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Energy services

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Abstract

Energy consumers are driven by their demand for energy services (such as space and water heating, cooking, transportation, lighting, entertainment and computing). This piece introduces the reader to the concept of energy services, and explains why it is important to analyze energy markets and climate policies from the perspective of energy services. The paper discusses the theoretical foundations and empirical evidence, particularly related to the rebound effect and the demand in developing economies. The paper concludes that governments should encourage the collection of statistical information about energy services in order to help economists analyse markets and policies through this lens. Most importantly, governments should formulate more integrated policies that focus explicitly on energy services, connecting markets for energy and for energy-using equipment with the development of technologies. Careful and balanced energy service policies are especially important as economies industrialise because they can help reduce economic, political and environmental vulnerability.

Keywords

Energy consumption; energy services; energy policy; climate change; consumer behaviour; direct rebound; price elasticity

JEL classifications

Q32; Q38; Q43; Q48; Q58

Article

1. What are 'Energy Services'?

Energy services refer to the services that are generated from consuming energy combined with appliances. For residential consumers, these services include space heating and cooling, water heating, cooking, refrigeration, lighting, computing, entertainment and passenger transport (Reister and Devine 1979, Reister and Devine, 1981; Goldemberg *et al*. 1985). For firms, these include high temperature processes, such as iron smelting, low temperature processes, moving of motors and machinery, separation, drying, and compressing air, as well as refrigeration, lighting, space and water heating, and freight transport.

For space heating and cooling, the service is measured in terms of the increase or decrease in temperature compared with the existing temperature (in degrees Centigrade or Farenheit) for a specified surface area. For example, a 100 square metre house is warmed 10°C for two hours – which is the equivalent to warming 2000 square metres 1°C for one hour. Transport is measured in terms of passenger-kilometres (or –miles), or tonne-kilometres (or ton-miles) for freight. The more efficient the vehicle, then the more passenger-kilometres can be achieved with, say, a litre or gallon of gasoline. The number of vehicle-kilometres in a country, divided by the gasoline consumed in that country, offers an indicator of the average fuel efficiency of vehicles (Frondel *et al*. 2008, Stapleton *et al*. 2016). For lighting, the unit of measurement is lumen-hours, which indicates the amount of illumination generated by a light source (Nordhaus 1997). A 100 watt incandescent bulb provides about 1300 lumens. So, if it is left on for 10 hours, it will have generated 13,000 lumen-hours and used 1000 watts. The same amount of lighting could have been produced over the same amount of time using a 20 watt CFL bulb, but consuming only 200 watts.

Energy services are closely related to end-use energy consumption and the concept of exergy. End-use energy consumption refers to the energy consumed for individual services. However, focusing on end-use energy consumption or prices does not take account of the efficiency of conversion of the energy into the service. Exergy, on the other hand, does take account of the efficiency and refers to the amount of 'work' produced (Ayres and Warr 2009). The strength of the concept of exergy is that it looks at all energy services in the same unit; however, it does not focus on the nature of the specific output, which risks ignoring important dimensions of the analysis (Sovacool 2011).

The purpose of this piece is to introduce readers to the concept of energy services. The next section explains why energy economists are increasingly analyzing energy service consumption, rather than only energy use. The third section presents the foundations for analyzing the demand and provision of energy services. In the fourth section, empirical evidence of the demand for energy services in the residential and transport sectors is presented, focusing on price elasticities and the size of direct rebound effects. The fifth section discusses the two-way relationship between energy services and economic development. Due to space constraints, other topics related to energy services are not discussed in detail – including fuel poverty (Boardman 2010), exergy (Ayres and Warr 2009), the impact of smart meters (Römer *et al*. 2012) and of net-metering (Gillingham *et al*. 2016a), energy service companies or ESCOs (Weiller and Pollitt 2013), and energy systems planning and operation, such as demand-side management (Strbac 2008). The final section draws conclusions about our knowledge of energy services and its role in improving policy-making.

2. The Importance of Energy Services

Energy consumption is driven by the demand for energy services. Individuals do not consume electricity for the voltage that speeds down the wires, or put gasoline in their cars for the pleasure of having a full tank. Instead, they consume them because of the lighting the electricity creates or the mobility the gasoline provides.

Consequently, studies of energy demand may strongly benefit from considering the relationship between energy services, technologies and energy consumption (Haas *et al*. 2008). If the relationship remains constant, it may not be crucial to focus explicitly on energy services. For instance, in the short run, the relationship does stay broadly constant, because the efficiency of the technology (that is, the amount of service generated for a given unit of energy) does not change much and, so, the focus on energy services may not alter the results of the analysis.

However, analyzing energy services is especially important in the long run, as technological change can radically alter energy consumption behaviour. Nordhaus (1997) showed how the price of fuel for lighting fell three-fold and the price of lighting (measured in lumen-hours) fell 75-fold in the last century, thus, traditional methods of measuring the price of lighting using the fuel price were off by a factor of 25. Fouquet (2011) and Muller (2016) showed that this is not an isolated example and that, in general, the trend in the (nominal and real) price of an energy service diverges from the trend in the price of energy for this service in the long run. While the average energy price has not shown a discernible trend in the long run, the price of energy services has tended to fall. The divergence implies that focusing exclusively on energy prices and consumption rather than energy services will generate misleading conclusions about energy consumption behavior. This long run perspective is particularly relevant when thinking about climate change mitigation.

