LONG RUN ENERGY DEVELOPMENTS IN THE UNITED KINGDOM

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Abstract: In this brief paper we aim to show that, while each country's experience is unique, there may be some value for others in reflecting on the United Kingdom's long energy and environmental histories. We suggest that the United Kingdom's experience, initially through its access to stocks of fossil coal resources that freed it from the limitations of the energy flows available from an 'organic' economy, illustrates both the valuable role that the availability of adequate supplies of energy can play in a country's economic development and the ways in which energy transitions can occur even before rising prices signal the scarcity of a particular energy resource. Through the example of lighting services, we have also indicated the extent to which technological and other forms of innovation can lead to remarkable reductions in the costs and increases in the quality and attributes of energy services, such as illumination, with beneficial effects on economic welfare for those who have access to them. We point out that the UK did not manage seriously to address energy-related environmental issues until the twentieth century. Because of the increasing importance of environmental and other externalities, including climate change, we have pointed to the value of bringing different policy regimes together in long term attempts to pursue *sustainable innovation in energy-related technologies and practices* and produce mixes of policy instruments that work synergistically and effectively together.

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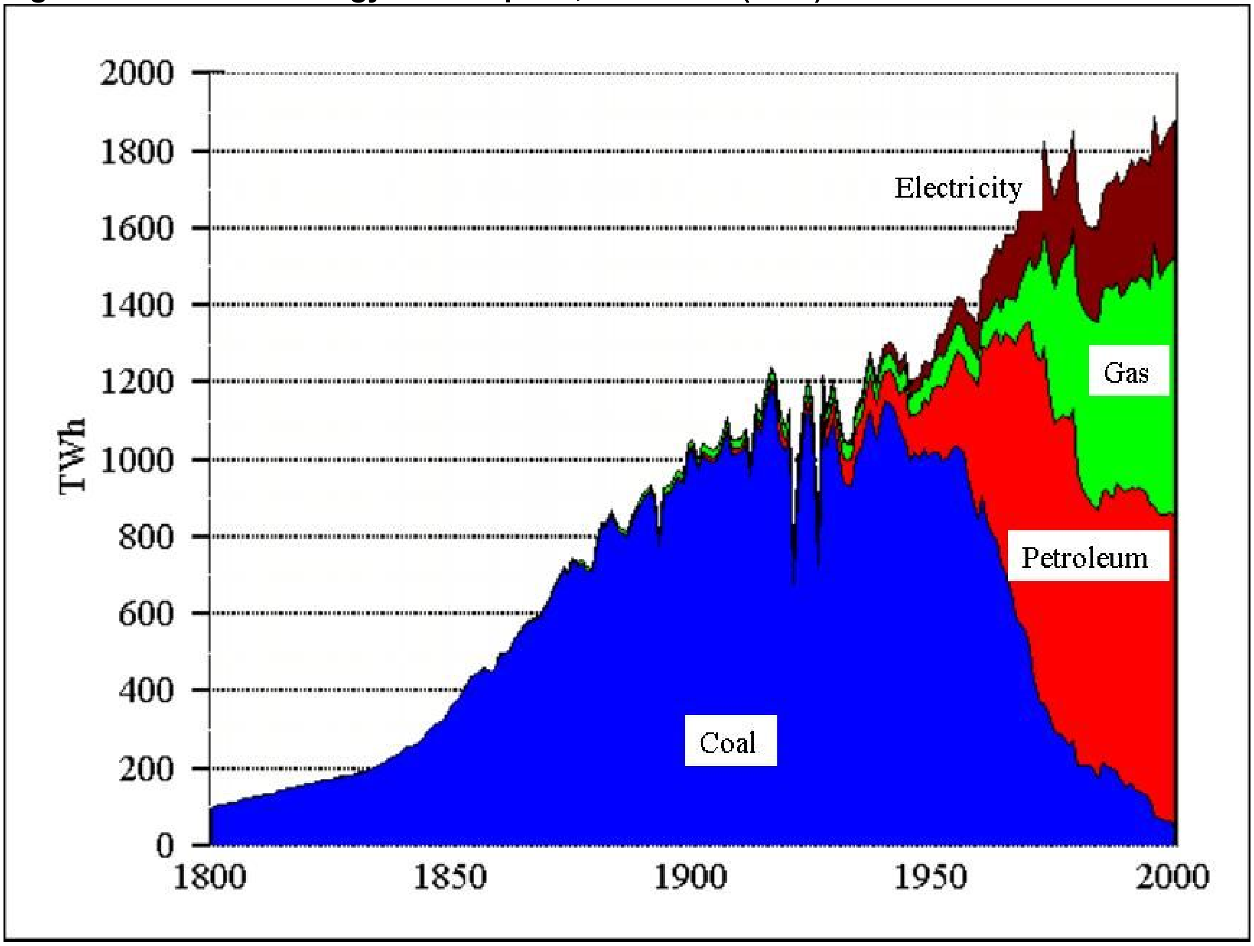
In previous work we have sought to demonstrate the value of examining the history of energy markets, technologies, institutions and prices over periods of more than a century (Fouquet and Pearson 1998, 2003a, 2003b; Pearson and Fouquet, 2003). We have argued that this kind of long-run exploration can help to understand the scale - and the limits - of energy's contributions to socio-economic development, its impacts on environmental quality and resources; and the effects of path dependency and lock-in of energy technologies and related institutions (see also Smil 1993). And it may guide us towards developing pathways to different and more sustainable energy and environmental futures. In particular, we think that the UK's experience illustrates the valuable role that the availability of adequate supplies of energy can play in a country's development, the ways in which energy transitions can occur, the role of energy prices, and the way in which energy contributes to economic welfare through its role in providing an evolving range of energy services of growing quality at lower costs.

