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# Historical Energy Transitions: Speed, Prices and System Transformation[1]

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**Abstract**

*The relatively rare and protracted nature of energy transitions implies that it is vital to look at historical experiences for lessons about how they might unfold in the future. The fastest historical sector-specific energy transitions observed here was thirty years. However, full energy transitions, involving all sectors and services, have taken much longer. Ultimately, the price of energy services played a crucial role in creating the incentives to stimulate energy transitions, but energy price shocks may have acted as a catalyst for stimulating processes that led to certain energy transitions. An additional key factor is whether the new technology offers new characteristics of value to the consumer, which can help create a market even when the initial price is higher. A crucial factor that can delay a transition is the reaction of the incumbent and declining industries. Nevertheless, governments have, in a few instances, created the institutional setting to stimulate energy transitions to low-polluting energy sources, and this could be done again, if the political will and alternative energy sources were available. Finally, past energy transitions have had major impacts on the incumbent industries which have declined, on economic transformations and on inequality.*

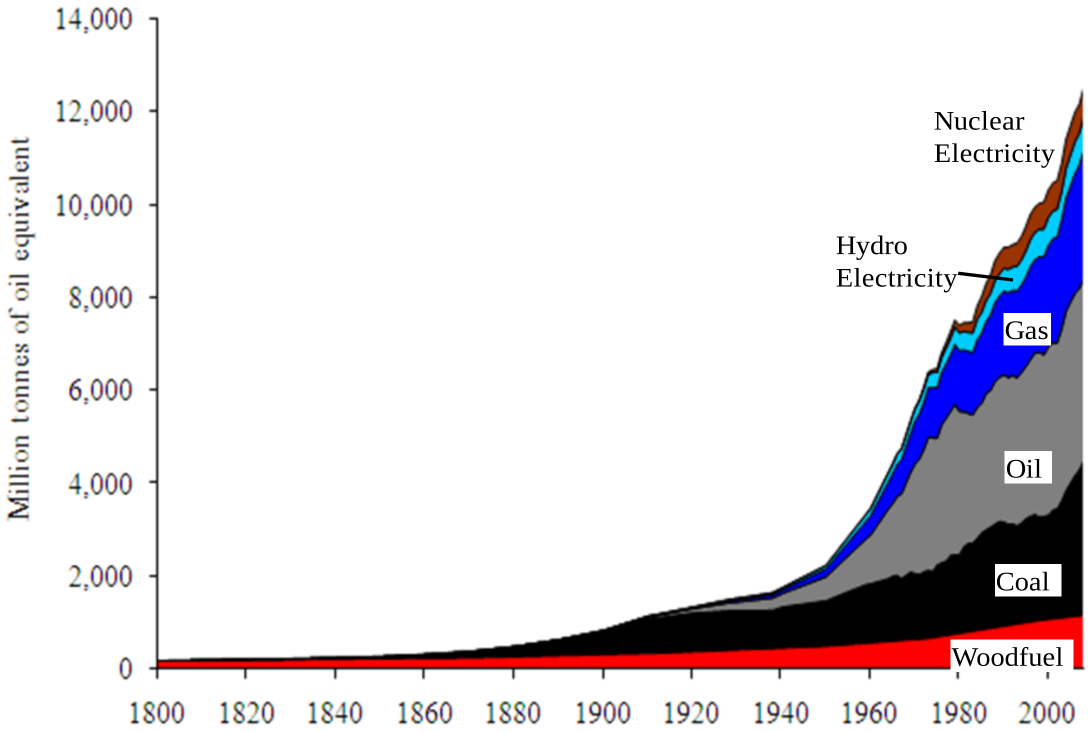
## 1. Introduction

Since the beginning of the Industrial Revolution, the global economy has extracted and used 0.5 trillion tonnes of oil equivalent of fossil fuels (see Figure 1) and has led to 1.2 trillion tonnes of carbon dioxide emissions. The rising global emissions, along with other greenhouse gas emissions, are threatening to intensify climate change. This threat means that fossil fuels, without worldwide carbon capture and sequestration mechanism or successful geo-engineering projects, will impose a rising burden on the atmosphere. This burden highlights the potential benefits from a transition out of fossil fuels to low carbon energy sources.