As Fouquet and Pearson (2012) argued, by not focusing on energy services, the analyst is making an implicit assumption about the price elasticity of demand for the energy service. Two 'straw-man' examples can be used to show this. First, the 'efficiency optimist' might suggest that if energy efficiency improves by 10%, energy consumption will fall by 10%. However, since the efficiency has improved by 10%, the consumer can get the same quantity of service with 10% less energy. This implies that the price of the energy service has fallen 10%. For energy consumption to fall by 10%, energy service use must remain unchanged. So, the 'efficiency optimist' implicitly assumes that the price elasticity of demand for energy services is zero. Alternatively, the 'laggard economist' might propose that since the price of energy is unchanged consumption of energy will remain the same. In this case, since the price of this energy service has fallen by 10%, for energy consumption to remain unchanged, energy service use must increase by 10%. So, the implicit assumption here is that the price elasticity of demand for energy services is one. Thus, focusing on energy rather than energy services forces the analyst to make assumptions about consumer behavior and is likely to create misleading estimates of consumer responses to long run energy price and efficiency changes. Ultimately, the size of the price elasticity of demand is an empirical question and needs to be estimated in order to help identify the scale of the 'rebound effect', which will be discussed in the fourth section.

Hunt and Ryan (2015) have made this point explicit, emphasizing the misspecification of models that fail to incorporate energy service demand and the biased elasticity estimates that result. In their analysis, the income elasticity of demand for energy is underestimated and the price elasticity is overestimated, because of the failure to model energy services and include energy efficiency improvements. However, they explain that the bias depends on the trends in income, real prices and efficiency improvements, implying that it is not possible to generalize the direction of bias (Hunt and Ryan 2015, p.283)

An additional advantage of focusing on energy services is that the demand for energy services stays relatively stable with the introduction of new energy sources and technologies. Traditional analysis sees energy transitions as disruptive events – with a radically declining demand for, say, biomass fuels and rapidly rising demand for coal – with no continuity. However, they can be seen as competing technologies and sources for producing the same energy service. In this way, long run patterns in energy service consumption can be identified that would be hidden by focusing only on the uptake and decline of energy sources and technologies (Fouquet 2014).

In addition, Smulders and de Nooij (2003) highlight the limitations of a study of economic growth that ignores energy services. They show that, within their model, energy conservation policies, which reduce energy consumption, lower economic growth. However, this assumes that growth in energy use is a key source of the growth in economic output, rather than energy service consumption, which is unlikely to decline following energy conservation policies. Indeed, Toman and Jemelkova (2003) emphasize the importance of energy services in driving economic development. They show that energy services can affect economic development through a number of different channels, and that these effects can change at different levels of economic development, and it is essential to model them explicitly.

Finally, the Nordhaus (1997) piece sought to highlight that the consumer price index (CPI) and the gross domestic product (GDP) are mismeasured if they do not take account of increases in the quality of service provision, which result from technological improvements. Lighting is just one example amongst many in which conversion of a good into a service is underestimated. In fact, Nordhaus (1997, p.60) suggests that 'estimates of the growth of real consumption services is hampered by significant errors in the measurement of prices and that for almost two-fifths of consumption the price indexes are virtually useless.'

In other words, focusing on energy services rather than energy consumption can greatly improve our understanding of energy consumption behavior, including the rebound effect (see the fourth section), of the relationship between energy markets and economic growth, and even of fundamental measurements of cost-of-living and economic activity. The main reason economists have tended to ignore energy services has been a lack of data on energy efficiency to convert data into services. As Sorrell (2007, p. 25) explains: 'For many energy services, the relevant data is simply unavailable, while for others the data must be either estimated or subject to considerable error.'

3. The Demand for Energy Services and its Household Production

Having discussed the importance of focusing on energy services, and before reviewing the empirical evidence, it is valuable to outline briefly the basic theory underlying the demand and provision of energy services. Energy service markets often involve the same agent demanding and providing the service by consuming energy and acquiring related equipment (that is, the physical capital). Here, the focus is on the residential and transport sector, although similar issues apply to energy service markets in industrial and tertiary sectors. One difference is the increasing separation of demand and supply with ESCOs (Energy Service Companies) providing the services, which will be briefly discussed.

The first modelling of the derived demand for energy, combining complementary durable equipment, dates back to Houthakker (1951). Early studies highlighted the fundamental importance of the relationship between energy use and appliances, but were not explicit about the consumer's objectives related to energy services (Berndt and Wood 1975, Pindyck 1979, Hausman 1979, Khazzoom 1980, Dubin and McFadden 1984, Dubin *et al.* 1986) - for a review of the early literature on energy demand modelling, see Taylor (1975). Then, a growing literature emphasized the importance of modelling energy end-use or service consumption, starting with Reister and Devine (1979)Reister and Devine (1981), Neels (1981), Goldemberg *et al*. (1985), Quigley (1984), Klein (1988), and Quigley and Rubinfeld (1989), though focusing on the production of services.