From the 16th to the 19th centuries, the British economy made a transition towards a new system liberated from the constraints of a traditional agrarian, 'organic economy' (Wrigley 1998), that is an economy bounded by the productivity of a scarce resource, a fixed supply of land, whose limited flow of outputs had to supply all basic needs for food, clothing, housing and fuel. In this new system, the opportunities to raise economic output and living standards were transformed by the exploitation of a stock of mineral resources, coal, and by associated technological breakthroughs in energy conversion (including the steam engine, which enabled the conversion of heat energy into mechanical energy, and the development of town gas). This, along with other technological, institutional and social innovations, helped to stimulate and resource the organization, urbanization, mechanization and industrialization that were part of Britain's industrial and societal revolution. Later waves of innovation led eventually to the development of the modern, service-based economy, via the discovery of newer fuels, the establishment of their supply infrastructures and the use of new and increasingly efficient energy end-use technologies. Figure 1 illustrates the evolution of final user energy demand in the United Kingdom from 1800-2000.

Fig. 1: UK final user energy consumption, 1800-2000 (TWh)

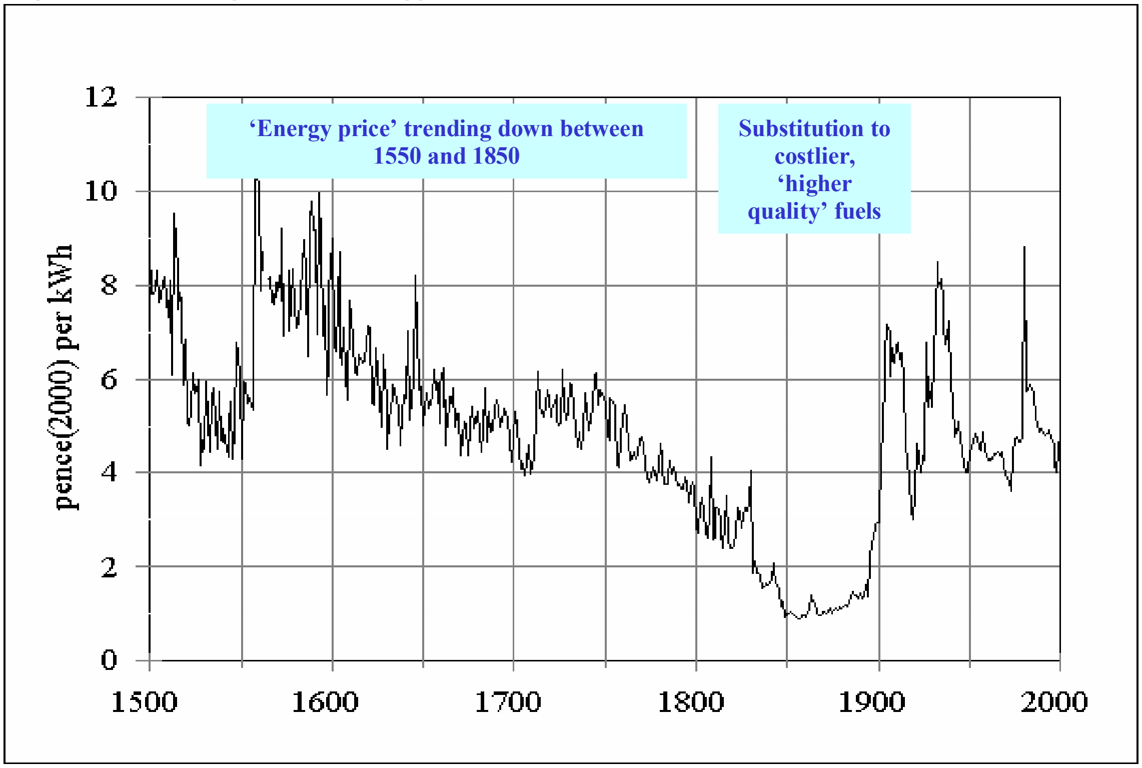


Source: Fouquet and Pearson (2003a)

Nevertheless, despite their importance, it is wise not to exaggerate the role of energy and energy-using technologies in Britain's economic development. The picture is richer than this, both because the industrial revolution is now recognised to involve a longer drawn-out and more complex systemic change that emerged from social, economic, institutional and political change as well as technological innovation (Mokyr 2002), and because the effects of innovation are often gradual rather than abrupt (David and Wright 