Energy Consumption in England & Wales

1560-2000

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Consiglio Nazionale delle Ricerche
Istituto di Studi sulle Società del Mediterraneo

Series on
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In copertina: Robert Boyle's first air-pump (engraving in New Experiments Physico-Mechanical), Oxford, 1660.

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Elaborazione ed impaginazione a cura di Antonio Marra

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FOREWORD

This paper belongs in a series providing statistical data on energy consumption in Europe on a country-by-country basis for the early modern and modern ages. The primary aim of the series and this book in particular is to set out the data and the methods by which it was obtained. Any interpretation of these quantitative results within a wider economic perspective can only be preliminary.

For ease of comparison the books will be laid out in a similar manner. After some introductory remarks on the purpose of this study and the definitions used therein, each carrier is examined individually and the statistical methods employed to create the series are explained. In the last chapter, the data is examined in a comparative perspective with other European experiences.

The statistical series are presented in the Appendix.

1. Traditional and modern energy sources

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1.1. The energy transition and the Industrial Revolution

The energy transition from traditional 'vegetable' or 'organic' energy sources to modern fossil carriers marked a strong discontinuity in the availability and use of energy, and has been one of the main foundations of modern economic growth. In the well-known formulation of Tony Wrigley, the economy was no longer dependent on the 'photosynthetic constraint' imposed by the ability of plants to convert annual insolation into forms of energy useful to humans, but could exploit the 'stored' energy amassed over millions of years in the form of coal and oil. In Wrigley's characterisation of transition, this is the very definition of the 'Industrial Revolution', a transition at least as profound as that from nomadic pastoralism to settled agriculture in the Neolitihic.[1]

Yet our knowledge of this major transformation is far from clear. Although Britain, even more than other European countries, has been blessed with major and high quality studies of the coal industry, the use of 'traditional' energy carriers that predated the dominance of fossil fuels is very poorly researched. Until very recently the available statistical information on energy in European historical accounting only concerned 'modern' sources. As coal accounted for around 95 percent of all energy consumption in Britain by the beginning of the 20th century, official energy statistics on energy carriers already provide us with an accu-

[1] Wrigley (1988); Wrigley (2003); also Sieferle (2001).

rate picture of subsequent developments. However, for earlier periods the data on fossil fuels provides us with only one-half of the equation when it comes to understanding the nature of the transition itself. Thus most currently available energy statistics can enlighten us as to when the steamship was adopted, but not when the sailing ship declined; when coal entered domestic hearths and industrial processes, but not the extent of wood or peat burning before; when steam power began to underpin the mechanization of manufacturing, but not the degree to which earlier industrial development had depended on harnessing water or wind power.

The energy consumption of those processes that provided energy from organic matter cannot be overlooked if we want to gain a more accurate view of these past economies. The imperative to achieve this is all the greater in the case of England, because along with the Netherlands it appears to have achieved an exceptional level of development by the late 18th century, even before the substantial mechanization of manufacturing processes. Indeed, in the view of economic historians working in the past two decades, growth during the 'classic' Industrial Revolution itself has come to be understood as a gradual process, and one not strongly orientated towards heroic achievements in key sectors. The dependency of overall growth on mechanization and the application of heat to provide motive power via the steam engine is no longer the *sine qua non* of modern growth. Thus a partial approach to the Industrial Revolution capable of clarifying only one side of the coin (that of fossil fuel consumption), would bias our perception of recent economic transformations. If we include traditional sources in our investigations, the interplay between the economy and energy, and the role of technology and infrastructure, can be analysed with much greater precision.

The purpose of the present research is to quantify the consumption of all energy carriers over the entire period of the British energy transition up until the present day. Once the possibility of dynamic change was created in the balance of different energy carriers in the economy, processes of development and substitution have occurred almost continuously. Unusually however Britain's transition is not a result of changes in (at the very most) the past two centuries, but must be traced right back to the middle of the 16th century. It is well known that coal had become the provider of the largest share of thermal energy by 1700, but in fact its dominance was established rather earlier.

This work is part of a series comparative studies of the issues outlined above across several European countries. It thus owes a great debt of inspiration, and in the later comparative sections, for data, to my colleagues in this endeavour. This work would certainly not have been possible without the lengthy discussions and exchange of information I have enjoyed in recent years with: Ben Gales, Sofia Henriques, Astrid Kander, Fridolin Krausmann, Magnus Lindmark, Paolo Malanima, Mar del Rubio, Heinz Schandl, Lennart Schön, Eric Tello, and Tony Wrigley. I have also benefited greatly from conversations and references from Leigh Shaw-Taylor and Simon Szreter. Out of this list two individuals should be singled out. Firstly, Astrid Kander, for her groundbreaking study of Swedish energy consumption, and development of methods for studying and visually presenting the data. Secondly, Paolo Malanima, who has generously encouraged work in these fields for a number of years, and whose first volume in this series of books on the energy consumption of different countries provided a model on which this work is at times very closely based.

1.2 Studies of the British energy economy

There have been numerous studies of the British energy economy over the past two centuries, and thus we are fortunate to have a rich tradition of empirical work on which to draw. However, nearly all of these studies have been focussed on the use of particular energy carriers (such as coal or electricity), rather than long-term developments in the aggregate total of consumption and the energy carrier mix. As different energy carriers have very different levels of efficiency (the efficiency of processes of combustion, for example, tend to be rather low in comparison to modern water turbines), the energy carrier mix has considerable implications for the overall energy efficiency of the economy. Studies of 'traditional' carriers have been rather more limited in extent and scope.

However, studies of the long-term aggregate energy history of the United Kingdom have been attempted within the field of energy economics. First among these was the work of Humphrey and Stanislaw, published in 1979 and drawing on a mix of secondary works and recent national statistics. Their analysis reached back to 1700 and sought to explain shifts in an 'energy coefficient', the ratio between the rate of change in aggregate energy consumption and the rate of change in output growth, and thus a kind of measure of changes in energy intensity (the energy required to produce each unit of income). While they discussed the possible power output of water- and windmills, these were not factored into their aggregate analysis that simply rested on fossil fuels and modern hydropower.[2] A similar approach has been taken more recently by Fouquet and Pearson, using only 'modern carriers' for their aggregate analyses and figures, but providing a literature survey of developments in energy use over the last millennium.[3]

Discussion of energy transitions in Britain, and especially during the Industrial Revolution, have largely revolved around debates on what prompts technological change in

[2] Humphrey and Stanislaw (1979).

[3] Fouquet and Pearson (1998).

manufacturing industry. As early as 1932 John Nef argued for a national 16th century 'timber famine' that provided an impetus for the transition to coal use.[4] This has become a frequently employed textbook example (occasionally linked with deforestation caused by shipbuilding). There has been, however, an almost equally long counter-argument that wood shortages were 'essentially local problems', derived largely from the work of Flinn and Hammersley on the iron industry, though charcoal iron production consumed only a small proportion of the English wood supply. Scepticism about any widespread 'timber famine' has recently been restated on a Europe-wide level by Bob Allen in a study utilizing price data.[5] However, the 1980s saw a strong re-assertion of the 'famine' view, shifted to the middle of the 17th century, in the work of Brinley Thomas. Some recent studies of the coal industry have also given cautious credence to the notion of wood shortages necessitating energy carrier and technical change.[6]

A further debate has developed around technical change in the 'classic' period of the Industrial Revolution, and especially over the shift from water-based motive power to the use of steam. Phyllis Deane hypothesised that developments in manufacturing technology can be linked directly to a need to overcome an 'energy shortage' deriving from both wood shortage and industrial plant saturating all of the sites that could reasonably be used for water power in the most intensely industrialized regions. More recent studies however have tended to emphasise the persistent importance of waterpower in manufacturing until the second half of the 19th century, while Gordon has argued that England remained far from exploiting all the possibilities of water

[4] Nef (1932), pp. 158-176; also Wilkinson (1988), p. 80.
[5] Flinn (1959); Flinn (1978); Hammersley (1973); Allen (2003).
[6] Hatcher (1993), p. 7; Thomas (1986).

power.[7] Other studies in the history of technology have in turn suggested that the contribution to economic growth of new general purpose technology such as the steam engine was in any case quite small, even in its heyday.[8] What much of this debate has lacked is the wider context of total energy consumption. This work seeks to place these debates on a more secure empirical footing.

Inevitably much of this study rests on assessments of secondary literature, and interpolation from a variety of benchmarks where information is available for particular energy carriers. Many areas of debate which have given rise to a lengthy literature are touched upon that cannot be given extensive consideration in this context. While it is hoped that this work may carry some of those debates forward it seeks above all to provide a wider context in which new research can serve to refine the data and our understanding of it.