Because energy transitions are seen by many scholars and analysts to be relatively rare and protracted processes, it is important to look at historical experiences for lessons about how they might unfold in the future. The literature on historical energy transitions has blossomed in the last ten years (Gales et al 2007, Geels and Schot 2007, Bartoletto and Rubio 2008, Madureira 2008, Kunnas and Myllyntaus 2009, Allen 2009, Ayres and Warr 2009, Wrigley 2010, Smil 2010, Mitchell 2011, Kander et al. 2013, Grübler and Wilson 2014, and Jones 2014). Perhaps triggered by unfolding events, and partly stimulated by the special issue in this journal, research output on using experiences from past energy transitions to inform the present and future policies has accelerated (Sarrica et al. 2016, Sovacool 2016, Chabrol 2016, Andrews-Speed 2016, Pearson 2016).

[1]. I would like to thank Benjamin Sovacool for comments related to this paper. Support for this research from the ESRC is gratefully acknowledged.

With this in mind, the purpose of this piece is to draw particularly on my own historical and long run research to offer some lessons about energy transitions. To contribute to a more refined or at least reflexive take on energy transitions, this short communication starts by reviewing the speed of past energy transitions. Afterwards, the role of prices in driving transitions is discussed. This is followed by a comment on incumbent industries that declined, with a focus on the experience of the coal industry. Then, the paper examines the impact of energy transitions on consumption patterns, economic development and inequality. Then, it explores past experiences in which environmental policy may have influenced energy transitions.




Source: Fouquet (2009)

**Figure 1. Global Primary Energy Consumption, 1800-2010**

## 2. The Speed of Historical Energy Transitions

Since the Industrial Revolution, it has taken, on average, nearly fifty years for sector-specific energy transitions (i.e. the diffusion of energy sources and technologies) to unfold in the United Kingdom (Fouquet 2010). Here, the definition used for a transition was from 5% to 80% (or the peak, if it did not reach 80%) of the energy consumption for a particular service (e.g., heating, power, transportation or lighting) in a specific sector – as Sovacool (2016) points-out in his conclusion, the definition is critical for determining the duration of transitions . As shown in Table 1, the average duration of the innovation chain (i.e., from the invention of the key technology to 80% share of energy consumption, or to the peak) was 95 years.

To put this in context, the wind turbine (which converted wind power into electricity) was introduced in the 1880s. More recently, the invention of solar photovoltaics (SPV) was in 1954. In other words, it is unlikely that either technology will meet the average duration of the innovation chain for successful energy transitions (although, SPVs may still do so, if they reach a share of 80% by 2050). However, it could be argued that because of the large number of inventions in energy technologies in the last 150 years, the strong path dependence in modern energy systems has delayed the uptake of certain technologies (Fouquet 2016a).

The shortest period between invention and uptake was ten years. This occurred in the cases of gas and kerosene lighting. The lack of technological lock-ins (as they were competing with the primitive tallow candles), the dramatically superior qualities of the energy source and the technology compared with the incumbent and the great demand for lighting in the nineteenth century implied that the innovation chain was exceptionally rapid (Fouquet and Pearson 2006). The fastest diffusion was from horse to railways in the mid-nineteenth century and steam engines to electricity in the first-half of the twentieth century. These new technologies and energy sources provided cheaper and better quality services. As a result, despite the need for an infrastructure to use the new energy source or technology, both made the transition very quickly - in 30 years.

**Table 1. The Average Duration of Energy Transitions in the United Kingdom**

| | Period | Driver | Duration of Innovation Chain | Duration of Diffusion |
|---|---|---|---|---|
| Shortest | 700-2000 | - | 50 years | 30 years |
| Average | 700-2000 | - | 245 years | 125 years |
| Average | 1700-2000 | - | 95 years | 49 years |
| Average | 1700-2000 | Cheaper Service | 65 years | 40 years |
| Average | 1700-2000 | Better Service | 155 years | 51 years |

Source: Fouquet 2010.

In other words, the speed of uptake of new technologies and energy transitions is influenced by the rise in demand for energy services. Faster growth (due to high income elasticities and rising incomes, which will be discussed below) is likely to imply a faster potential energy transitions. This also suggests that energy transitions may be more demand-led. Alternatively, when income elasticities are low, demand may be less of a driver of energy transitions. When income elasticities are low, such as at high levels of economic development, energy transitions may have to be led by supply-side transformations. Thus, the policy drivers for stimulating energy transitions in developing economies and post-industrialised economies may be very different.