However, economists have been slow to explicitly model the demand for energy services, and were eventually stimulated by Nordhaus' (1997) seminal piece on the price of lighting, by Modi *et al*.'s (2006) emphasis on the provision of energy services in developing economies and by the interest in the rebound effects that hamper efforts to mitigate climate change through energy efficiency improvements. The following outline summarises the demand-side perspective presented in Hunt and Ryan (2015), while incorporating the supply-side approach proposed by Neels (1981) and Quigley (1984), which is also discussed in Frondel *et al*. (2008).

A consumer or household's objective is to maximize utility - here, the focus is explicitly on taking account of the energy services consumption (ES) generated for meeting this utility:

$$\text{Max } U_t = u(ES_t,\ X_t), \tag{1}$$

subject to constraints

$$Y_t = P_{ESt} \cdot ES_t + P_{Xt} \cdot X_t \tag{2}$$

where X_t is a composite of goods and services, P_{ESt} and P_{xt} refer to the prices of the energy services and of the composite goods, and Y_t is the consumer's budget, which should be permanent wealth (although it is often proxied by income). Other constraints, for example, relating to the availability of information, technical problems using certain products and the existence of institutional factors which influence the ability to make decisions and to choose goods, might also be included for a more realistic (but more complicated) optimization problem.

Based on the above analysis, but for simplicity assuming only economic constraints, utility depends indirectly on prices and income; the indirect utility function is

$$U_t{}' = (P_{ESt},\ P_{xt},\ Y_t). \tag{3}$$

The fact that the indirect utility function represents the consumption of energy services and composite goods as a function of prices and income is particularly valuable for analyzing economic behaviour since neither utility nor preferences can be observed, whereas prices and income can. Thus, for example, the demand function for energy services is

$$ES_t = f\ (P_{ESt},\ P_{xt},\ Y_t). \tag{4}$$

By specifying the nature of the optimization problem, principally the constraints faced by consumers, and solving it, we can examine the way optimal choices vary with changing constraints. Tracing out these variations in consumption, the behavioural relationships between consumption and constraints, such as described in the energy service demand function, can be identified. Knowledge of the energy service demand function, for example, can then be used to assess the implications of changing economic activity and policies on fuel consumption. The effects of these changing constraints can be analyzed in the form of the own price elasticity of demand:

$$\varepsilon_{PESt} = (\partial ES_t/ES_t)/(\partial P_{ESt}/P_{ESt}), \quad (5)$$

the income elasticity of demand:

$$\eta_{Yt} = (\partial ES_t/ES_t)/(\partial Y_t/Y_t), \quad (6)$$

and the cross price elasticities:

$$\varepsilon_{Pxt} = (\partial ES_t/ES_t)/(\partial P_{xt}/P_{xt}). \quad (7)$$

This conventional model of consumer behavior outlines the demand for energy services. The supply of energy services is less conventional, however. Rooted in Becker's (1965) theory of the allocation of time, households produce their own services by combining labour, capital and energy. At a larger scale, firms similarly generally produce their own energy services.

Technological developments over the last two centuries have led to a move away from labour inputs and towards physical capital and energy sources, implying that many energy services, such as heating and lighting, are now provided with virtually no labour requirements. Car driving is the only energy service where substantial labour is required today – and suggests that the diffusion of driver-less cars, and the associated decline in the labour costs (in time), may have a significant impact on the consumption of passenger transport services. With this feature of the modern provision of most energy services, a simplified model of the household production would include only capital (k_t) and energy used (e_t).

The relationship depends on the efficiency of the technology (φ_t) – that is, the amount of energy services generated by a specified quantity of energy. As Hunt and Ryan (2015, p.274) explain: 'three particular characteristics of energy-using equipment are of relevance: much of it is longlived - once installed it may have a useful life that spans decades; much of it is fuel(s)-specific; and its technical characteristics tend to be fixed, requiring a given level of energy use per unit of services produced.' Given that this relationship is often a constant at any point in time, the provision of energy services can be determined by the energy consumption multiplied by the efficiency of the appliance:

$$ES_t = \varphi_{et} \cdot e_t. \quad (8)$$

Frondel *et al.* (2008) highlight that improvements in energy efficiency may be associated with higher capital costs. Therefore, ideally, the cost of producing energy services should take account of an estimate of these capital costs, as well as any time expenditure and the price of energy. However, a common assumption made is that the price of energy services is determined by the marginal cost of production, which is generally simplified to the price of energy (P_{et}) divided by the technical efficiency of the appliance being used (see Nordhaus 1997):

$$P_{ESt} = P_{et}/\varphi_{et}. \quad (9)$$

Feeding equation (8) and (9) into equation (5) and (6) enable energy economists to estimate the own-price and income elasticity of demand for energy services.