1.3. Definitions

We must be clear in our definitions from the beginning. This study will seek to include in its investigation every form of energy *exploited directly* by human beings yesterday and today. The objective is to reconstruct the input into the economic system of all primary sources of energy whose exploitation carries some cost for humans. Thus the effect of solar radiation in heating the atmosphere to permit the conditions for life, for example, is not included, as this imposes no costs on humanity.

This energy carriers analysed comprise the following sources:

[7] Kanefsky (1979); Greenberg (1982); Gordon (1983).
[8] Crafts (2003a); Crafts (2003b), p. 19.

1. *Food for human beings;*
2. *Firewood;*
3. *Fodder for working animals;*
4. *Wind;*
5. *Water;*
6. *Fossil fuel sources;*
7. *Primary electricity.*

Military energy consumption for weapons, although important, is not included in modern energy balances. Bombing releases vast amounts of energy but is hard to incorporate into analyses of economic growth (is bombing your neighbours a contribution to economic development?) It is therefore disregarded in these calculations.

The following time series only take into account energy sources that have a cost (not just in monetary terms) for human beings. Thus, the annual production of biomass not collected by human beings in a forest, or the grass of a meadow not consumed by the animals exploited by human beings for food or work, is not regarded as part of the energy balance. In contrast, the grass eaten by an ox or cow used by peasants does become part of human energy consumption, either as fuel for the animal, if it is used for work, or as food, if its dairy products or meat are eaten. I have also included wind and flowing water in my series, since, although free, their exploitation is possible only by utilizing a piece of capital equipment, such as a ship or mill, which has a cost.

1.4. Primary sources

In the following time series, to avoid duplications - always a risk in reconstructions of this kind - only *primary energy* will be considered. By primary energy, we mean a source that has become useful for human beings, and is harnessed, at a cost, to be converted into heat or mechanical work. Sources of energy that have already been processed (inevitably involving losses) are not included in the accounting that seeks to include only *inputs* into the system and thus avoid double counting. Thus, charcoal is a *secondary source* and as such excluded, whereas we include the firewood used to produce charcoal. The calories of charcoal are merely a transformation of the calories the firewood already possessed, with some losses due to the process of combustion. For the same reason, electricity produced by means of coal and oil power plants is not included in the time series, since these series already include coal and oil.

The statistics that this work presents will detail the input of energy into the economic system, regardless of how efficiently that energy is exploited. Thus, I will estimate the calories consumed by human beings as food; the feed consumed by working animals; the flow of water driving a mill's wheel or a modern turbine. Much of these calories will not actually be employed to do useful work that generates economic value. A large part modern energy history concerns improvements in the efficiency of energy use. For example, processes of combustion are generally more inefficient than mechanical processes, and machines powered by electricity do not experience wastage from power that is not being usefully employed, as the machines only employ electricity when they are actually working (though computers and televisions left on standby represent an exception to this trend). Humans and animals, however, must be kept alive for long periods when they are not actually working, and so the ratio of economically *useful* energy to energy inputs may be low (although one may make the argument that the energy inputs to people to enable them to be consumers are equally essential for economic growth).

2. Energy consumption

2. Energy consumption

2.1. Traditional sources

Statistical information on commercial, modern energy sources is available for England and Wales as for many other modern countries.[1] Official statistics on production began to be collected in the mid-19th century, but for earlier periods historians have provided plausible estimates of coal production reaching back to the second half of the 16th century.[2] Time series of traditional sources, however, need to be put together 'from scratch' (or at least from secondary sources) by a process of data collection and estimation.

It is difficult to derive time series of traditional fuels. Since it is impossible to gather information on oil for lamps and wax for candles, and since, everything considered, their contribution to the energy budget was negligible, the only 'organic' fuel that has been taken into account is firewood. There would also have been a small degree of firing derived from other plant matter such as straw, bracken, gorse and furze, in addition to the use on occasion of dried dung.[3] But as firewood was overwhelmingly the most important source of 'traditional' thermal energy, this carrier will receive the most attention here.

[1] There are series of national statistics that may be obtained from the British Parliamentary Papers, and Annual Abstract of Statistics. Very useful compilations have been produced by Brian Mitchell. Mitchell (1962); Mitchell (1992).

[2] Hatcher (1993), Flinn (1985).

[3] Warde (2005).

However, one source that I have not sought to quantify may have been of local importance: turf or peat. This was a major source of fuel in late medieval and early modern times, even for urban centres, and especially in the north.[4] A survey for the Commissioners of Land Revenue in 1791 recorded that peat was still a significant domestic fuel in the counties of Derbyshire, Devon and Pembrokeshire.[5] It would seem highly likely that turf was important enough a fuel to have registered as a small share of total energy consumption in the 16th century and perhaps later, though probably not amounting to much more than 1-2 percent of total energy consumption.

The problem of quantifying water and wind energy is perhaps the most difficult of all, both in establishing the number of units (mills, sails, etc.) involved, their power, the capacity actually employed, and their efficiency. Sometimes, in calculations about water- and wind-energy consumption, analysts have employed the method of estimating indirectly the energy actually consumed, accounting for it as if it were produced by means of modern energy carriers. This means that the water-energy consumption of a traditional mill is supposed to be equal, for the same volume of production, to that of a modern mill driven by fossil fuels or electricity. Actually, since combustion inevitably entails heavy losses and in energetic terms is an inefficient conversion of energy into applied power, this method yields estimates of energy consumption that are much too high; 5-6 times higher than those yielded by a *direct* estimation of water- and wind-energy consumption. It is the latter, direct method, that is, employed below.[6]

[4] Hatcher (1993), pp. 117, 124-5.
[5] HCJ (1792).
[6] See Malanima (2006), p. 23.

2.2. Food

Food for humans is never included in current energy statistics, and would make up a vanishingly small part of the modern total. However this is not the case in pre-industrial economies, where direct human energy inputs were far more important in the provision of motive power. Indeed, it is not an economically trivial issue, even in the industrial age. Fogel has argued that a significant proportion of British economic growth between 1790 and 1980, as much as a half, may have been permitted by improved diet leading to greater work intensity.[7] For the purposes of this analysis, we are concerned with the *whole* population, even though a high proportion may not be economically active. Children, the unemployed, the infirm or the elderly do not generally contribute to national income at any given moment in time. However, they occupy positions in the economy necessary for it to function (children might be considered as analogous to foals in their relationship with working horses, for example, and even the unemployed might be considered analogous for these purposes to sick livestock or machines in need of repair. It is an indication of the 'energy inefficiency' of organic life-forms that they must consume energy even when they are not functioning at an optimum level!). Before the 20th century it is likely that the elderly in many cases remained economically active in some form until near death. For similar reasons I have not disaggregated working from non-working hours in calculating energy consumption, because it is absolutely economically necessary that the labour force receives nutrition to keep it alive between working hours. This also helps us avoid the pitfall of not valuing essential work such as domestic childcare that is not included in national income statistics. This of course raises the possibility that shifts in 'energy intensity' (GDP/energy

[7] Fogel (1994), pp. 383, 388.

consumption) in an economy where human energy consumption is a significant proportion of the total may be to do with the manner in which National Income statistics value economic activity. However, it is also true that the level of wages *as a whole* must incorporate payments to those who do not offer labour that statisticians consider productive; otherwise that officially 'non-productive' sector of the population would be unable to survive.

One approach to human energy consumption has simply been to hold an average figure constant over time. This is in fact a dubious proposition, as even within quite short periods, food consumption levels can shift markedly. We should note that a fall in working hours, holding calorific consumption equal, would automatically make human energy consumption more inefficient. However, it seems likely that in the long-term the nature of work determines the amount of calories consumed, rather than activity during leisure hours. Indeed, in industrialising economies, the fact that working hours increased, thus greatly improving the efficiency of humans as energy converters was an important reason for rises in labour productivity measured by the day or year, and increasing specialisation of labour. (Although workers may also need to consume more calories, these would probably increase at a slower rate than hours worked, because of the high proportion of calorie intake required simply to support basic metabolic function). Clearly, energy consumption by humans can vary over time, and also varies according to demographic structure (young and old generally consuming less than young and middle-aged adults[8]) and occupation (heavy labourers consuming as much as twice as much as office workers).

[8] This is a common assumption, though the evidence of the British Food Survey from the 1990s and 2000s is not clear-cut, especially in regard to the elderly consuming less.