1999) . For example, steam made its largest impact on British productivity growth in the second half of the 19th century and after (Crafts 2004), nearly one hundred years after the early inventions, while the penetration of gas and then electric light took decades, as did many more incremental energy system improvements. This reminds us that the rapid uptake and influence of new technologies cannot be automatically assumed and that the processes, institutions and policies involved may take time to develop, and be susceptible to a variety of influences, including government policies.

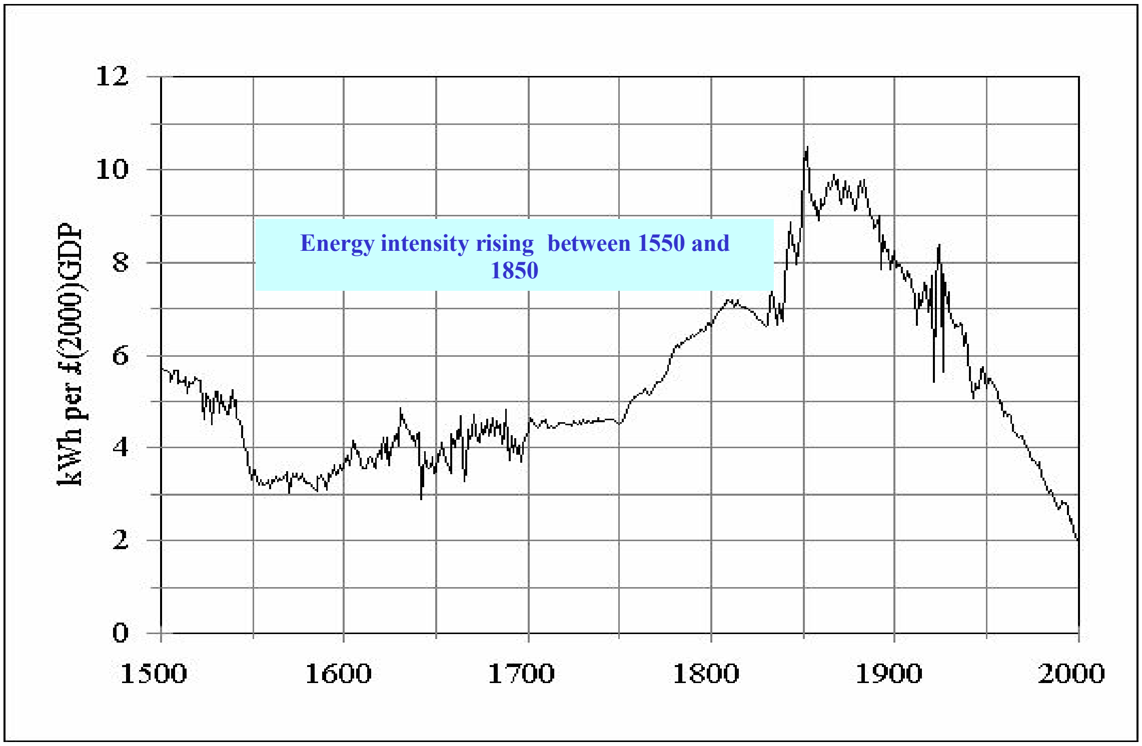
For almost three centuries, until about 1850, falling 'real' energy costs (see Figure 2) were one of the factors that stimulated rising final energy intensity, i.e. energy per unit of GDP (shown in Figure 3). From the latter years of the 19th century through the 20th century, however, the energy intensity graph trended downwards, as the economy's structure shifted towards lighter industry and services, as technological progress and the substitution of capital for energy and labour increased the efficiency of energy production and use and as the pace of investment in energy-embodying infrastructure slowed. During this time, as noted, the UK economy shifted towards increasing use of newer energy forms, town gas (and later natural gas), petroleum and electricity. Although initially much more expensive than coal, they were of higher 'quality' and hence ultimately more valuable, especially when used with new and enhanced energy end-use devices, like the electric motor, the incandescent lamp and the internal combustion engine. These transitions tended to occur before signs of any substantial price increases associated with the depletion of the previously dominant fuel. And, as with coal, their prices tended to fall significantly with economies of scale, technical progress and various forms of 'learning by doing' (Fouquet and Pearson 2003a).

