

Electricity replacing steam

Electricity entered the UK supply mix for power at the end of the 19th century and was still tiny compared with energy derived from steam. However, as soon as 1907, when electricity accounted for just 3 per cent of the total supply of power, steam power demand peaked at 13 mtoe. It was not until the end of the 1950s that electricity finally overtook steam as the primary source of power in the UK; but by that stage, steam demand had been declining for 50 years.

Chart 22: Energy demand for power in the UK

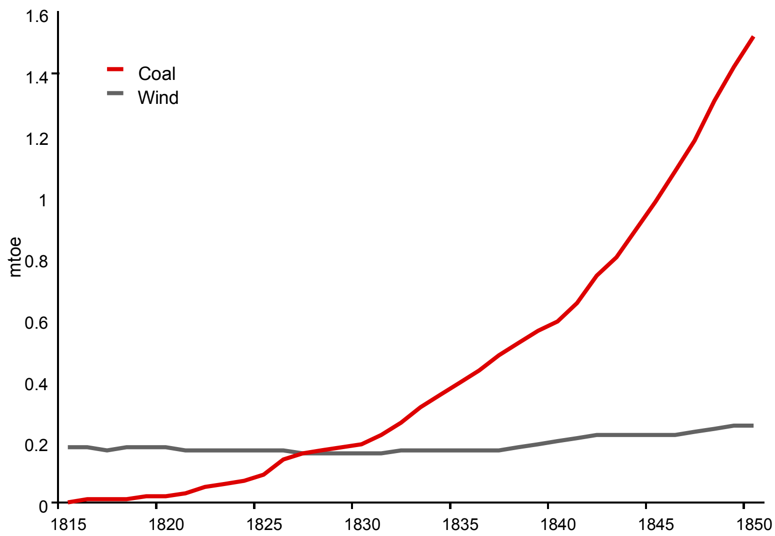


Source: Fouquet.

Steam ships replacing sailing ships

Data from Fouquet for the UK also indicate that the demand for wind energy for land and sea freight stagnated as that for coal grew very rapidly.

Chart 23: Energy demand for land and sea freight in the UK



Source: Fouquet.

The counterargument

The traditional counterargument to the above is that coal demand continued to rise even during the 20th century. However, we believe that this argument is not relevant as it reflects the staged nature of the energy transition. The main driver of incremental demand in recent decades was China, and demand there is now falling.

Incumbents get it wrong

It is axiomatic in financial markets that incumbents fail to see change coming. Most incumbent telecom suppliers did not forecast the mobile phone revolution, IBM saw no future for computers, Microsoft did not initially anticipate the rise of the internet, and Goskomstat failed to predict the demise of the Soviet Union.

Of course, they tend to be in good company in this respect. The three greatest economists of the late 18th century – Adam Smith, David Ricardo and Thomas Malthus – failed to realize that fossil fuels were about to change everything.

The application of this observation is that investors should be wary of the giant energy models that are currently used to forecast future energy supply and demand. Such models are excellent in the short term and as a tool to answer 'what if' type questions, but lack the flexibility to handle systemic change.

Why we could be wrong

There are a number of standard objections to the picture of rapid change that are raised time and again by those taking a look at the historical record. They are each valid on their own terms, but we do not see them as being particularly relevant to the debate about whether renewables can rapidly capture incremental demand.

Intermittency

The argument is often made that the sun does not shine at night, wind is intermittent and so on.

According to IRENA, this is a problem that can be solved up to levels of 30-40 per cent of the electricity supply through better grids and storage and demand management and better system design. In this context, Germany and Denmark are pioneers: 15 per cent and 43 per cent of their electricity, respectively, came from intermittent renewable sources (solar and wind) in 2014.

Meanwhile, the global supply of intermittent renewables is less than 5 per cent of electricity demand.

The conclusion is that there is a lot of growth yet to come globally before limiting factors kick in.

Irreplaceable areas

There are some areas where it is expensive for renewables to replace fossil fuels with current technology. Heavy trucks, aeroplanes, petrochemicals and winter heating in cold countries are all areas in relation to which this has been raised as an issue.

However, once again, this is not a relevant argument for investors today. Just because we cannot figure out how to replace all energy supply today does not mean that we will be unable to replace a large share of supply in the near future. And by the time we get to, say, 20-30 per cent, costs will be lower, and entrepreneurs will likely have figured out how to replace a greater share of energy supply.

Interseasonal demand

Heating demand is up to six times higher in the winter than in summer. The concern is that this would necessitate huge amounts of storage or very large grids. Again, we think this argument looks too far into the future. The world already has a functioning heating storage system and delivery system (called gas) and it can continue to use this while renewables eat into the share of fossil fuels.

US policy

The US is one of the world's biggest users of fossil fuels, and presidential candidate Donald Trump has often expressed a sceptical view on renewables as well as a favourable one on fossil fuels. The fear is that the world would fail to go down the renewables path without US leadership. Without making at attempt at calling the result of the election, we believe that this potential development is more of a concern for the US than for the rest of the world. If the US elects to follow the path of a dying technology it will simply be leapfrogged by China until such time as it has a Sputnik moment and decides that it is necessary to embrace renewables.

Energy density

It is often argued that the low energy density of solar and wind is an insuperable burden compared with the high energy density of fossil fuels. The argument is that cities need concentrated power and that means the need for an energy dense energy supply.

We tend to regard this as a variant on the problems above and therefore not a cause for concern. In the first instance, there is already a solution to the energy density of cities, which is called electricity; most electricity is generated outside cities and brought in on a grid. In addition, there are some solutions that work today for cities, such as rooftop solar, on-street EV charging and offshore wind turbines; and there will, no doubt, be others.

The UK

David McKay, in his famous book titled *Sustainable Energy – Without the Hot Air* used the UK as the paradigm for his analysis and the foundation of much of his scepticism about the impact of the renewables revolution. However, the UK is a global outlier. Few countries are small, rich, densely populated, cold and lacking in sunlight and, to boot, have a powerful domestic lobby to stop the use of land for solar and wind energy.

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TRUSTED SOURCES

Trusted Sources UK Limited

London +44 20 7183 5280
Hong Kong +852 2534 7426 (IND-X Advisors)
info@trustedsources.co.uk **www.trustedsources.co.uk**