From the 1940s the National Food Survey provides data on calorific intake in the United Kingdom. Whilst we know that there are some regional dietary divergences it seems reasonable to take these figures as being representative for England & Wales. Before this date, we may take either a demand or supply side approach. The first estimates the calorific intake of different sections of the populace and weights these according to occupational and demographic structure. The supply side, by contrast, estimates the total agricultural output (accounting for trade) that is directed to human food consumption, and divides this by the population to arrive at a per capita figure.[9] More recently, modern FAO (The United Nations Food and Agriculture Organisation) statistics on per capita food consumption take this supply-side approach, and thus do not account for a very considerable amount of wastage, and significantly overestimate consumption levels.

Given the long time-span and varied data, this study has employed different, and perhaps not entirely consistent methods. Estimates for 1600 and 1700 are taken from the very careful work of Muldrew, based on a mixture of demand-and supply-side observations.[10] As Muldrew provides data on the food intake of men, women, and children, the trends in average consumption are mapped over time through a combination of linear interpolation between benchmark dates, and adjustments reflecting the age and

[9] Unfortunately, this figure is very difficult to derive, and estimates of supply (and indeed consumption) are frequently based on monetary evaluations of output, further modelled according to prices and wages with elasticity assumptions, methods that cannot determine calorific content. For example, Feinstein (1998), Boulton (2000), Jackson (1985). This study makes use of calculations of net output from Wrigley (2006) and Holderness (1989).

[10] I am very grateful to Craig Muldrew for making unpublished research available to me.

sex structure of the population.[11] A further benchmark date has been established for cereal consumption at 1800 by the work of Wrigley, Overton, and Campbell.[12] To this I have added estimates for the consumption of meat and dairy products derived from budget models developed by Feinstein and Allen, and separate estimates of sugar consumption.[13] In 1800 average calorific consumption was possibly as much as 2,900 Kcal per person, a level only briefly surpassed in the 20th century. According to Muldrew, per capita consumption was it its peak around 1700 at just under 3,300 Kcal, an age of both plentiful food, still widespread manual labour, and a low dependency ratio. A century earlier levels were lower, roughly equal to those pertaining in 1800.[14]

A further benchmark is provided by estimation of the average daily consumption of the *working population* re-

[11] Wrigley & Schofield (1981).

[12] Wrigley (2006), p. 458; Overton & Campbell (1999). These estimates from the production side of over 10 bushels being consumed per capita are certainly higher than the more usual 6-8. Collins (1975), p. 97.

[13] See note 14. The 1800 figure is derived from estimates of cereal production consumed as food supplied by Wrigley (and based on Overton and Campbell), where per capita consumption was equivalent to around 10 bushels of wheat; adding on per capita sugar consumption figures from the 1790s and an estimate that 20 percent of the calories came from meat, dairy products, eggs and vegetables. The figures for working class diets provided by Allen and Feinstein suggest a slightly lower proportion for these last products, but we must also account for the more varied diets of the middle class and wealthy. The small contribution of sugar to an already high calorific intake suggests that the expansion of colonial sugar imports should be seen as a bonus to the British diet, rather than an *essential* energy reserve that fuelled industrialisation and 'divergence'. Wrigley (2006), p. 440; Allen (2001), p. 421; Feinstein (1998), p. 635.

[14] The dependency ratio may be a critical figure, as Oddy found that his estimates of per capita calorific intake derived from Davies' estimates of the diets of the poor in the 1790s were inversely correlated with household size. Armstrong (1989), p. 738.

corded in the 1851 census.[15] Under 15s have been added to the 1851 consumption estimate with the assumption that the ratio of their average consumption to adult consumption was also steady over time.[16] Trends between the benchmark dates are derived from independent interpolation of consumption levels by adult men; adult women; and children respectively, with the totals summed for each year.[17] Average consumption in 1851 is estimated to have been around 2,400 Kcal.[18] There is a danger of circularity in such an approach; estimates of how much food would be required to do certain types of labour are then attached to occupational structure, when it is possible that labour per-

[15] It is interesting to note here that the benchmark calculations of 1700 and 1851 give a very similar ratio between the average food consumption of men and women, although each is calculated on a completely different basis.

[16] Although changing contributions to household income from child labour should perhaps make us cautious on this count.

[17] Wrigley & Schofield (1981); Mitchell (1962), p. 12.

[18] This is based on allotting notional daily consumption figures to 93 different occupational categories from the census, on the basis of estimates of daily calorific intake for specific tasks provided by Roine. It should be noted that these were developed for male individuals who were probably taller than heights prevailing in 1851. Women were assumed to consume 73 percent of the intake of men. The result is of course senstitive to the system of attributing daily intakes; for example, if the daily intake of women in the category 'no or uncertain occupation', of which there were 2.65 million, were raised from 1752 to 2,190 Kcal on the assumption that they may have performed arduous domestic tasks, total average daily consumption would rise to 2,650 Kcal per day. A 300 day working year is assumed, with an average male consumption of 2,400 Kcal on holidays. It is intriguing to note that this model suggests that there would be a significant rise in average daily consumption, of the order of several hundred calories, if the agricultural sector was raised roughly to the levels that pertained in 1800. This suggests that a larger part of the 'British food puzzle' outlined by Clark, Huberman and Lindert may be resolved by shifts in occupational structure than they suspected. Occupational data provided by Leigh Shaw-Taylor from the 1851 census; Lindmark (2007); Clark, Huberman, Lindert (1995), p. 225.

formance was low because people did not eat a sufficient amount of food to effectively labour. This approach assumes that by and large, people did eat enough; we are also seeking the *average* calorific intake, and thus for the purposes of this analysis its actual distribution is unimportant. Oddy has provided a rather lower estimate for this period of British energy intake at 2–2,300 Kcal per day per head; thus the fall from 18th century norms may have been more precipitate. The estimates of net output of cereals, meat and dairy products provided by Holderness, and trade statistics, do not suggest that per capita food availability was much lower in 1850 than in 1800.[19]

The early 19th century trend would also seem to contradict the anthropometric studies of Floud, Wachter and Gregory; height data suggests nutrition was significantly worse in the 18th century than at most later dates, that it must have improved after the Napoleonic wars, and deteriorated mid-century before steady improvement after around 1870.[20] Of course, height is a function of *childhood* nutrition, and there is no necessity that *average* nutrition would follow the same trend, although it calls into question the assumption made here that child nutrition stood in a constant relation to adult nutrition. However, there are two further factors to consider. Growth is related to work intensity as well as nutrition, and it may be that children worked rather harder in the 18th century than they have been given credit for, as studies of child labour have focused on a later date. Equally, adult nutrition is more closely related to the *work* that the body does, rather than its size. While at later

[19] Oddy (2003), p. 4; on distributional issues, see Oddy (2003), pp. 53-4, 603, 66-7; Holderness (1989), pp. 134-170; John (1989), pp. 1012-7; Burnett (1979), pp. 7, 9 & 13. I have assumed that 87 percent of imports to Great Britain were consumed in England and Wales. See also Clark, Huberman & Lindert (1995).

[20] Floud, Wachter & Gregory (1990), pp. 136-154, 319; also Floud and Harris (1997).

dates consumption was correlated with income levels, we cannot assume that this was always the case.[21] Hence a population of adults who had been malnourished as children might still eat heartily if they laboured hard in adult life; indeed, this might be a conscious family strategy.[22] The link between anthropometric data and nutrition, especially bare calorific intake, remains controversial.

The likely cause of much of the decline posited here between 1800 and 1851 is a shift out of agricultural labour to less onerous activities.[23] Indeed, this may have been compounded by a gradual deterioration in the urban diet, though this itself may have reflected changing physical demands. Although the *rural* heights identified by Floud et al were relatively low, the heights of *agricultural workers* were high, which suggests that 18th century military recruitment was disproportionately from the non-agricultural rural population.[24] This may also have been true for the period 1700-1800. These figures are much higher than those proposed by Fogel, who proposed an average consumption c.1790 set at 2,060 Kcal, with adult males consuming 2,700 Kcal.[25] The main reason for the divergence is that Fogel employed estimates that seem to have greatly understated the amount of cereals available for human consumption. It

[21] Harris (1998), p. 416.

[22] Given this is is questionable whether the evidence of inequitable distribution of food in the household should be interpretated as discrimination against women and children or allocation on the basis of need. Harris (1998), p. 418; Johnson and Nicholas (1997), pp. 214-5.

[23] Although the modelling of 1851 consumption levels employed here used modern estimates of calorific need for different work tasks, contemporary household budgetary evidence does indeed suggest that agricultural labourers consumed more than those in urbanised and sedentary occupations. Armstrong (1989), pp. 738-740. Clark, Huberman and Lindert (1995), p. 227.

[24] Indeed, their data suggests as much. Floud, Wachter & Gregory (1990), pp. 95-6, 109, 200-7, 220-1, 224.

[25] Fogel (1994), p. 342.

may be that, as we must in the late 20th century, we should actually account for a large amount of wastage in a land of relative plenty, meaning that real consumption levels would have been lower.