Fig. 2: UK average real 'energy' price series, 1500-2000



Source: Fouquet and Pearson (2003a)

Fig. 3: UK final use energy intensity (energy consumption per unit real GDP), 1500-2000



Source: Fouquet and Pearson (2003a)

Overall, therefore, with the caveats expressed earlier, it may be suggested that the UK's access to the energy resources and technologies that enabled it to break free from the energy limits of an organic economy was a significant element in its industrial and social revolutions. What form did the benefits from enhanced energy supplies take? Energy economists understandably tend to focus on the costs of fuels and energy technologies, which are traded, have an explicit market price and are taxable. However, the benefits from energy access take the form of satisfaction not from energy itself but from *energy services*, i.e. from the quantity, quality and cost of the *services* yielded by combinations of fuels, their associated supply infrastructures and institutions, and end-use appliances. Access to modern fuels and technologies enhances the quality, reduces the cost and increases the affordability of energy services - like illumination, cooked meals, comfortable temperatures and transport services, leading to huge welfare gains.

For Britain this can be illustrated clearly in the case of lighting services. Over the last three centuries industrialized societies have been increasingly freed from dependence on sunlight and moonlight because technological innovation and mass production of lighting appliances, falling costs of fuels and rising incomes have revolutionized our ability to illuminate. In a recent paper (Fouquet & Pearson 2003b) and in ongoing work Fouquet and Pearson 2006), we present evidence of the decline in the cost of illumination and the associated rise in light use in the United Kingdom, from the 18th century to the present day.