This section presented a simple model of the demand for energy services in which the consumer also produced the service. This implies that the same consumer and producer is actively involved in selecting the production technology and the energy sources. Recently, energy service companies (ESCOs) have begun to take on the responsibility for producing these services. While this can create a principal-agent problem, it is also seen as a way to stimulate energy efficiency improvements and reduce the energy efficiency gap (Gillingham and Palmer 2014). If these companies expand their role beyond the provision to firms, in the future, energy service markets may become more conventional, in the sense of the consumer and producer being different agents - for more on this particular development, see Groscurth *et al*. (1995), Olerup (1998), and Weiller and Pollitt (2013).

The opposite may be occurring in the market for power. While the final services associated with power (for example some heating, cooling, lighting, entertainment, computing, and so on) are provided by consumers, they have not produced their own power since the early days of electricity generation. However, since the introduction of micro-wind turbines and the drop in the price of solar panels, more households are becoming ‘prosumers’. That is, consumers are entering the market for the production of electricity (and, in some cases, selling their surplus, known as ‘net-metering’), and blurring the roles (Römer *et al*. 2012, Gillingham *et al*. 2016a). In other words, no single model can capture the different characteristics of all energy service consumption and provision. Nevertheless, the model presented above outlines a simple framework for thinking about the market for energy services.

4. The Direct Rebound Effect and the Price Elasticity of Demand for Energy Services

The main reason energy services have received a great deal of attention in the last decade is due to the debate about rebound effects. They refer to consumer, producer and market responses to energy efficiency improvements (Sorrell and Dimitropoulos 2008, Gillingham 2014). As mentioned before in the second section, they include a direct effect on the consumption of energy services and, thus, energy in response to a higher efficiency improvement and lower energy service price. There are also indirect effects on consumption behaviour related to complements and substitutes of the cheaper energy service (and associated energy source), to a probable increase in purchasing power (after taking account of the expenditure on the new efficient technology) and, therefore, to an increase in the consumption of other goods and services. Finally, macroeconomic rebound effects occur because the reduction in the price of energy services tends to boost the economy, stimulating further energy service and energy consumption. Thus, for instance, a 10% improvement in energy efficiency is unlikely to lead to a 10% saving in energy use. Instead, the sizes of the different and combined rebound effects are empirical questions (see, for instance, Sorrell 2007, Gillingham 2014).

Despite the recent interest, the origins of the debate on the size of the rebound effects began 150 years ago. In 1865, William Stanley Jevons published *The Coal Question*. As a leading political economist of the time, his book sought to shed light on the murky debates surrounding the potential exhaustion of coal resources that were central to Britain’s economic supremacy (Madureira 2012). One of his most controversial passages in the book warned that ‘. . ..it is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. . .. Every improvement of the engine when effected will only accelerate anew the consumption of coal. . .’ (1865).

The idea that energy efficiency improvements could lead to increases in energy consumption became known as Jevons' Paradox.

Jevons' Paradox (also now known as 'back-fire') is effectively an extreme case in which the rebound effects are sufficiently large that the efficiency improvements lead to increases in consumption. There is now a large theoretical literature supporting the existence of rebound effects which either implicitly or explicitly analyze the price elasticity of demand for energy services (Khazzoom 1980, Saunders 1992, Howarth 1997, Turner 2013, Gillingham and Chan 2015). However, empirical studies have tended to estimate much smaller rebound effects than Jevons (1865) anticipated. So, in the recent cases investigated, energy efficiency improvements led to savings in energy consumption, all other things being equal (Greening *et al*. 2000, Sorrell 2009). Thus, the inconsistency between Jevons' predictions and the recent empirical evidence suggests a paradox to the Jevons' Paradox.

Ultimately, measuring all the different (i.e. the direct, indirect and macroeconomic) rebound effects empirically at the same time is challenging (Gillingham 2014, Gillingham *et al*. 2016b). "Measuring the rebound effect is not an easy task, as it involves an estimation of the elasticity of the demand for a particular energy service with respect to energy efficiency. Instead of using this original definition, the majority of available studies have estimated the rebound effect using price elasticity, since data on energy efficiency has always been limited. In principle, rational consumers should respond in the same way to a decrease in energy prices as they do to an improvement in energy efficiency. This assumption, however, does not always hold up, as energy efficiency itself may be affected by changes in energy prices." (Sorrell 2007, p.4).

Nevertheless, the price elasticity of demand for energy services offers a means of estimating the direct rebound effect associated with efficiency improvements. As Hunt and Ryan (2015) explain, a number of early studies tried to include data on energy efficiency, either by using a deterministic or a stochastic trend (Beenstock and Willcocks 1981, Dimitropoulos *et al*. 2005) or by measuring energy efficiency directly or indirectly (Walker and Wirl 1993, Haas and Schipper 1998, Haas and Biermayr 2000, Fouquet and Pearson 2012, Fouquet 2014, Schleich *et al*. 2014). Earlier studies used the efficiency indicator as an additional explanatory variable. The more recent studies used these measures of efficiency to produce indicators of the price and consumption of energy services, which were used to estimate the price elasticity of demand for energy services.