From the late 1880s household surveys provide extensive information on eating habits.[26] The surveys suggest that *household* diet (rather than the diet of individual household members) was strongly influenced by income, rather than occupation. The range of estimates for particular income groups is not large, and thus arriving at a national estimate is largely a question of how we weight these groups. Although incomes were rising the beneficial nutritional effects, especially with falls in internationally-traded food prices after 1870, may have been offset in terms of energy intake by increasing sedenterization of the workforce.[27]

Oddy suggests that at the end of the 19th century, survey data indicates a per capita daily consumption of around 2,100 Kcal. If anything this may have been optimistic. A very rough test of calorific intake is to take the daily figures provided by Oddy ranked by income for the 1890s and 1904 and attach these to the male occupational structure recorded in the census, with an estimate of the average wage level in each sector. The 1904 survey data is likely to give a figure higher than the real national average because urban diets of full-time workers appear to have been better than their rural, and of course urban non-working counterparts; and the dataset does not differentiate the diet at lower wage levels (under 25s per week). This approach can only be rough and ready but suggests that 2,000 Kcal is a more likely average for the years around 1900, especially as those

[26] Oddy (2003), pp. 237-44.
[27] Oddy (2003), p. 28.

in female-headed households probably ate a little less than the average in male-headed households.[28]

However, rising incomes before the First World War may have seen dietary improvements, as it is clear that general nutritional standards declined with price rises, supply problems, and economy campaigns *during* the war. Yet when rationing was finally introduced in 1918, the energy provided amounted to some 2,350 Kcal per head; about the same, though of course with a far less varied diet, as that consumed in 2004.[29] Food surveys conducted in the 1930s indicate that this upward trend continued. Despite rather uneven sampling in terms of both region and income group, it would seem unlikely that per capita calorific consumption was below 2,500 Kcal: in other words, a little under that maintained by rationing during the Second World War.[30]

At the beginning of the twenty-first century, average daily calorific intake was around 2,380 Kcal, having fallen from a likely peak of over 3,000 Kcal in the late 1950s. The data provided by the National Food Survey provides only household data from 1940, and excludes the consumption of alcoholic drinks before 2001. Before 1995 food and beverages consumed outside of the home were also not accounted for, and thus the results must be adjusted. In 1974 household consumption of alcoholic drinks added a further 9 percent to average calorific intake and this has been used to inflate the figures between 1940 and 2004. Extra-household consumption inflated calorific intake (including alcoholic drinks) by 12 percent in 2000 and this is assumed to have risen from 5 percent in 1940. Energy derived from *food* consumption within the household had fallen to as lit-

[28] Oddy (2003), pp. 63-69. For wage data, Boyer (2003), p. 286; occupational data, Mitchell (1962), p. 62.

[29] Oddy (2003), pp. 89-91.

[30] Oddy (2003), pp. 127-9.

tle as 1,750 Kcal by 2000.[31] A small part of the rise in the average between the middle of the nineteenth and the middle of the 20th century probably comes from a changing demographic structure with a decreasing proportion of young children (36 percent of the population were under 15 in 1851, but only 24 percent by 1931).

Table 1. *Per capita* Food Consumption

Year	Kcal
1600	2,750
1700	3,300
1800	2,900
1851	2,400
1900	2,000
1918	2,350
1940	2,700
1956	3,100
1974	2,750
2004	2,380

Sources: see text.

2.3. Firewood

There are no wide-ranging surveys of household and industrial consumption of firewood, and thus estimates from the demand side can only be built up from very scattered evidence from account books and commentary. As it is apparent that the consumption of different households could be quite divergent, and equally that there were probably regional variations in demand, it is nigh on impossible to come to a definitive national figure for consumption. Indeed, as insufficient research has yet been done on the timing and geography of the transition to fossil fuel consump-

[31] DEFRA, (2007); DEFRA (2000). The datasets are available from http://statistics.defra.gov.uk/esg/publications/efs/default.asp; Oddy (2003), p. 219.

tion, there are only a very few benchmark dates at which it is possible to hazard a guess as to the proportion of the national population, and industrial production, that relied on each energy carrier for their thermal energy supply.

Here, wood consumption will be estimated from the supply side, using data assembled by landscape historians and historical ecologists on the area of the country that could be reasonably supposed to have supplied firewood (from woodland, wood pasture, standing trees, and hedgerows). This method remains rudimentary but is able to put a reasonable *ceiling* on the possible level of wood consumption, if we assume that the large proportion of each year's wood production was burned. The process involves some estimation of the proportion of harvested wood that was not used for combustion, but construction and packaging, which should be deducted to provide a maximum figure for annual firewood consumption. In turn, these supply-side estimates can be placed against likely demand to see if we can arrive at plausible, mutually consistent estimates of the amount of energy provided by wood. This method equally assumes that wood-cutting for fuel was not destructive and did not lead to rapid deforestation. Contemporary and theoretical evidence points against this. Indeed, 17th century commentators were in agreement that demand for fuelwood tended to provide a guarantee of sustainable management, and that it was clearance for farming that posed the greatest threat to the extent of the forests.[32]

The primary source of wood output, unsurprisingly, was woodland; that is, areas of relatively dense tree cover. Today approximately 1.4 million hectares of England and Wales are classified as woodland, possibly a larger area than for the past thousand years. Forestry statistics are intermittently available throughout the 20th century, but no systematic national surveys exist prior to 1895. Rackham and Collins

[32] For example Yarranton (1677), pp. 57-60.

provide estimates for the beginning and the end of the 17th century, but for intermediary dates interpolation must be used.[33] Fortunately, while woodland steadily declined in area between 1550 up until the 1920s, the absolute extent of deforestation was not that great, falling from around 900,000 hectares to 769,000 hectares by 1905,[34] and then rather rapidly to 660,000 hectares in 1924. This means the margin for error in calculating changing firewood supply from this source is unlikely to be very large in any sub-period. It is worth noting that even at its greatest output in the mid-18th century, the charcoal iron industry did not consume more than a fifth of the production of English and Welsh woodlands.

What was the yield of this woodland? Today, the annual increment in broadleaf forest in England is 3.3 cubic metres per hectare. Collins estimates that early modern yields were around 3.6 cubic metres of stacked wood per hectare, or 2.25 metres cubed of solid cordwood.[35] According to estimates made in the Forest of Dean in the 1690s, coppiced woodland yielded about 4 cubic metres per hectare.[36] Coppicing was the main form of woodland management and before the later 18th century as much as 90 percent of woodland output may have been cordwood produced by coppicing and consumed as fuel.[37] However, 'woodland' spaces

[33] Rackham (1990), pp. 88-9; Rackham (2006), p. 131; Collins (1996), p. 1100.

[34] Collins (1989), p. 492.

[35] Collins (1996), p. 1099. He gives a higher figure elsewhere for coppiced woodland. Collins (1989), p. 491.

[36] House of Commons Journal (1788), p. 574.

[37] Collins estimates however by the early nineteenth century that as little as 600,000 acres was coppiced, which would greatly reduce the firewood supply. However this distribution may be accounted for by the persistance and growth of underwood trades and firewood use in the south-east and Midlands, whilst coal had come to dominate the fuel economy elsewhere and agricultural demand for underwood was lower.

like Dean also had extensive glades and areas for grazing, so those areas deliberately and systematically harvested for wood probably had unusually high yields. Here we take a relatively high estimate of productivity as the modern 3.3 cubic metres per hectare, and consider 90 percent of that wood to have been used for fuel. This would make for a supply of around 2.7 million cubic metres in 1550, or not far off one cubic metre per person per year from woodland, even at an assumed high rate of exploitation. By 1850 the supply would have fallen to 2.3 million cubic metres, but in reality was probably somewhat lower. Over 8 percent of production, for example, was used for agricultural poles and packaging alone at this time.[38]

Of course, anyone familiar with the English landscape knows that very large numbers of trees stand outside of woodland. There is unfortunately little information about the fuel derived from this source, but as with so many issues, a trail has been blazed by the historical ecologist Oliver Rackham. He reckons the highpoint of standing trees in the landscape to have come around 1950, with 60 million being present, a figure Rackham likens to roughly the equivalent of half of woodland trees (though the high stocking rate of woodland this implies must be a result of the 20th century obsession with conifer plantations). Rackham estimates that roughly the same number were present in 1750, but the process of enclosure, agricultural change, and possibly exploitation of standing timber for construction, had drastically reduced the figure to as little as 23 mil-

Collins (1989), pp. 491-3. Gregory King estimated that only half the *value* of wood cut went into firing. Hatcher (1993), p. 31; King (1695-1700).