Rubio and Folchio (2012) present evidence on the energy transitions from coal to oil for 20 Latin American countries over the first half of the 20th century. They argue that these small energy consumers had earlier and faster transitions than leading nations. By outlining a whole series of energy transitions, they identify a number of different energy transition processes. Factors such as domestic energy resources, the size of the internal market for energy services, trade relations and policy decisions have been important in determining the nature and speed of the transitions experienced. They suggest that the lessons will be particularly relevant for understanding the way in which non-pioneering countries might adopt low carbon energy sources and technologies.

Underlying every full energy transition - from biomass to coal, coal to oil or oil to natural gas - is a disaggregation of a number of sectors and services. For every sector (including the residential, industrial and transport sectors) and for every services (e.g., heating and lighting), technological and institutional solutions needed to be developed to achieve a specific transition. The technology and institutions needed for each individual transition often differed for each sector and service. As a result, there has been a tendency towards very slow full or aggregated energy transitions (for a more detailed discussion of the complexities of transforming energy systems, see Grübler et al 2016, Smil 2016). Whether a full transition can be accelerated, as Sovacool (2016), Kern and Rogge (2016) and Bromley (2016) argue, depends on creating all the correct conditions for this to occur.

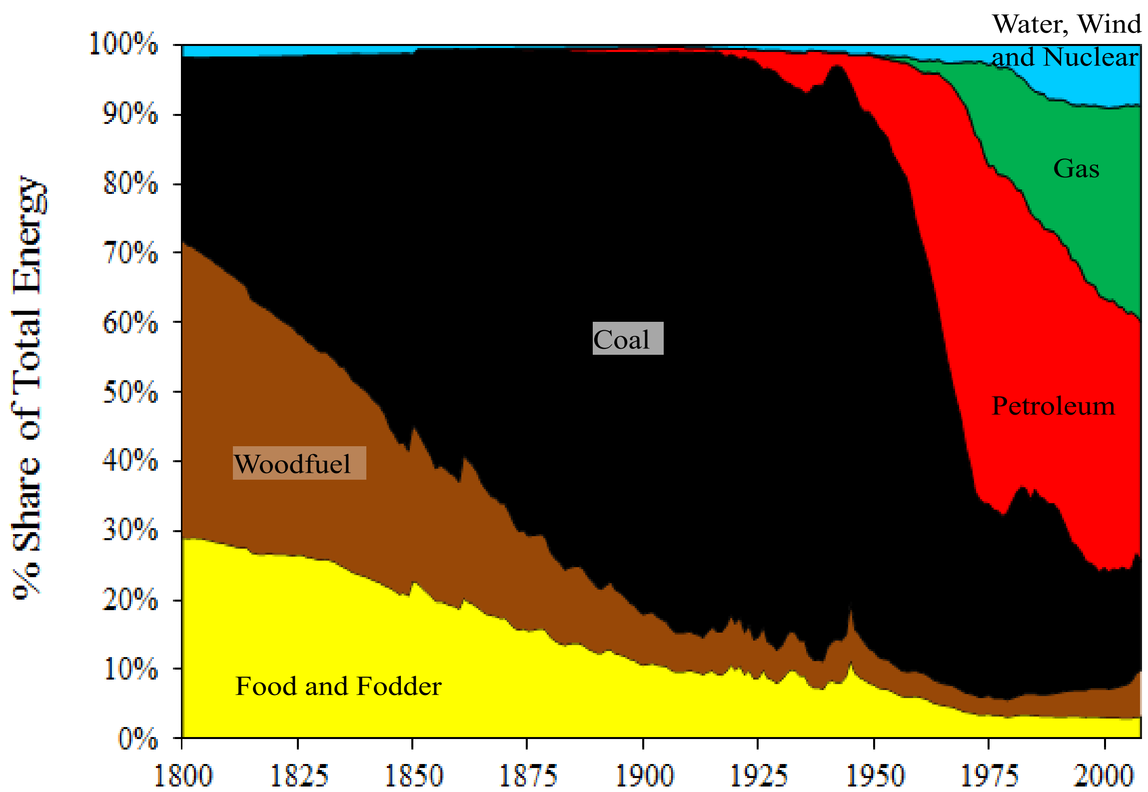
## 3. The Role of Prices in Energy Transitions

For each individual energy transition, the technology or new energy source that emerged and would eventually become dominant started as a niche product. A small group of consumers were willing to pay a premium for the energy services attached to the new technology. A successful new energy source or technology provided the same service (i.e. heating, power, transport or light) with superior or additional characteristics (e.g. easier, cleaner or more flexible to use). For instance, electric lighting in the late nineteenth century, which was more costly than gas lighting, offered a novelty factor that expensive restaurants and theatres were willing to pay for. Over time, economies of scale subsequently improved the technology and the price of the energy source, driving down the cost of generating energy services, making it competitive with the incumbent energy technology and source.