Frondel *et al*. (2008) outline the assumptions made in efforts to estimate this price elasticity and direct rebound effects. Ideally, as explained in the third section, the price elasticity of demand for energy services can be estimated based on variations in the fixed costs of capital (and labour, associated with the capital investment), and the marginal costs of labour and energy services. However, this is rarely done or even possible, and a second-best is to estimate the elasticity based on variations in the marginal cost of energy services – as a number of the later studies above did. These studies ignore the endogeneity of the fixed costs of capital and the marginal cost of the energy services (as often more efficient equipment is more expensive). Finally, traditional studies have used the price elasticity of demand for energy as a proxy for energy services. Frondel *et al*. (2008) offer a rare study where all three methods were used on the same data, and so provide an opportunity to compare the results. The authors were surprised to find that the price elasticity estimates using the three different methods were similar, but the coefficients on other explanatory variables were substantially different. Thus, their study highlights the ambiguity of using only energy data given that consumer behaviour is driven by energy service demand.

Given the greater availability of data on transport use and energy consumption related to transport services, this service has been studied most extensively and has offered an opportunity to estimate actual price elasticities of energy services and measure the direct rebound effect. For instance, using a panel data set of US states between 1960 and 2004, Small and van der Dender (2007) estimated the long run price elasticity of demand for car transport to be −0.22 in the second half of the twentieth century, falling to −0.06 between 2001 and 2004. This implies that the direct rebound effect associated with a 10% efficiency improvement fell from 2.2% to 0.6%. Focusing on the more expensive and densely populated Great Britain, Stapleton *et al*. (2016) estimated the direct rebound effects for car transport over a similar time period to have ranged from 0.9% to 3.6%. The similar results for these two studies suggest that the widely different economic, political and behavioural characteristics may not have influenced greatly the sensitivity to changes in the price of car transport. On the other hand, Frondel *et al*. (2008) found substantially larger direct rebound effects for Germany – averaging 5.8% for a 10% efficiency improvement, which they explain as due to greater potential for substitution between modes of transport.

While some uncertainty about the scale of the direct rebound effect still remains, the growing number of studies are offering a range of values for the price elasticities of demand for various energy services. The first effort to summarise the finding was in Greening *et al*. (2000), indicating the range to be between 0 to −0.5, with a concentration in the range of −0.1 to −0.3. More recent efforts include Sorrell (2007), Azevedo (2014), Gillingham (2014), Gillingham *et al*. (2016b). The latter selected estimates from nine studies based on rigorous identification strategies, and argued that this lowers slightly the range (between −0.05 and −0.40). An early example of a randomized controlled trial (that is, an experiment set up purposefully to identify the causality) associated with energy efficiency improvements found that the price elasticity of demand for clothes washing was −0.06 (Davis 2008). Table 1 presents estimates for a few key energy services based on a general review of the literature. The broad conclusion is that direct rebound effects are an important issue, but they are unlikely to lead to Jevons' Paradox (or 'backfire') for households or personal transport in developed countries – without drawing a conclusion about the combined impact of direct, indirect and macroeconomic rebound effects – see Chitnis and Sorrell (2015) for an attempt to measure the combined effects.

Table 1 Estimates of Price Elasticities of Demand for Energy Services in Industrialised Economies.

Energy Service	Range of Estimates	Number of Studies
Space heating	−0.02 to −0.60	9
Space cooling	0.00 to −0.50	9
Water heating	−0.10 to −0.40	5
Lighting	−0.05 to −0.12	4
Transport (car)	−0.05 to −0.87	20

Source: Greening *et al*. (2000), Sorrell (2007), Sorrell and Dimitropoulos (2007), Azevedo (2014) Gillingham (2014) and Gillingham *et al*. (2016b).

As discussed earlier, modelling energy service demand is important for explaining past behaviour, forecasting future consumption and anticipating the impact of policies, including efforts to mitigate climate change and potentially begin the transition towards a low carbon energy sources (Pearson 2016). An important issue is the projection of dramatic increases in air conditioning demand and use over the next few decades, because of declining costs of air conditioning and electricity, improving energy efficiency, and rising incomes and temperatures in developing economies, with potential positive feedback loops (Davis and Gertler 2015). Other studies, such as Anandarajah *et al.* (2009), Anandarajah and Strachan (2010) and Fujimori *et al.* (2014), also explicitly model energy service demands for their long run scenarios – see Table 2, as an example. These studies show the relevance of the estimates for practical purposes. However, these are generally based on limited reviews of the evidence, and the assumptions made in the model tend to remain constant through time. Indeed, a key issue raised in the literature reviews, such as Azevedo (2014), Gillingham (2014) and Gillingham *et al.* (2016b), is about the 'external validity' of the studies. That is, it is unclear whether those estimates will be the same if different methods or models are used and in different time periods or contexts. Gillingham *et al.* (2016b) emphasize the empirical strategy used, and that these studies tend to assume other characteristics related to the energy source and technology remain unchanged and increases in energy efficiency are costless. Azevedo (2014) stresses that most studies are for the residential and transport sectors in developed economies, particularly in the US.