[38] Although he uses a high annual yield of 2 tons per acre from coppicewood, Rackham has recently suggested, very roughly indeed and without the analytical intent of this work, that only half of wood harvested was burned as fuel. However, the low level of overall consumption indicated here would suggest that this supposition errs on the low side. Rackham (2006), p. 131.

lion around 1870, according to the Ordnance Survey maps.[39] As the presence of standing trees in the landscape seems to be associated with the prevalence of hedgerows, the numbers before 1750 have been back-projected according the estimates of the national extent of hedgerows (see below). The figures obtained are open to a test, because estate surveys across this era give information for agricultural land on the numbers of standing trees relative to acreage; by 1870 there were only just over 2 trees per hectare in England and Wales. Our estimates of standing trees fall at around 4 per hectare in 1800 and 5 in 1700. In some regions these figures would have been very much higher. Estate surveys show a much higher stocking rate in the late 17th century than was later the case, sometimes amounting to over 20 per hectare in East Anglia around 1700.[40]

However, we are now confronted with two further issues; what proportion of these trees were exploited for fuel, and how much wood did they produce? Trees harvested for fuel would almost certainly have been pollarded to allow systematic use over time. Pollarding was favoured by tenant farmers until the second half of the 18th century because they had no rights to timber on their farms.[41] I have estimated that half of all standing trees – a high proportion – were pollarded before the 19th century, and only a quarter by 1800. These are high figures and can only be conjecture. In turn, it is estimated that an individual mature broadleaf tree produces about one hundredth of the annual increment per hectare, or 0.03-0.04 cubic metres, although it may be that given the lower competition from neighbours with fielden trees, the rate is a little higher than this. This would suggest a maximum annual output of just under a million cubic metres from standing trees in 1750, having risen from

[39] Rackham (1986), pp. 222-3.
[40] Barnes & Williamson (2006), p. 19.
[41] Barnes & Williamson (2006), p. 19, Marshall (1787), p. 98.

0.37 million cubic metres in 1550. By the middle of the 19th century this form of management had almost entirely disappeared.

Hedgerows as a source of wood add a further area of difficulty, but not imponderability. Again, the figures must be rough and ready until further research is undertaken, but can provide us with a range and magnitude of production that indicates that British wood supply cannot have diverged very far from the figures presented here. In 1998, England and Wales had just under 450,000 kilometres of hedgerow, a decline from around 680,000 kilometres after the Second World War. There is little reason to believe that the total length of hedgerows was much greater a century earlier, but the five centuries prior to 1850 saw an almost continuous process of net hedge-laying and expansion, the most famous of which was associated with the Parliamentary enclosure movement from 1760 onwards. Just like the process of enclosure, the process of hedge-laying was far more evenly spread in time than was traditionally supposed. Rackham estimates that 200,000 miles were laid in the five hundred years before the 19th century, a total of around 400 miles per year. This has simply been projected back to give a hedgerow length of around 250,000 kilometres in 1550, with an average width of 2 metres. Certainly many hedges were much wider, some wide strips that amounted almost to woodland, and the general disposition of hedgerows requires further research. However, it is doubtless also the case that many were not systematically exploited for fuel.

While this process of estimation is very rough and ready, it is equally clear that their proportion of national wood supply, notwithstanding the frequency of prosecution for the offence of 'hedge-breaking', was small.[42] Output is esti-

[42] This assumes that hedgerow yield was the same as for broadleaf woodland (3.3 m^3 per year), which may well be too low, by a factor of 100 percent or more. However, it will also be the case that much hedgerow

mated at around 166,000 cubic metres in 1550, rising to 250,000 cubic metres by 1700. While botanical and documentary evidence suggests that up until this date hedge-laying was often done with providing a supply of fuel in mind, subsequent hedges were largely from hawthorn and simply intended as a physical barrier.[43] Indeed, some counties such as Cheshire that enjoyed very extensive hedgerows and hedgerow trees in the late 18th century nevertheless were almost entirely orientated towards coal as a fuel.[44] The new hedgerows thus are not likely to have added much to the supply of fuel.

In total, it is estimated that England & Wales had some 3.2 million cubic metres of firewood *per annum* at their disposal in 1550, a total that may have risen very slowly to peak at about 3.6 million cubic metres in 1750. The estimates presented above have erred on the side of over-estimating supply, so as to not overstate the case for a 'timber famine'. However, even if the most speculative estimates, on standing trees and hedgerows, are quite far out, it seems extremely unlikely that England and Wales ever had more than four million cubic metres of firewood each year at their disposal. To give a clear indication of this, the extent of woodland, standing trees and hedgerow in England and Wales reached an extent in the late 20th century at least comparable with that which pertained several centuries earlier. If this was devoted to wood production in a similar fashion, some 3.7 million cubic metres of wood could be produced annually. As can be seen in the table below, coppiced woodland remained the dominant source of firewood, although in the early 18th century at least a third of supply came from non-woodland sources. The production of wood

was not actually exploited for fuel. On hedge-breaking and wood-collecting, see Bushaway (1982), pp. 214-33.

[43] Barnes & Williamson (2006), p. 64.

[44] James (1981), p. 172, HCJ (1792), p. 328.

would also have been augmented to a small degree by the use of other fuels such as furze, straw, bracken and dried dung.[45]

Table 2. Estimated proportion of supply of firewood (%)

Date	Woodland	Standing Trees	Hedgerow
1550	83	12	5
1600	77	17	6
1650	72	22	6
1700	68	26	6
1750	66	27	7
1800	76	12	12
1850	77	8	15

Sources: see text.

These figures imply that even in the reign of Elizabeth I, it is doubtful that much more than 1 cubic metre of wood per person *per annum* could be supplied – certainly a historically low figure by northern European standards.[46] This suggests that fears of a general 'timber famine' by the early 17th century may have been well-founded and were only alleviated by the very early and rapid expansion of coal use, although it should be emphasised that this does not indicate that wood shortage was the *cause* of the transition to fossil fuel use. As the wood supply in fact remained relatively stable over time, roughly the same number of domestic consumers may have burned wood in 1800 as did in 1550 – a figure consistent with the population of those counties recorded as being largely dependent on wood-burning in a survey of the 1790s.[47] However, the charcoal iron industry, among other users, must have put a very significant amount of pressure on supply at its peak in the mid-18th century, when it consumed the production of up to a quarter of a million hectares. At 2 percent of the surface area of England

[45] Davidson (1982), pp. 74-6.
[46] Warde (2006).
[47] See note 13.

and Wales, Hammersley considers this a small and sustainable demand, but in fact it represented almost a third of the national woodland! [48]

2.4. Animals

Britain has never conducted a full census of draught animals. Agricultural statistics record animals held on farm each year after 1870, but not their use. By this period, large numbers of horses worked in urban centres, industrial plant or mines. The early 19th century saw a tax on horses. Before this period there is no really reliable statistical data that covers a broad geographical range until we reach the demesne farms of the late medieval period, when the work of John Langdon and above all Bruce Campbell allows estimates to be made. For the long centuries before 1800 there are only scattered studies of probate inventories, and a very few estimates by the economic arithmeticians, such as Gregory King, who almost certainly greatly exaggerates the number of horses in the kingdom.[49] Nevertheless, the lack of statistics and the great desirability of further research is not a counsel of despair. As with the case of firewood, the available evidence does allow us to make plausible estimates for the numbers of draught animals over long periods of time. This is in part because all the evidence points to the fact that a series of ratios, above all the ratio between cultivated land and draught animals employed, move within

[48] Collins has a considerably lower estimate of 320,000 acres against Hammersley's 650,000. Hammersley (1973), p. 606; Collins (1996), p. 1100.

[49] The breakdown of horse use implied by King was not in fact achieved in England and Wales until around 1900, thus while his estimate of horses in agriculture is quite plausible, the larger numbers employed in transport and industry seem greatly exaggerated. King, (1695-1700).

only a relatively narrow range in the long-term. Thus the general course of agriculture gives us some handle on the likely numbers of livestock. However, this method cannot overcome inevitable uncertainties as to the numbers of horses, oxen, and very occasionally mules and donkeys employed in the transport and industrial sectors. Fortunately, after 1800 this area of research has already been subject to thorough and rewarding scrutiny by F.M.L. Thompson and E.J.T. Collins, and we may draw on their work here.[50]

By the 19th century, only a small proportion of draught power came from beasts other than horses; only four of England's counties employed oxen to a large degree, according to Burke.[51] Use of other beasts, including cows, was not unheard of but insignificant. However, these decades stood at the very end of a very long process of substitution of oxen by horses that had been underway since the High Middle Ages.[52]

Campbell's monumental study of demesne agriculture provides two benchmark dates in the 14th century when there were around 4.8 draught horses per 100 sown acres, and 10.4-12.2 oxen. It has been assumed here that the peasant sector (a little over half of the agricultural land) had similar stocking rates of horses, but there is clear evidence that relatively speaking numbers of oxen were lower. Wrigley has recently provided a rather higher estimate of horse numbers; most of the discrepancy comes from what I consider an over-estimate of numbers of foals.[53] Following

[50] Thompson (1976); Collins (1983).