However, the price of the energy service is crucial for achieving a full energy transition. If the price of the service fell sufficiently (either because the energy efficiency improved or the price of energy declined), full transitions could occur. For instance, kerosene was used for lighting in the late 1800s largely by the poor and rural population that could not afford the investment in the infrastructure to supply gas to their homes. However, in urban areas, the price of kerosene lighting never dropped cheap enough to compete with gas lighting (once piping was installed) and, therefore, gas lighting remained the dominant source of lighting until the price of electric lighting dropped sufficiently.

The price of the energy service matters in the long run, but the fluctuations in the price of energy can create tipping-points and lock-ins. Energy price shocks, as occurred in 1915-1917, 1921 and 1926 for British coal or in 1973, 1979 and 2008 for international oil, were critical junctures in the history of energy transitions and of energy technological developments (van de Ven and Fouquet 2014, Hamilton 2013). They pushed consumers to become more efficient and away from the expensive energy source. Then, in the next period of economic growth, some producers and consumers were willing to make investments in new energy technologies and networks.

For instance, during the First World War, the price of coal imported from Britain soared and a number of economies, such as France, Germany, Italy Austria and Sweden, invested in hydropower to limit their dependence on coal-generated electricity (Kander et al 2013). It also triggered the transition to oil, which lasted for more than fifty years (see Figure 2). However, the oil shocks in the 1970s led most economies to reduce their dependence on oil – in Europe, falling from 52% in 1973 to 34% in 2008 (see Figure 2). Given the long lifespan of energy-using equipment, this process of adoption of new technologies often took ten to twenty to fifty years. Thus, in terms of efficiency improvements and energy transitions, the global economy has only seen the beginning of the full impacts of the oil price shock in 2008. They are likely to push global markets further away from oil and are likely to take several decades to unfold. Nevertheless, currently low energy prices imply that pressure for energy transitions have now declined for a number of years.



Source: Based on Kander et al (2013).

**Figure 2. Share of Primary Energy Consumption in Europe, 1800–2008**

**4. Energy Transitions and Declining Industries**

The nature of a new energy technology (as well as the companies or organisations selling and promoting it) has played a crucial role in its uptake (Smil 2010). However, successful uptake tended to depend on the co-evolution of technologies, industries and institutions that enabled new energy sources to emerge from niches and become core elements in the regime (Geels 2002, Foxon 2011). This allowed ‘technological clusters’ to dominate and ultimately create ‘lock-ins’ (Grübler et al. 1999, Unruh 2000, 2002, Fouquet 2016a).

One of the most important factors in determining the speed of a transition is the process of ‘un-locking’ of technology and industry clusters and, in particular, how incumbents react to new competitors. The threatened incumbents in transitions have been known to ‘fight back’, potentially creating ‘sailing ship’ or ‘last-gasp’ effects (Rosenberg, 1976, Utterback 1994, Barbier 2013, Pearson 2016). Also, in certain countries, resource endowments and government objectives were pivotal in pushing or delaying the uptake (Madureira 2008). And, of course, political decisions can be influenced by threatened industries, such as those producing fossil fuels. In other words, transitions are just as much about the decline of incumbent industries, as about the rise of new ones.

So, the decline may involve powerful pressure groups, economic and technological sailing-ship effects, unemployment and social tensions. Madureira (2012) focuses on one crucial industry of this ultimately international transition and industrial revolution. He compares the experiences of iron industries in different countries during the Industrial Revolution, with a particular emphasis on how the declining charcoal industry reacted to the emergence of coke. He suggests that during the transition the incumbent industry may follow a number of different experiences, including rapid decline or defiance and temporary expansion. This may in part be due to the decline in the price of incumbent energy sources following the advances of new energy sources and technologies (Chakravorty et al 2011).