Table 2 Price Elasticities of United Kingdom Demand for Energy Services Used in Scenarios towards a Low Carbon Pathway.

Residential Sector Services	Estimates	'Service' Sector Services	Estimates	Transport Services	Estimates
Electrical appliances	−0.31	Electrical appliances	−0.32	Car	−0.54
Gas appliances	−0.33	Cooking	−0.23	Bus	−0.38
Space heating	−0.34	Space heating	−0.26	Rail (passenger)	−0.24
Water heating	−0.34	Water heating	−0.26	Rail (freight)	−0.24
		Lighting	−0.32	Goods Vehicles	−0.61
		Cooling	−0.32	Air travel	−0.38

Source: Adapted from Anandarajah *et al.* (2009).

In fact, over decades, price elasticities of demand for energy services appear to have changed considerably as per capita income has increased (Fouquet 2014). Estimates for residential heating, transport and lighting in the United Kingdom indicate that price elasticities peaked (at values of about −1.5) at levels of per capita income of between \$(2010) 4000 and \$(2010) 5000 (see Figure 1, bottom-half). That is, in Britain in the 1870s and 1880s, a 10% reduction in energy prices or a 10% improvement in energy efficiency (both reducing the price of energy services) increased transport and lighting use by around 15%. This implies that energy efficiency improvements associated with transport and lighting led to rises in energy consumption, as Jevons (1865) had predicted – offering an explanation for the paradox of Jevons' paradox. Furthermore, given that elasticities of demand for energy services change, efforts should be made to incorporate more realistic assumptions, including changes in energy service demand at different phases of economic development (as will be discussed in the next section), in long run scenarios of energy consumption and climate mitigation strategies, as prepared by the IPCC and the IEA.

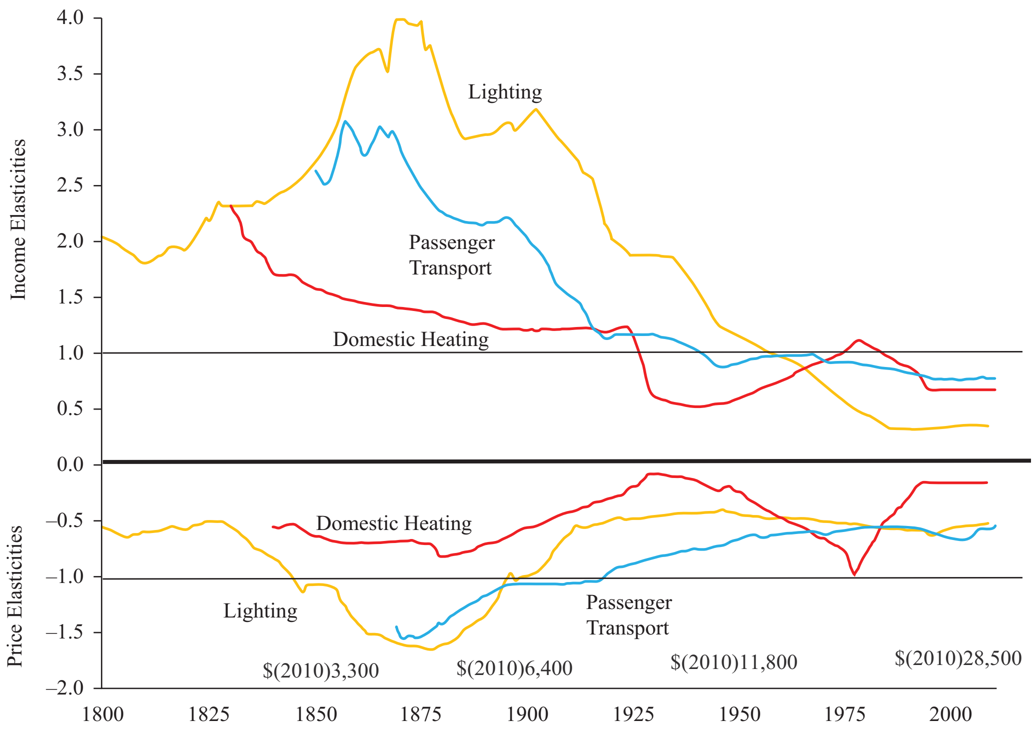

Figure 1 Income and Price Elasticities of Demand for Energy Services in the United Kingdom, 1800-2010 (*Source*: Fouquet (2014)).

5. Energy Services and Economic Development

Energy services have been increasingly linked to the debate about the role of energy access for economic and sustainable development. Energy services are seen as key to stimulating economic growth and development, and to ensuring improving living standards (Modi *et al*. 2006, AGECC 2010, UNDP 2011).