[51] Burke (1834).

[52] Langdon (1986), pp. 254-274.

[53] Wrigley (2006), pp. 448-450. Wrigley uses the figures Thompson provides for unbroken on-farm horses and on-farm horses employed in agriculture to estimate that some 35 percent were immature in 1871, and employs this ratio for earlier dates. However, the immature on-farm horses recorded in the nineteenth century must also have been supplying the large numbers of adult horses used in commerce and industry. I esti-

Campbell and Langdon's independent work produces two commensurable estimates of total oxen numbers, which at this time, assuming an oxen provides two-thirds the power of a horse, amounted to 43 percent of the total draught power.[54] Data is much less extensive for the next two benchmark dates, 1600 and 1700. The horse number for 1600 is simply a speculative estimate based on the likely ratio of draught animals to the cultivated acreage, given long-term trends. I then consider 25 percent of the horse total to be immature or off-farm horses, and thus the figure of draught animals should be inflated by a third. Oxen numbers are then derived from the ratio between horses and oxen found in Langdon's work on inventories from the 1570s.[55] For 1700, the estimate of Gregory King for horses in agriculture is used, and then inflated with an estimate that King's figure does not include some 30 percent of the total number of horses (non-agricultural horses plus foals). This produces an estimate of some 6 horses for every 100 sown arable acres in 1600, and 6.94 in 1700. At each date oxen provide 21 percent and 17 percent of the available

mate that the proportion of immature horses to mature is generally less than half of Wrigley's figure, no more than 15 percent of total horses. Campbell estimates that young horses amounted to between a tenth and a fifth of the total, and in the 19th and 20th century the figure lay between 10 and 15 percent in all western European countries. However, one may also note that Stone records very low life expectancies for working horses in the fourteenth century. It is assumed here that 10 percent were employed in the non-agricultural sector in 1300, (the figure on desmesnes for carting was 13 percent) and thus that on-farm working horses made up 75 percent of the total. Wrigley also uses a different procedure for estimating stocking rates in the peasant sector; while I have assumed horse stocking on demesne and peasant farms was similar, Wrigley has taken total peasant stocking rates to be 75 percent of demesne rates and then applied the ratio of horses and oxen provided by Langdon to this figure. Campbell (2000), pp. 124-127, 133.

[54] Campbell (2000), pp. 123-4; Landgon (1986), see note 61; Kander & Warde (2006).

[55] Langdon, (1986), see note 61.

draught power respectively. By the early 19th century there were about 700,000 horses working in agriculture, and over a million horses in total. This suggests around 7.2 agricultural horses for every 100 sown acres. In 1800 draught oxen are assumed to number around 10 percent of the number of draught horses in agriculture.[56]

19th century statistics have been effectively surveyed by Collins and Thompson, but still require some manipulation for our purposes. After 1871 their data is for Great Britain, so a deduction must be made for Scotland (some 13 percent of the total). Furthermore, horses held simply for leisure reasons should not be included in our analysis. This last category was a large 18 percent of the total in 1901. I have assumed that some 15 percent of the stock was used for private purposes in the second half, and 10 percent in the first half of the 19th century.[57] Tax records from 1812-21 suggest around 1.2 million horses and foals in England and Wales, at which stage nearly 60 percent were still employed in agriculture. The 19th century saw the most dramatic rise in horse numbers, to peak at over 2.85 million in 1901. All these additional horses were employed outside agriculture, which made up only one third of horse numbers in 1901. Around a fifth of horses were used for the movement of commercial goods, a little under a fifth for leisure, and 14 percent for buses and trams. The introduction of motor vehicles squeezed horses back towards the farms; of the million remaining in the mid-1930s, over half were used in agriculture, and over a quarter for riding and leisure.[58]

[56] This is consistent with the proportions found in early nineteenth century European economies. Kander & Warde (2006); Young (1813), p. 312; 10 percent is the proportion of the national herd in the 1860s taken up by those horses found in counties that predominately used oxen in the early nineteenth century.

[57] Collins (1983), p. 85.

[58] Collins (1983), p. 85; BPP 1816.I., pp. 453-4; 1819.XV., pp. 423-5; 1821.XVI, pp. 323 & 338.

Numbers are one vexed problem. What, however, were the energy inputs to these beasts? Animal food consumption, as with people, may be highly variable according to the amount of work that they are doing, so the length of the working year and the nature of the labour will influence food intake. The amount of work that an animal is capable of doing will also be dependent on its stature, and over the nineteenth and early twentieth centuries the working horses became considerably larger. The very largest animals were generally urban dray-horses, the lightest those used for leisure riding, with most agricultural horses falling somewhere mid-way in between. These changes were accompanied by physiological developments in breeds, so that horses became more efficient in their energy use, and equivalent amounts of power could be generated from less fodder.

To make energy consumption calculations, it is insufficient to know horse numbers, the overall age structures of the national herd, horse sizes (weight or height), or what particular horses consumed for particular tasks in a set period of time. None of this data can lead us to a reliable overall estimate, which would be most adequately provided by knowing what different types of horse were fed *over the entire year.* Such data is not forthcoming. Rather than attempt to model horse fodder consumption in detail, some estimates have been taken of average daily calorific consumption for horses, and applied to the entire herd, with adjustments for size changes over time. Because of improved efficiency, large 20th century draught horses may not have consumed dramatically more than their forebears. Collins estimates that draught horses needed 20-25,000 Kcal per day during the ploughing period in the early 20th century. Estimates from the 1830s and 40s are little different, ranging from over 15,000 Kcal for light work to 26,000 Kcal for colliery horses and a huge 38,000 Kcal for a heavy dray-horse at work. Given that many horses were of an age where they could not be employed for any length of time in heavy work, and that agricultural horses would probably do very little work at all for at least a quarter of the year, it seems reasonable to assume an average daily intake very much towards the lower end of this scale. I have discussed this issue elsewhere with regard to agricultural draught livestock.[59]

Table 3. Draught Animal Numbers (in horse equivalents)

Year	No.
1600	476,000
1700	841,000
1800	906,000
1871	1,588,700
1901	2,328,000
1934	810,000

Sources: see text.

2.5. Wind

Wind energy was consumed in two forms: by sailing ships, and by mills. Due to their geographical location England and Wales were highly favoured for the application of both, Britain being among the countries in Europe most exposed to consistently strong winds. As is well known, England's pre-eminence as a trading nation was reflected in the large size of its merchant marine from the late 17th century onwards, until the rapid transition to the use of steam powered vessels that occurred in the second half of the 19th century.

[59] Only something a little over half of the fodder is effectively digested by the horse, and the overall efficiency of food energy consumed to power applied is only around 10 percent. Collins (1999), pp. 216-7; Kander & Warde (2006).

Statistics on the tonnage of sailing ships are available from 1788.[60] The size of the fleet peaked in 1868 and ceased to be of significance around the time of the First World War. For earlier dates, we can rely on the careful studies of Ralph Davis for reasonable estimates of tonnage back to 1560. However, A sudden jump in the statistics on tonnage recorded for both London and English outports between 1786 and 1788 suggests that the statistical data gathered by Davis for the 18th century underestimates tonnage. Indeed, as Jackson suggests that the 1788 law on ship registration was enforced such that 'the tonnage registered… consisted of practically everything that floated', it seems that the likeliest cause for the discrepancy is a shift from masters providing estimates of tonnage based on 'tons burden' or 'carrying capacity', to procedures for 'measured tonnage' to be calculated more accurately.[61] It is thus likely that the rapid advance shown in the data employed here between 1775 and 1788 is an exaggeration, and that the trend over the 18th century as a whole is somewhat flatter. In other words, the pre-1788 method of calculating tonnage tended to underestimate it by later standards. In the statistical period, aggregate data is available for by port from all the component parts of the United Kingdom. In 1788, English registered vessels made up 83 percent of the total, a very high proportion, which fell in mid century to only 76 percent but recovered a little thereafter.[62] The merchant marine had an important 'mutliplier effect' in terms of energy consumption because a large proportion of the fleet was employed as colliers.

One method of calculating the energy consumed by a sailing ship has been developed from Italian statistical prac-

[60] BPP 1843.LII, p. 381; 1852.XLIX.I, pp. 2-3; 1862.LIV, p. 101; 1871.LXI, pp. 2-3; Mitchell (1962), pp. 217-222.