In a similar vein, Turnheim and Geels (2012) explore the destabilisation and decline of an incumbent industry, and illustrate the application of their analytical approach by applying it to the experiences of the British coal industry between 1913 and 1967, and then from 1967 to 1997. The destabilisation is seen to result from a combination of external pressures and internal reactions. The British coal industry's inability to adjust to new circumstances (because it was locked into the old regime) was instrumental in its destabilisation and ultimate decline. Using a multi-dimensional framework, the authors show that, although economic and technical factors may drive external pressures, political, social and cultural factors play a pivotal role in directing the pressures and determining the reactions to them. These experiences offer some important lessons for the way fossil fuel industries may react to demands for regime changes towards a low carbon economy and how governments might aid the transformation of the energy system.

Larger and more concentrated energy firms and industries are likely to exert more pressure on governments to protect their dominant position (Fouquet 2016a). Evidence indicates that, in France, where nuclear power is the dominant source of power, a highly concentrated industry, and closely involved in political decision-making, the process of liberalising and 'competivising' the electricity markets and potentially shifting to a different energy system has been slower than in other economies (Glachant and Finon 2005). Similarly, the large expenditure on lobbying by energy-intensive companies to derail US climate policy is evident (Meng 2015). In 2014, six of the top ten largest companies in the world (as measured by sales revenue) were oil companies and two of the other four in the top ten were car companies, also part of the fossil fuel-based energy system (Forbes 2015) – their revenues amount to 4% of global GDP. As a comparison, in 1900, when coal was king, global revenue from coal was roughly 2% of global GDP (Mitchell 2010, Bolt and van Zanden 2014), though this level of financial power did not halt the transition towards oil. In other words, as Barbier (2013) stresses, there is considerable financial and political power to delay a transition to low carbon energy sources and technologies.

## 5. Energy Transitions and Energy Consumption

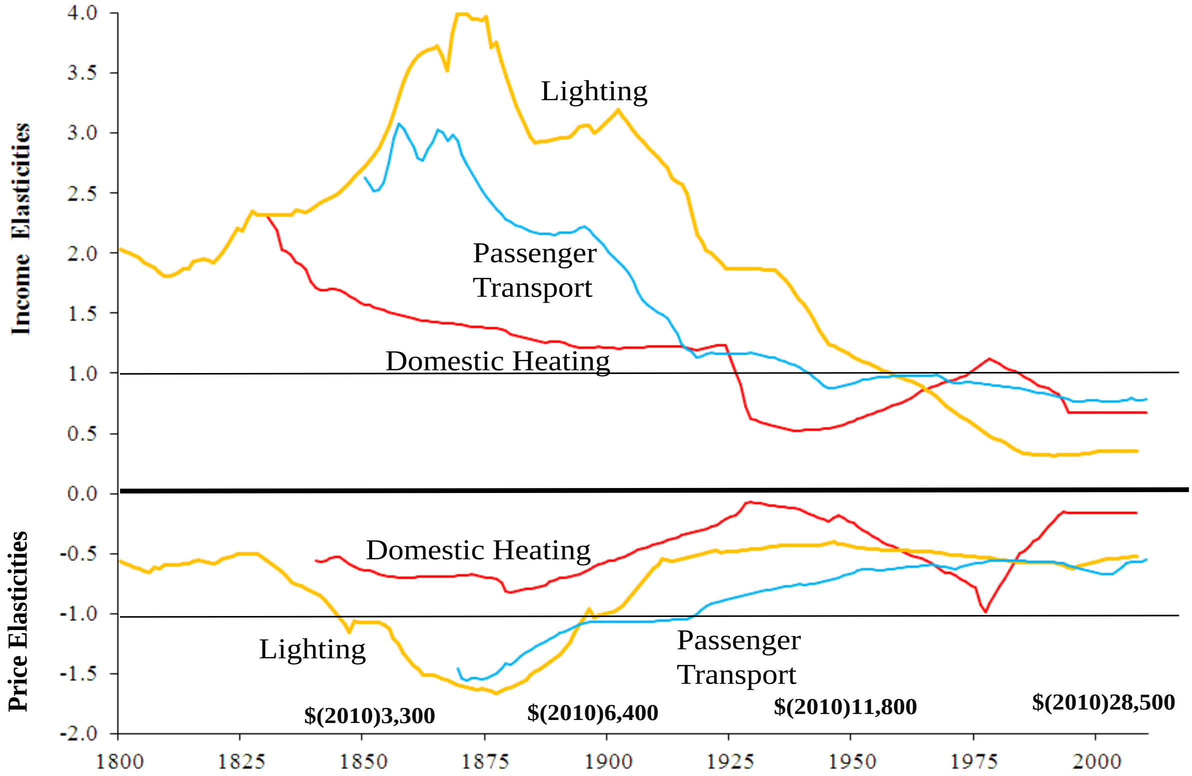
One important observation is that past energy transitions have been characterised by major increases in energy consumption (Grübler et al. 1999). Indeed, the transition from biomass to coal, which began on a global scale at the end of the nineteenth century, and the transition from coal to oil, which unfolded after the second World War, led to dramatically greater levels of energy consumption (Figure 1).