This then feeds through into greater consumption of energy services. Davis *et al*. (2014), in a rigorous analysis of Mexican households, find evidence of increased electricity consumption associated with air conditioning following improvements in the efficiency of equipment – in other words, there appear to be very large rebound effects. Sorrell (2007), for instance, argued that the direct rebound effect in developing countries may be larger since the demand for energy services may be far from saturated. In general, the hypothesis is, and the limited evidence suggests, that price and income elasticities of demand for energy services are greater in developing economies.

The main finding from Fouquet (2014) is that, as the United Kingdom's economy developed over the last two hundred years, trends in income elasticities followed an inverse U-shape curve (see Figure 1, top half). For instance, they reached a peak (about 2.3, 3.0 and 4.0 for income elasticities of demand for heating, transport and lighting, respectively) in the nineteenth century (at levels of GDP per capita below $(2010) 6000). After the peaks, there were, at first, rapid declines, then more gradual declines. Income elasticities took almost 100 years to reach unity (that is, a 10% increase in income led to a 10% rise in energy service consumption), in the mid-twentieth century, at between $(2010) 9–12,000 per capita. The results also indicate that income elasticities were significantly different from zero at high levels of per capita income in the twenty-first century, implying that current increases in income generate rises in energy service consumption (roughly, around 5% rises for a 10% increase in income). These rises feed through directly into greater energy consumption.

Developing economies may well also experience inverse U-shaped income elasticities, given saturation effects – that is, an additional unit of energy service generates less benefit or utility to the consumer. However, whether they peak and reach unit elasticity at similar levels of per capita GDP as the United Kingdom is unclear. Because today's developing economies have access to cheaper energy services (compared with the United Kingdom at the same level of income), they may experience earlier peaks (Fouquet 2014, van Benthem 2015).

These results offer the beginnings of a stylised fact about the relationship between elasticities of demand and economic development (Fouquet 2008, 2014). Sovacool (2011) describes the process as the 'energy service ladder'. That is, at very low levels of economic development, consumers focus on meeting basic needs, particularly food and cooking. As income grows, shelter and indoor climate become important – such as space and water heating, in temperate climates. As income rises further, these demands start to grow less proportionately than income (for example, income and price elasticities for heating fall). In turn, other demands are met, for instance, mobility, lighting and entertainment (implying rising income and price elasticities for transport and lighting demand). As income increases further, these income and price elasticities start to fall. Thus, pending confirmation from further studies, these general patterns could help to guide forecasts of energy service and, therefore, energy consumption. For example, while the IEA (2014) does incorporate saturation into its models (thus implying declining elasticity through time), they do not take account of the likelihood of peaking elasticities in developing economies.

As mentioned at the beginning of this section, while rising income drives up demand, rising consumption of energy services is likely to stimulate economic and social development – although it is hard to disentangle the direction of causality. This is made even harder by the idea that energy services can affect economic development through a number of different channels, and that these effects can change at different levels of economic development (Toman and Jemelkova 2003). Access to modern sources of energy for heating, cooking and power can bring about substantial health benefits, associated with reducing exposure to indoor air pollution or providing clean water and refrigeration, which can in turn yield improvements in productivity. Equally, they can enable a reallocation of household time (particularly for women) which can stimulate additional livelihood opportunities and improved education. Lighting may allow for greater flexibility in time allocation through the day and evening, as well as better conditions for education. Finally, lower transportation and communication costs may enable greater market size and access. In other words, although it can sometimes be hard to identify in the macroeconomic data, there appears to be a close relationship between electricity access and economic development (Toman and Jemelkova 2003, Modi *et al*. 2006, AGECC 2010, UNDP 2011).

Fuel poverty in general, and especially in developing economies, has major social consequences. 'Worldwide, approximately 3 billion people rely on traditional biomass for cooking and heating, and about 1.5 billion have no access to electricity. Up to a billion more have access only to unreliable electricity networks. The "energy-poor" suffer the health consequences of inefficient combustion of solid fuels in inadequately ventilated buildings, as well as the economic consequences of insufficient power for productive income-generating activities and for other basic services such as health and education. In particular, women and girls in the developing world are disproportionately affected in this regard.' AGECC (2010, p.7).

However, these health, education and welfare benefits tend to be ignored by policy-makers in developing economies (Reddy *et al*. 2009). Looking at experiences in Brazil, Bangladesh and South Africa, Winkler *et al*. (2011) stress that, despite access, affordability limits the ability to meet demands for specific energy services, and that policies addressing affordability appear to have more success in stimulating low energy-intensive services, such as lighting and entertainment, than high-intensive ones, such as cooking and cooling. Reddy (2015) discusses practical ways to make available affordable and reliable energy service to poor and often rural populations. One recommendation is to promote the development of small enterprises to provide relatively basic energy technologies. However, the implementation and scaling-up of the provision of energy supplies to meet service demands will need the close collaboration among numerous different stakeholders including households, local bodies, energy utilities, governments, entrepreneurs, research organisations, non-governmental organisations, community groups, financial institutions, and international agencies. Inevitably, coordination failures are a major barrier to enabling these multiple stakeholders to achieve the objectives in socially desirable ways.