[61] Davis, (1962), p. 7; Jackson (1981), p. 129.

[62] BPP, see note 69.

tice by Paolo Malanima. We know that, immediately after the unification of Italy (1861), the ratio of a steamship's tonnage to its power (expressed in Hp) was 2.8. Thus, power is the result of net tonnage divided by 2.8. In the same period, tonnage being equal, a sailing ship was usually estimated to have one third of the power of a steamship. This is because in the steamship it is estimated that two-thirds of the energy output of the engines is lost in the transmission and motion of the propellers that does not provide useful energy. Thus, to calculate the power of a sailing ship, all we need to do is divide its tonnage by 2.8 x 3 = 8.4.[63] However, as we are interested in energy *inputs,* this method would assume that energy can be transmitted from the sails to provide for the useful forward motion of the ship in a perfectly efficient manner. Lindmark has devised an alternative method that makes an assessment of wind energy hitting the rig. Allowing for loss largely because of the interference of sails with each other, Lindmark calculates that the energy input is approximately 0.6 kW per ton. This is the figure employed here, which gives an estimate approximately twice that of Malanima. Indeed, this would imply a 50 percent loss of energy between sails and the provision of forward motion to the vessel, which does not seem unreasonable. It is doubtless true that ships became more effectively rigged over time, so this would overestimate the input per ton to early vessels.[64]

The next step is to decide how much of this power was actually used. Since ships were not used every day, and did not always travel at full speed, less than half a day at full power all year round seems a reasonable assumption: some 3,650 hours per year. However, it is likely that the usage of ships became considerably more efficient over time. Loading became swifter and laying up times shorter as hull qual-

[63] Malanima (2006), pp. 36-7.
[64] Lindmark (2007).

ity and organisational efficiency improved. Thus I have assumed a 100 percent increase in productivity over the 18th century, based on evidence of the increased frequency of voyages, and much shorter laying up times, in the east coast trade of England.[65]

There are no reliable statistics on windmills. It is likely that nearly all of those that existed were used for grinding corn or drainage. I have assumed that a fifth of the mills estimated by Collins to be employed in agriculture were windmills, giving a total of 2,400 in 1840, 2,000 in 1880, and 1,300 in 1910. Only 350 working windmills remained at the end of the First World War, and as few as 50 by 1945. Surveys of mill sites (which give no indication of the working lifespan of the mill) would indicate that these numbers are probably maxima.[66] Before 1840, windmill numbers are indexed against the population. This rather crude method produces a rough doubling of numbers between 1760 and 1820, in line with an actual estimate by Richard Hill. Although Wailes suggests very much higher figures of over 10 000 operating at their peak, these seem quite implausible. A high proportion of windmills were used in Fen drainage and this occupied no more than 220 in 1852. This period also saw a large number of improvements to windmill design that enhanced efficiency.[67]

The power and energy consumption of windmills is also largely matter of guesswork. Collins reckons on an average of 6 Hp for water- and windmills used in the agricultural sector; von Tunzelmann half this figure. Windmills could only be effectively used, even in the exposed east of the country, for around a quarter of the year, and at full power

[65] Ville (1986), pp. 358-9, 369.

[66] Collins (1999), p. 215; see the mill archive at http://www. millarchive.com/.

[67] Davids (2003), p. 273. Tunzelmann (1978), pp. 122-5; also, Tann (1989), p. 414.

for as little as a twentieth.[68] I have estimated that windmills were able to operate at 3 Hp for around 2,200 hours each year.

2.6. Water

Water was employed to generate power through the use of water wheels, and in the 20th century to power the turbines that generated hydroelectricity. Only the former will be considered in this section. Although the method of power generation was identical, statistically it is convenient to treat industrial (and mining), and agricultural mills separately. Industrial surveys provided information on the horsepower available from water in the 1830s and 1870s, although these miss out many areas of the non-agricultural economy and were clearly incomplete. The first reliable general survey dates form 1907. In contrast, Collins provides estimates of numbers of agricultural mills (grinding corn, oilseed and other agricultural products and providing on-farm power), but the power exerted by the mills must be taken from more scattered examples.

It is clear that the 18th and 19th centuries saw considerable advances in mill and wheel design that advanced the size of wheels and the power that could be generated from them. Early in the period undershot wheels were common, with an efficiency of as little as 15 percent and sometimes a power of less than 1 Hp. By the latter part of the 19th century enormous iron wheels could provide up to 500 Hp with an efficiency of 85 percent. However, it must be remembered that we are interested in *inputs,* that is, the energy in the water borne through the mill-race and against the wheel. Efficiency improvements in wheel design will not alter this figure, but merely increase the proportion that can

[68] Collins (1999), p. 221; Tunzelmann (1978), p. 124; Davids (2003).

be transmitted as *useful* energy, i.e. increase the work done by the wheel. For measuring inputs the improved management of watercourses to allow a greater proportion of the fall and volume of flow within each river system was more important in increasing the energy available from water. However, as statistics record only the Hp of mills, we must add that energy which was not effectively utilised by the wheels, or that was lost in the process of transmission. The introduction of suspended iron wheels considerably improved the efficiency of transmission in the 19th century. An alternative method employed by Gordon is to calculate the energy obtained in the average flow of the river basins and assume that a set proportion of this was guided against waterwheels. In this case one must employ assumptions about how millwrights were able to deal with intermittent water flow, and the degree to which the flow could be constrained to generate useful flows. The efficiency of wheels will also be determined by the height of the water's fall onto the wheel, so a system with fewer mills, each exploiting a higher fall, will be more efficient than many mills on a river, each exploiting only a small fall. Gordon calculates that only 0.8-7.2 percent of water power potential was harnessed in the 1830s, a figure surprisingly close to that of 6 percent calculated by Robert Kane for Lancashire in 1845.[69]

It is easiest to begin our calculations with the most reliable data from 1907 and the First Census of Production, covering the *capacity* of waterpower (rather than that actually used) for everything from the railways (the largest user of water power!) to musical instrument making. 84,388 Hp are recorded for England and Wales.[70] The previous major survey, the Factory Returns of 1870, are clearly defective in both terms of their general reliability, and the lack of coverage of certain areas of the economy (such as railways and

[69] Gordon (1983), pp. 257-8.
[70] BPP 1912-3.CIX, pp. 17-914.

waterworks, but also the majority of small workshops with few employees).[71] The 1870 Factory Returns record some 32,632 Hp in England and Wales.[72] For those categories surveyed in both 1870 and 1907, there were 42,862 Hp present in 1907, an increase of 31 percent. However, there were also a further 21,837 Hp recorded in 1907 in industries such as railways, mining and quarrying that were not covered by the 1870 returns. If the rate of change in the use of water power was equivalent to those sectors that were included in both surveys, the total for 1870 should be inflated to around 43,000 Hp. The rest of the gap between the two surveys is taken up by categories that did not exist at the earlier date (such as electricity), those that are ambiguous (such as 'local authorities'), and the fact that the later figures measured capacity whilst the earlier ones measured use.

However, other factors should be taken into account. Kanefsky argues that there was a 'substantial fall' in the use of waterpower over this period.[73] This may be true in a relative sense when measured against steam, but is it so in absolute terms? For this to be the case, the 1870 Factory Returns would have to be substantially awry, much more than the 15 percent error (across all forms of power) that Kanefsky estimates. We can examine this problem by looking at the returns industry by industry (of which there are 77 categories in 1907) to see if technical change, change in productive capacity, or simple under-recording is likely to account for the differences between 1870 and 1907. Clearly, the major employment of waterpower by the electricity industry indicates that it was by no means a redundant technology. In some major sectors, notably cotton and wool, the employment of waterpower appears to have been remarkably

[71] Kanefsky (1979).
[72] BPP 1871. LXII. pp. 90-163.
[73] Kanefsky (1979), p. 369.

consistent between 1838 and 1907, suggesting a continuing use of 'vintage technology' on certain sites. The sectoral level comparison suggests that the 1870 Returns considerably underestimated the employment of water in engineering, shipbuilding, gunpowder production and the chemical industry. A plausible, if impressionistic shortfall in the 1870 Returns is about 5,000 Hp – in other words, about 15 percent of the recorded total. Kanefsky estimates that an additional 25,000 Hp were used in non-ferrous metal mining, a figure that had dwindled to little over 3,000 Hp by 1907. Taken together these imply that that the true total figure for 1870 should be around 70,000 Hp. There was, thus, a rise in the use of water power between 1870 and 1907.[74]

In England and Wales, the amount of waterpower recorded as being employed in the textile industry was remarkably stable between 1838 and 1907, at around 20,000 hp.[75] The 1838 Factory Returns only covered the textile industry, so elsewhere we are dependent on guesswork. The textile sector made up around 37 percent of the estimated total in 1870. It is likely that the other major employers of waterpower in the 1830s were the metal trades, paper, and mining. Tin output roughly doubled in the period 1838-1870; pig iron output roughly quintupled; lead was quite stable; coal production at least doubled; and paper production at least doubled.[76] It seems unlikely that the growth in the use of waterpower remained roughly proportional to growth in output; rather, growth was disproportionately in the use of steam, especially in iron and steelworking. But given the scale of rises in production even if there was gen-

[74] Kanefsky estimated 100,000 Hp, but this included grain mills. I have added 20,000 Hp for non-ferrous metal mining in addition to the 2,000 Hp projected back from the 1907 statistics. Kanefsky (1979), pp. 370-2.