If this was true for future transitions, it would have major implications for long run demand for energy and carbon dioxide emissions. A transition to, for instance, electric vehicles might, therefore, produce major increases in electricity demand (beyond the expected substitution from petroleum), and may lead to large emissions if it was generated from fossil fuels.

However, energy consumption is driven by the price of energy services, the demand for energy services and the shifts in this demand, resulting from changes in income, in particular (Fouquet 2016b). This implies that the impact on energy transitions on energy consumption depends, to a large extent, on the decline in the price of energy services (i.e. often, the combination of the price of energy and the improvements in energy efficiency) and the income and price elasticities of demand for these energy services. Since there is evidence that income elasticities have followed an inverse U-shape curve and price elasticities have followed a U-shape curve with economic development (see Figure 3), the scale of the increase in energy consumption following an energy transition depends considerably on the level of economic development.

Indeed, income and price elasticities were very high (in absolute terms) in the United Kingdom at the end of the nineteenth century and in the first half of the twentieth century (See Figure 3). As a result, energy transitions fed through into large increases in energy consumption. In other currently industrialised economies, which developed twenty to fifty years after the United Kingdom, may well have experienced peaks in elasticities between the 1920s and 1960s, and, therefore, the increase in consumption following energy transitions would have been greatest in this period. Today, with substantially lower elasticities, energy transitions would have less impact on consumption. For currently industrialising economies, their elasticities may be peaking today (Fouquet 2014, van Bentham 2015). As a result, present or near future energy transitions would through into rapidly greater consumption in industrialising economies.

One caveat related to the declining impacts of energy transitions is if the new technology offers new characteristics, altering the value of the service to the consumer. For instance, gas central heating radically altered residential energy consumption. Similarly, the steam locomotive greatly changed conceptions of mobility, space, and time (Schivelbusch 1986) – arguably, without railways, and perhaps the telegraph, Albert Einstein may not have developed his theory of relativity (Galison 2003). Equally, driving a car rather than taking a bus allowed for greater flexibility and privacy of transport services, with major impacts on urbanisation and society (Nye 1998). As a result, the energy and technological transition led to increases in demand (and rises in the income elasticity of demand), thus, meaning that energy consumption increased substantially, despite being at relatively high levels of economic development. Looking forward, it is possible to imagine that the diffusion of driver-less cars (although not necessarily related to an energy substitution, has been associated with electric vehicles) may have a significant impact on the consumption of passenger transport services and, therefore, on overall energy consumption.




Source: Fouquet (2014)

**Figure 3. Income and Price Elasticities of Demand for Energy Services, 1800-2010**

## 6. Impacts of Energy Transitions: Transformation and Inequality

Energy technologies and sources are central to economic production and the consumption of energy services, such as heating, power, transport and lighting. In addition to the changes in energy consumption following energy transitions, there is also some evidence that energy transitions have also transformed production processes. These have often altered social structures which may have put new pressures on political systems. Thus, while appreciating the role of many other factors at play, energy transitions can be seen as catalysts for certain economic, social and political transformations.

For instance, the introduction of steam engines offered additional flexibility to the geography of industrial activities. Power was no longer limited to being close to a source of running water, which provided the main source of power for major industrial activities, such as textile manufacturing. In addition, steam engines were less intermittent than hydropower. As a result, steam engines could spread across the whole country and be used all year (Fouquet 2008). In turn, the introduction of steam engines in the nineteenth altered the role of workers (Humphries 2006). Finally, the growth in production associated with steam engines generated a huge increase in the demand for labour and led to a rural exodus towards the cities (Allen 2009).