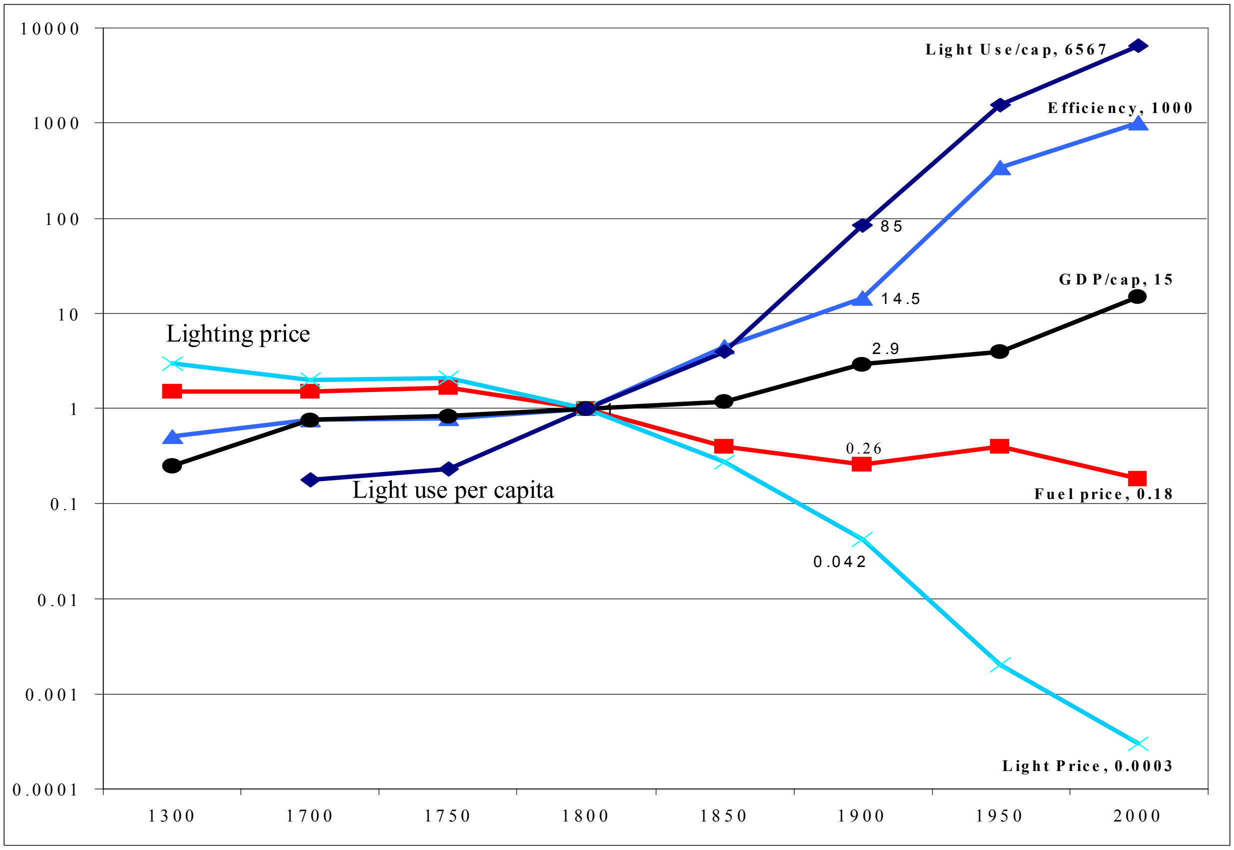
Table 1 shows estimates of the key variables associated with the price of fuels and the costs and consumption of lighting services, over the period 1300-2000. The first two variables in Table 1 are measures of the price of the lighting fuel (in pence per kWh) and the efficiency of lighting appliances (in lumen-hours per kWh). They show a relatively modest decline in fuel prices and proportionately smaller increase in efficiency between the 14th and 18th centuries. The price of lighting fuels (associated with the shifts from tallow candles to oil, gas and then electricity) falls considerably in the second half of the 19th century, and then rises and falls in the 20th century (from the use of high-value electricity, which also has a very high initial price). There are, however, dramatic improvements in the efficiency of lighting technologies - in the 19th century (fourteen fold), particularly in candles and in oil and gas lamps, and in the 20th century (nearly seventy fold), as gas lighting and the incandescent lamp developed and penetrated. These efficiency improvements indicate the major role played by technological innovation, especially over the first fifty years of the 20th century.

Table 1: Key Lighting Variables and Indices in the United Kingdom (1300-2000)

	Price of Lighting Fuel/Energy Source		**Efficiency of Lighting**		**Price of Lighting Services**		**Consumption of Light per Capita**		**Consumption of Light (total)**		**Real GDP per capita**	
Year	*Pence (year 2000) per kWh*	*Index 1800=1*	*lumen-hours per kWh*	*Index 1800=1*	*£(2000) per million lumen-hours*	*Index 1800=1*	*Million lumen-hours*	*Index 1800=1*	*Index 1800=1*	*Index 1800=1*	*£(2000)*	*Index 1800=1*
1300	38	1.50	18	0.5	19,875	3.0	-	-	-	-	-	0.25
1700	38	1.50	27	0.75	13,050	2.0	0.00058	0.17	5	0.1	900	0.75
1750	41	1.65	29	0.79	13,690	2.1	0.00074	0.22	7.5	0.15	1,000	0.83
1800	25	1	35	1	6,630	1	0.00320	1	50	1	1,200	1
1850	10	0.40	150	5.1	1,775	0.27	0.0127	3.9	350	7	1,400	1.17
1900	6	0.26	240	13.5	276	0.042	0.2740	84.7	11,000	220	3,500	2.9
1950	10*	0.40	11,600	318	10	0.002	4.94	1,528	250,000	5,000	4,700	3.92
2000	4	0.18	25,000	682	1.7	0.0003	21.25	6,566	1,270,000	25,400	18,000	15