Sovacool (2011) highlights how thinking about energy services emphasizes the role culture and social values play in influencing energy use. Indeed, the challenges of governing the development and expansion of energy markets will differ in each country partly because of the cultural aspects. For instance, an awareness of the value of travelling long distances to eat turkey with relatives in late November in the US or the value placed on well-ironed clothes on Sunday mornings in Uganda inform us about national patterns of energy service demands.

Providing an in-depth study of energy service behavior in Mexico, Cravioto *et al*. (2014) confirm that services are prioritised differently as incomes rise. Furthermore, they stress that the ability to measure the levels of satisfaction or utility generated may be easier by focusing on energy services. With this in mind, they find high levels of utility associated energy services provided to poor populations. However, they find that there is a relatively rapid declining marginal utility as energy service uses and incomes rise.

6. Concluding Discussion

This piece has sought to introduce the reader to the concept of energy services. This piece has shown why it is important to take account of energy service demand. Ignoring services, when analyzing energy markets, (especially when looking at the long run, where technical efficiencies of appliances and equipment can change considerably) is likely to lead to mis-estimation of price trends, mis-specfication of models, and biases in estimates.

The debate about the rebound effect, and identifying the actual energy savings resulting from efficiency improvements, has created a major increase in the interest in energy services. These empirical studies have shown that the non-zero price elasticity of demand implies that, after improving technical efficiency, consumers increase their consumption of energy services, but also generally reduce their energy consumption - though not by the same percentage as the efficiency improvements due to generally small, but non-negligible, rebound effects.

One of the historical barriers to using energy services in energy economics was that it 'distanced' the analysis from the influence of energy producers and suppliers. Particularly following the 1970s oil crises, and the growing role of OPEC, energy economics had tended to focus on energy supply and market structures (Fouquet 2013). Since the 1990s, environmental concerns have driven energy economists' research agendas, and issues related to the demand have become more important. This has meant a growing interest in incorporating energy end-use and service consumption.

As mentioned before, another limitation of this approach to understanding energy consumption behaviour (and a barrier to becoming the dominant modelling method) is the lack of data. Information about aggregate production and consumption by broad fuel categories is readily available. Detailed data on end-use energy consumption, on energy efficiency or on energy services require far more effort and expense for statistical agencies.

A conclusion of this paper is, therefore, that there is a need to coordinate the methodological development for the collection of data on energy end-use and energy services consumption and prices across national statistical agencies, and encourage the collection of this data. Once this data becomes readily available, over time and across countries and regions, energy economists will be able to model and analyze the drivers of energy demand more accurately. This is likely to improve the reliability of future energy consumption and carbon dioxide emission scenarios. Furthermore, this information will enable stakeholders to observe the success of policies aimed at providing cheaper energy services while reducing energy use.

With this in mind, another important recommendation is that governments should be developing policies that seek the decoupling of energy services from energy (Fouquet 2015). They ought to create packages of measures, including targeted energy efficiency investments, that encourage more service consumption (which is welfare-enhancing), and less energy use and carbon emission (which is welfare-reducing). In other words, they need to develop policies that focus explicitly on energy services. For instance, there is a long run trade-off between lower energy prices and higher investment in energy efficiency (Newell *et al.* 1999, Popp 2002). Here, it is proposed that governments should take account of the trade-offs between energy prices and efficiency investment in the long run and ideally find the optimal trade-off between them. Indeed, energy service policies should go beyond simply looking at balancing energy prices and technical efficiency. They should seek to integrate policies related to the pricing and provision of energy sources with those focusing on promoting energy efficiency improvements, including research, development and demonstration (R,D&D) and considerations about behavioural features to address the energy efficiency gap (Gillingham and Palmer 2014) – and not exclusively through efficiency standards, which have received considerable criticism (Anderson *et al.* 2011). Finally, the active development of energy service policies should seek a broader and more strategic approach to thermal comfort, mobility, illumination, entertainment and computing.

The need to integrate policies related to energy services is particularly important for developing economies. Indeed, Fouquet (2016) stresses that policies promoting cheap energy (through large energy infrastructure projects and fuel subsidies) tend to discourage energy efficiency investment and lock economies into energy-intensive consumption patterns for decades. In turn, this behaviour leaves these economies vulnerable to energy price shocks, inflation, trade balance deficits, political pressures from energy companies and environmental pollution. Thus, successful long run economic development depends partly on careful and balanced policies related to energy services.

Despite the statistical and institutional barriers, it is hoped that there is sufficient grounds to convince analysts and policy-makers of the value of focusing on energy services in analyzing energy markets and in formulating climate policy. For analysts, their models and data ought to be based on energy services. Policy-makers need to, first, set up the framework for collecting data on energy services, combining information about energy price and consumption with the technical efficiency of equipment, then use models and analysis to determine the appropriate strategies. This may help formulate policies that are more effective at achieving their economic, social and environmental objectives.

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See Also

- energy-GDP relationship;
- energy transitions;
- rebound effects

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