Similarly, the shift from steam engines to electricity enabled a much more flexible and decentralised production process. As electrification of industrial activity intensified, it led to major changes in the production process itself. Before, a factory was designed around a single power source. A large waterwheel or a steam engine provided the power down a long line of machines. Initially, the electric motors that replaced steam engines followed this design. However, large energy savings could be achieved if a series of motors each powered only a few machines. It became appropriate to fit each machine with its own motor. This shift reduced the amount of energy required for the power generated and allowed greater flexibility in the production process (Devine 1983).

Another issue to consider is the inequality associated with energy transitions. In the nineteenth and early twentieth centuries, as new energy sources and technologies were introduced (such as gas and electricity, as well as railways), large shares of the population were left on the margins of these revolutions for decades (Clark 1990). Only later, did energy and energy service companies provide access to poorer populations, often due to the pressure of government. The growth of the provision of third class railway services waited until the introduction of the Cheap Train Act of 1886 (Leuing 2006). The provision of the prepayment devices to enable poorer households to use gas lighting (without them needing to invest in the capital investment) had to wait until gas companies´ market shares were threatened by the development of electric lighting (Fouquet and Pearson 2006).

A key problem in present-day developing economies is providing universal access to energy services to poorer members of society (Karekezi et al. 2012, Lee et al. 2016). Historical experiences of the unequal access to energy services and policies to meet a large latent demand have not been properly understood, and they are likely to be of great relevance to present-day developing countries, with large shares of the population at the margins of the energy service revolutions.

## 7. Transitions to Low Polluting Energy Sources

Throughout history, citizens have been harmed by environmental problems resulting from fuel combustion. For example, Fouquet (2011) shows that, after a period of declining coal prices and soaring consumption of energy services and, thus, of coal, which fuelled the First and part of the Second Industrial Revolution, the nineteenth century British firms and households were externalising the social costs of energy production and consumption on a massive scale. In the 1880s, nearly £(2000) 20 billion (around 20% of GDP) of estimated damage was being caused by air pollution resulting from coal combustion. The study also indicates that the relationship between air pollution concentration and damage was non-linear, and increasing at higher levels. As a comparison, air pollution in China in 1995 was estimated to have caused damage equivalent to 9% of GDP, although the level of concentrations in London and other British cities was roughly 50% higher.

As a result, citizens have demanded reductions in pollution and, at times, transitions to low polluting energy sources (Fouquet 2012). These experiences offer interesting parallels with a potential low carbon transition. In particular, they indicate that greater demand for environmental legislation tended to coincide with periods of economic growth, because, first, the damage increased due to greater consumption and pollution and, second, rising incomes enabled citizens to be concerned with more than their basic economic needs. Also important in influencing the demand for environmental change was the public's awareness of the impacts. The outrage and political action following the 1952 Big Smog in London indicates that the demand for climate stability will probably increase as a result of extreme and shocking events that (most, particularly mainstream media, will agree) can be attributed (with a high degree of confidence) to climate change – such as when Bloomberg Businessweek used the title "It's Global Warming, Stupid" after Super Storm Sandy devastated New York City.

Independently of governments, markets have sought energy transitions (Fouquet 2010). In the case of low-polluting energy transitions, there have been few examples, but the switches to gas and electric cookers in the early twentieth century hint at the possibility that markets might take the lead in certain sectors and services in the transition to low carbon energy sources. This is particularly of interest when the niche demand leads to declining prices through a process of economies of scale and learning by doing, as solar panels have been doing. A niche non-free-riding demand can exist for low carbon energy sources and technologies. This demand will be greater if the sources and technologies have desirable characteristics that fossil fuels and their related equipment do not have. The demand for gas and electric cookers was driven in part by the desire for cleaner and easier to use fuels. In turn, a powerful driver of demands for the gas and electric cookers was social status. Thus, if low carbon sources and technologies can be seen as status-enhancing, they may achieve an important niche demand. If this niche demand develops, and producers can achieve economies of scale, then the prices might become competitive with fossil fuels. In this case, markets could drive part of the transition to a low carbon economy (Fouquet 2012).

More probably, though, government will need to help create the demand for these energy sources, especially when the price of the low-carbon option is more expensive. Transitions have often required the discovery of new solutions for many different sectors and services, the transformation of energy systems (Fouquet 2016a), and the decline of energy industries and technologies that were represented by powerful pressure groups (Fouquet 2010). Thus, given the scale of the change and the time they took to unfold, governments have tended to be reluctant to push for energy transitions in the first instance. Furthermore, transitions have and may create new environmental problems (as did coke and town gas, petroleum products, nuclear power and even certain renewable energy sources).