Source: Fouquet & Pearson (2006) *Energy Journal*, Vol. 27(1)

Figure 4. Indices of Key Lighting Variables in the United Kingdom (Log Scale, 1800 = 1), 1300-2000



Source: authors' own estimates – see Section II

Source: Fouquet & Pearson (2006) *Energy Journal*, Vol. 27(1)

Thus the history of the evolution of artificial light in the United Kingdom illustrates the kinds of dramatic improvements that can be achieved in the quality and cost of energy services and the consequent enhancements in economic welfare. Similarly striking changes can be observed in the development of other energy services, from transport to heating and cooling. One implication of these improvements is that they highlight the possibilities for substantial and increasing gaps between rich and poor populations that can arise from differential access to and ability to pay for modern fuels, energy infrastructures and end-use technologies. Correspondingly, the poor, whose ability to pay is so much less than that of the rich, often pay much more than the rich per unit of energy service because they cannot afford the first costs of the efficient technologies.[4]

[4] Robert van der Plas has observed, for example, that in parts of rural Africa people's access to light today is the same as that available in Europe in the Middle Ages.

A second implication of these energy efficiency improvements is that innovations in energy service provision may not only be vital for the satisfaction of human wants. They could also – by reducing energy use per unit of service (and as long as there were no substantial 'rebound' effects) - play a potentially important role in slowing the depletion of energy and environmental resources and in retarding and even in some cases reversing the growth of local, regional and global pollution.

Although we have discussed the beneficial effects of greater access to and affordability of energy services in the United Kingdom, there are also important issues relating to the harmful environmental impacts arising from the use of energy resources. For example, London has a long history of air pollution.[5] There was a slow growth in legislation to attempt to control it (a royal proclamation banned the burning of 'sea coal' in the 13th century, while in 1661 John Evelyn presented King Charles II with a treatise on the problems of smoke in London).[6] The report of a Select Committee of Parliament, set up in 1819 to consider the effects and possible control of smoke from steam engines and furnaces, is said to have marked the beginning of a gradual process that culminated in the Clean Air Act of 1956. For example, the Smoke Nuisance Abatement (Metropolis) Acts 1853 and 1856 gave the police in London powers act against furnaces used to raise steam, factories, public baths and wash houses, and steam vessels on the River Thames. Although there had been some improvement, by the beginning of the twentieth century smoke from coal burning in private houses was a serious issue: when industrialists were charged with smoke pollution, a frequent defence was to cite the 95 per cent of smoke that came from the chimneys of the seven hundred thousand private houses in London. By the 1950s, however, and with the regular occurrence of thick 'smogs',[7] the inadequacies of the legislation on the control of emissions from industrial sources began to be recognised. In particular, the 'Great London Smog' of 1952 is estimated to have caused 3500-4000 premature deaths. This led eventually – despite some government reluctance - to the introduction of the

[5] As, of course, do many other cities in the United Kingdom, particularly those that grew rapidly in the 19th century, with industrial expansion.

[6] This paragraph draws on *50 years on: The struggle for air quality in London since the great smog of December 1952*, Greater London Authority, December 2002. See: www.london.gov.uk/mayor/air_quality/docs/50_years_on.pdf

[7] The word 'smog' was first used in 1905 to describe the combination of smoke and natural fog that London used to experience.

Clean Air Act of 1956 and the amended Clean Air Act of 1968 - and the regulation for the first time of domestic emissions. The reluctance to change the regulations may well have been lessened by the increasing adoption of oil as a fuel to provide domestic and other forms of heating. Smokeless zones ('Smoke Control Areas') were introduced where only authorised low-emission 'smokeless' fuels were permitted in any domestic or commercial setting. There were new restrictions on heights of industrial chimneys and power stations were relocated to areas outside the city. These measures, coupled with the discovery and increased use of Britain's natural gas reserves from the late 1960s, led to dramatic reductions in smoke and SO_2 concentrations in London in the second half of the 20th century.

Thus, despite growing concern in the 19th century, it was not until the 20th century that the United Kingdom began seriously to address the environmental side-effects of its growth in energy production and use, and to begin to take serious action to control these harmful 'externalities'. Its experience illustrates the importance of developing environmental policy regimes and associated instruments, including economic instruments, such as pollution charges or tradable emissions permits, to encourage such internalisation. In recent years, for example, the United Kingdom has experimented with its own pilot carbon Emissions Trading Scheme (see Pearson 2004, for a critical review), and is now part of the European Union CO_2 Emissions Trading Scheme. As we note below, however, the United Kingdom has found it difficult to manage an increasingly crowded 'policy space' in which different policy instruments interact in complex and not always well-anticipated ways (Sorrel 2003b, 678). And it has not always found it easy or politically popular to internalise externalities through pollution charges, as the recent history of the attempts to tax vehicle fuels on environmental grounds illustrates.

In this area of environmental externalities and energy pricing, the international challenge today, particularly in the developing world, is: (a) how to ensure increasing access to affordable forms of energy that do not simultaneously cause inappropriate levels of local, regional and global environmental damage; and (b) how to balance the desire to subsidise energy for the poorest consumers whilst simultaneously avoiding giving signals to general energy consumers that encourage inefficient uses of energy and the waste or depletion of scarce resources.

In relation to global sustainability challenges and greenhouse gas emissions, our recent examination (Pearson and Fouquet 2003) of morevthan 100 years of the history of energy use and carbon emissions of a group of four post-industrialized countries, including the United Kingdom, and a group of large rapidly developing countries, including China, suggests that, as well as many common elements, including four or five apparent 'patterns' in the relationships between CO2 emissions, income and time, there are also considerable variations in the pathways within and between the two groups. It also suggests that: (a) there is no unique pathway to be followed by developing countries; and (b) that they face severe challenges if they are to increase energy services and the quality of life while avoiding path dependency and carbon lock-in. Thus whether today's rapidly developing countries follow the examples of the USA, the United Kingdom or Japan on energy and carbon intensity and emissions may depend on a variety of internal and external factors and decisions. And if industrialized countries want developing countries to pursue trajectories different from their own historical experience - and from those that the developing countries themselves might choose – they are likely to have to help in making the emissions-income relationship different from what it would otherwise be, through financial assistance, technology transfer and other means.

Given the powerful role that innovation has been shown to play in reducing the cost and increasing the quality of energy services, and in enhancing economic welfare, it is clear that it matters that innovation takes place to continue to reduce the costs and enhance the quality of energy services. But given the propensity of energy supply and use to cause serious local, regional and global environmental damage (and widespread concerns over energy security and diversity), it is also clear that it matters that innovation processes also address this problem. Part of the challenge, of course, is that while profit-seeking entrepreneurs have an incentive to innovate in the kinds of energy production or technology attributes that are obviously valued in the marketplace today, environmentally benign attributes (such as low or zero levels of damaging emissions like CO2) have a market value that comes at present only from governmental regulatory action. And where that action is seen to be of uncertain commitment and durability, the incentives for private action are limited.

Nevertheless, the United Kingdom government, along with a number of other governments, has increasingly committed itself to the promotion of moves towards more sustainable systems of energy production and use[8] - and has also set out some more specific long-term targets that aim to embody this commitment, such as the current aspiration to follow a path to cut CO2 emissions by 60 per cent by 2050 whilst also achieving social and economic goals.[9] It is clear that this type of long-term goal cannot be satisfied simply by ongoing incremental innovation; it requires radical transitions and systems-level innovation to meet end-user demands for energy and transportation services. Historically, however, separate policy regimes have addressed innovation, environmental sustainability and energy issues, each with its own goals and favoured types of policy measures and instruments. Moreover, policy planning time horizons have not generated policies to be implemented for the long term.