Nevertheless, the experience of the Clean Air Act of 1956 shows that, with sufficient pressure and resolve, governments can initiate transitions to low polluting energy sources. Despite it having been a general period of low air pollution by historical (though not today's) standards, the episode with the strongest demand for improvements in Britain was after the Big Smog of 1952 when the death toll in London was particularly shocking and scientists could attribute these deaths to poor air quality, and a growing range of substitute fuels and heating technologies was available (Fouquet 2012).

However, even with a major demand for improvements and legislation introduced, it is far from certain that the legislation will be effective. Legislation was often weak or included loopholes, such as the addressing black smoke and industrialists argued their smoke was "brown"… Alternatively, legislation is often not enforced or requires lengthy court proceedings. The smoke abatement movement in the Victorian era faced a case of government failure because of politicians' belief that legislation would harm business and industry (Fouquet 2012). Thus, overcoming the perceived economic damage from legislations is still the most likely way to sway politicians. Yet, just like in Victorian Britain, while politicians are cautious of harming industries, they are even more reluctant to address household behaviour, and their emissions associated with residential and transport energy consumption, because of the fear of losing votes - so, presumably, less democratic systems can overcome this problem more easily.

So, even with effective legislation introduced, for it to be sustained (i.e., enforced and not revoked by future governments), it must be of limited cost to polluters, and pro-legislation pressure groups must continue to maintain their pressures on politicians over long periods of time (e.g. a decade or more). For demand to be sustained, it seems likely to either require a series of shocking events, or a wide scale change in value systems that can support (and in lifestyles that can accommodate) long term political pressure.

Nevertheless, the Alkali Act of 1863 (and the Montreal Protocol in 1979) show that environmental legislation can be effective if the victims are sufficiently influential, the polluters are a clearly defined and observable group, relatively cheap solutions are available and equipment exists for monitoring pollution levels. This suggests that legislation targeted at specific groups may be more effective and sustainable than when covering a heterogeneous array of polluters (Fouquet 2012).

Finally, crucial to the outcome of past experiences was the evolution of ideology, of government attitudes towards intervention and of the relationship between the market and the state. It would be difficult to identify trends in the forces over the next century. Nevertheless, they will evolve, such as perhaps new beliefs about our relationship with nature or the potential globalisation of markets and governments, and will play an important role in determining any transition to a low carbon economy.

**8. Conclusions**

The purpose of this short communication was to outline some of the key issues identified from research on historical energy transitions. Critical issues to consider are the speed of transitions (sector-specific and full economy transitions), the price of energy services, as well as shocks that can trigger unfolding events, the benefits that the consumer may gain from the transformation, the role of government play in internalising the external costs of pollutants, the industries that will decline, other transformations that will ensue and the changes in inequality that may occur.

Undoubtedly, one should be aware of the uncertainties about the relevance and transferability of historical insights to potential future energy transitions. Theory acts as the bridge between previous experiences and lessons for understanding future behaviour and formulating policies. However, at present, no formal economic theory of how energy transitions unfold exists – although others have presented potential frameworks for thinking about energy transitions (Geels and Schot 2007, Andrews-Speed 2016). Thus, one should take care about understanding what lessons from historical energy transitions are relevant and transferable for the future.

Looking forwards, it is important to place the challenges currently faced in a broad historical context. The ability to exploit fossil fuels and the associated Industrial Revolution created a remarkable opportunity for humanity to improve its standards of living. However, given the unsustainable and temporary nature of the fossil fuel energy system, it is equally vital to ensure that this wealth and value be used to ensure that our current living standards are sustainable. Thus, the fossil fuel energy system must be the springboard for another energy system and a new era in economic development.

Sovacool (2016 p.212) reminds us that energy transitions are complex processes, arguing that “most energy transitions have been, and will likely continue to be, path dependent rather than revolutionary, cumulative rather than fully substitutive.” Indeed, each country’s experience will be different. Crucially, energy transitions are non-deterministic. That is, energy transitions are not inevitable; instead, they depend on a series of actors and forces creating a new path. Therefore, the complex interaction of the choices actors will make and the forces that continue to be applied on markets, along with a little serendipity, will influence the existence, speed and nature of transitions to low carbon economies.

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