Thus policy-makers and stakeholders face a dual challenge, to adopt long term policy goals for sustainability and to develop strategic and operational frameworks that translate them into the design of mixes of energy policy measures and instruments sufficient to promote the kind of radical innovation needed. For example, the problems of interaction and harmonization that occurred between various United Kingdom policy instruments, including the Renewables Obligation, the UK's voluntary Emissions Trading Scheme and the mandatory European Union Emissions Trading Scheme, highlighted the issue of securing a mix of policy instruments that work synergistically rather than antagonistically towards a long-term goal—and that are sufficiently effective and flexible to evolve as national and international circumstances change.[10] This challenge of developing frameworks and strategies for sustainable innovation has some high level political support in several governments, including that of the United Kingdom (for the UK, see for example the 2003 *Innovation Report* various subsequent policy documents, including the 2007 UK *Energy White Paper*.[11]

Recent research, carried out with colleagues at Imperial College London, has sought to complement these ongoing policy moves by outlining recommendations for the development of policy processes that would promote sustainable innovation (Foxon et al. 2004, 2005). This

[8] For example, at the 2002 Johannesburg summit.

[9] See the 2006 UK Government Report – *The Energy Challenge* (http://www.dti.gov.uk/energy/review/page31995.html) and the 2007 UK White Paper -*Meeting the energy challenge* (http://www.dti.gov.uk/energy/whitepaper/page39534.html).

[10] See Boemare et al. (2003); Pearson (2004); Smith (2002); and Sorrell (2002, 2003a,b).

[11] "Innovation will also be essential for meeting the environmental challenges of the future – including moving to a low carbon economy and reducing waste. We need to find new ways to break the link between economic growth and resource depletion and environmental degradation" (DTI 2003, p.9).

guidance draws on empirical analysis of recent policy developments, through two case studies of United Kingdom and European Commission policy making[12], and through insights from practical policy experience. It was also developed and refined through interactions with stakeholders from the national and international policy, business, consultancy, academic and NGO communities. The five main recommendations of the guidance (discussed in detail in Foxon et al. 2005) are:

(1) Establish a *Sustainable Innovation policy regime* that brings together *innovation, environmental policy* and *energy regimes* (the promotion of sustainable innovation would be an explicit policy goal, and the regime would facilitate systemic changes in current technological and institutional systems, aimed at clear, long-term sustainability goals and outcomes).
(2) Apply *systems thinking* (in order to engage with the complexity and systemic non-linear, dynamic interactions of innovation systems and policy-making processes).
(3) Advance the *procedural and institutional* basis for policy delivery (while acknowledging the constraints of time-pressure, risk-aversion and lack of reward for innovation faced by real policy processes).
(4) Develop a more *coherent and integrated mix* of policy instruments that would cohere synergistically to promote sustainable innovation.
(5) Incorporate *policy learning*, *evaluation and review* (to ensure a highly responsive way to modulate the evolutionary paths of sustainable technological systems and to mitigate the unintended harmful consequences of policies).

Concluding comments

In this paper we have suggested that the United Kingdom's experience, initially through its access to stocks of fossil coal resources that freed it from the limitations of the energy flows available from an 'organic' economy, illustrates both the valuable role that the availability of adequate supplies of energy can play in a country's economic development and the ways in which energy transitions can occur even before rising prices signal the scarcity of a particular energy resource. We have also pointed out, though, that energy transitions and the penetration of new fuels and technologies takes time and cannot necessarily be accomplished quickly. Through the example of lighting services, we have indicated the extent to which technological

[12] The case studies address low carbon innovation policy in the UK, and EC policy making processes relating to alternative energy sources for vehicles.

and other forms of innovation can lead to remarkable reductions in the costs and increases in the quality and attributes of energy services, with consequent effects on economic welfare for those who have access to these modern technologies and fuels. Because of the increasing importance of environmental and other externalities, we have pointed to the value of bringing different policy regimes together in long term attempts to pursue sustainable innovation and produce mixes of policy instruments that cohere synergistically. We do not underestimate the difficulties associated with trying to do this – but suggest that the severity of the issues indicates the importance of engaging with the challenge. Finally, while each country's experience is unique, we hope to have shown that there may be some value for others in reflecting on the United Kingdom's long energy and environmental histories.

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