[75] This was not the case for the United Kingdom as a whole, however. Tunzelmann (1978), p. 139.

[76] Mitchell (1962), pp. 115-7, 129-132, 160, 263-4.

eralised substitution of steam for water power it seems unlikely that the use of water in 1838 was *higher* than in 1870. I estimate that around 30,000 Hp was obtained from water wheels (excluding food processing and textiles) in 1838, making for a non-agricultural total of around 50,000 Hp.[77] These kind of figures are consistent with an estimate following Gordon, that if 6 percent of the capacity of the UK's industrialised river basins were employed for water-power in 1838, this would imply around 29,100 Hp being available.[78] Most of this capacity would have been used by textiles and the metal trades.

We can set earlier benchmark dates for estimating the use of waterpower at 1800 and 1700, but the quantities involved are quite small. I will consider 20,000 Hp an absolute ceiling for the later date[79], and 10,000 Hp for the earlier.[80] The great bulk of this power was probably utilised in mining, especially lead mines. These results suggest that, contrary to what some have argued, industrial steam power was already outstripping waterpower at the very beginning of the 19th century.

Collins estimates that there were some 12,000 agricultural mills in 1840, 8,000 in 1880, 6,500 in 1910, and 4,500

[77] Including approximately 3,000 Hp for the paper industry, 2,500 Hp in tin mining, somehwere under 20,000 Hp in lead and other non-ferrous metal mining, and 4,000 Hp in metal-working.

[78] Covering the basins of the Derwent, Dowe, Irwell, Ribble, Spodden, Mersey, Aire, Trent, Tame, Erewash and Leen. Gordon (1983), pp. 257-8.

[79] This would include 2,500 Hp employed in the cotton industry, 2,800 Hp in paper, and perhaps 2,000 Hp in metalworking, with much of the rest in mining. It implies 2000 wheels of on average 10 Hp in operation. Reynolds (1983), p. 139.

[80] Including 1,400 Hp in paper. Manchester and Sheffield had around 160 mills at this time. If they averaged a quite respectable 5 Hp, this would amount to 1,300 Hp. Most non-agricultural waterpower was probably employed in lead mining, as copper was of minimal significance in 1700. Reynolds (1983), pp. 123, 139, 269.

in 1938. One point of comparison suggests that quite a lot of this power was based on-farm, and that it was by no means overwhelmingly used to grind cereals. The Census of Production of 1907 records 24,205 Hp from water power being used in grain milling in England and Wales. Collins' estimates suggest over 31,000 Hp available in 1907.[81] We can also compare estimates with employment data. For example, 24,400 millers were included in the census of 1851, implying a ratio of roughly two millers per mill. Between 1815 and 1840, mill numbers have been calculated using overall population trends. This is because there should be a very rough fit between food consumption levels and the size of the population, which is a more important factor in determining long-run changes in demand for agricultural products than the per capita food consumption level.[82] Secondly, some occupational evidence suggests that millers remained a relatively stable proportion of the adult male workforce, suggesting that milling provision is correlated with population size.[83] However, before this date it appears that mill numbers varied little. Although data is sparse, it is plausible that mill numbers in mid-16th century England and Wales were around 7,000, based on Langdon's work in the Midlands that implies manorial mill numbers were around 20 percent higher in 1500 than they had been at the taking of the Domesday survey in 1086, when some 6,000 were inventoried.[84] I have additionally estimated that there were

[81] Collins (1999), p. 221; BPP 1912-13.CIX, p. 494.

[82] This does not account for the possibility of earlier widespread under-employment of mills, but this in turn could be set against an over-estimation of the hours of work done by each mill, discussed below, if there was over-capacity in the system by, for example, the provision of a relatively dense netowrk of grain mills to reduce the distance farmers had to take grain and other products for milling.

[83] On data from the 1851 census, and derived from baptismal records in the West Riding, the proportion of millers is roughly 0.006 percent. I am grateful to Leigh Shaw-Taylor for providing this information.

[84] Langdon (1991), p. 424.

around 500 industrial mills at this time, largely involved in textiles (fulling), mining and metallurgy. Mill capacity was thus greatly underused before around 1750, more of which below.

Collins estimated that agricultural waterwheels on average generated 6 Hp throughout the period 1840-1940. There are considerable variations in the literature on the average power of mills. 18th century estimates imply around 2-5 Hp being standard, though a survey by Reynolds of 40 mills brings quite high values of 6.6-7.4 Hp. Certainly the development and diffusion of the breast and overshot wheels after 1750 greatly improved the efficiency of power generation. It would seem implausible that such developments simply required less water inputs and did not permit an improvement in the power capacity of the wheels at shaft, and thus I have opted for a lower estimate of 4 Hp for mills in 1700, rising to 5 Hp by 1800, and 6 Hp in 1840.[85]

Two further calculations must be made. Firstly, to estimate the energy consumption of watermills we need to know how long, on average, the power of a watermill was exploited per year. Secondly, to estimate energy *inputs* (i.e. the power of water in the mill race, not the power generated at the shaft of the wheel), we must make an estimate of the efficiency loss in the operation of the wheel. Kanefksy estimates for the late 19th century that manufacturing industry was able to employ 80 percent of capacity available to it, and that the equivalent figure was 60 percent elsewhere.[86] I have assumed this to be the case from a maximum use during a 14-hour day for 300 days per year, a total of 4,200 hours per year. Thus most non-manufacturing waterwheels are calculated as having worked the equivalent of full capacity for 2,520 hours per year. However, in the early modern period it is likely that mills worked at well below capacity.

[85] Reynolds (1983), pp. 172-8, 269; Gordon (1983), p. 258.
[86] Kanefsky (1979), p. 373.

This can easily be demonstrated. Given the rough rule of thumb that it required one horsepower to mill one bushel of wheat in an hour, we can use estimates of food consumption to calculate the milling time required to keep the populace supplied with flour.[87]

Per capita consumption of grain, calculated in terms of wheat, was about 10 bushels per year.[88] When the population of England and Wales stood at four million (in 1585), 40 million hours of milling time would have been required, the equivalent of 4,000 mills of 4 Hp worked for 2,500 hours per year. As there were some 7,000 mills, on average they would have had to work for only around 1,450 hours per year each, in other words, they used a mere 35 percent of their capacity. Thus agricultural mills (which were, of course, used for other purposes aside from grain milling), would have only reached their 19th century 'capacity' (60 percent utilisation) around 1770. I have thus estimated that mills were used for 1,500 hours per year in 1560, and 2,000 hours between 1650 and 1700.

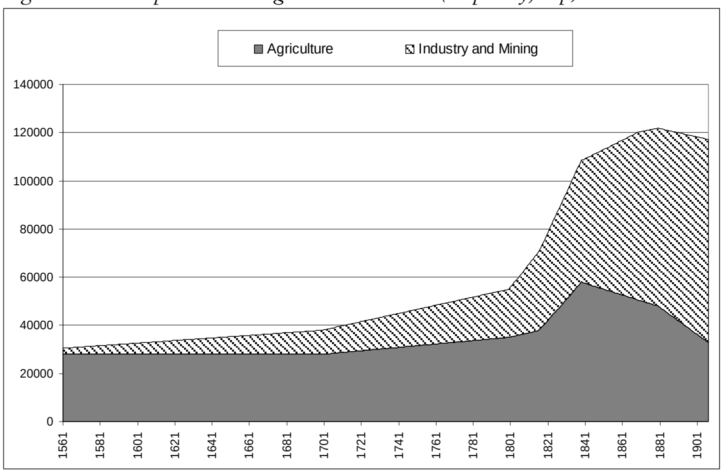
In the 18th century, most wheels were 'undershot' – that is, the water ran at the bottom of the wheel, giving efficiencies of only around 25 percent at most. By the late 19th century, a combination of overshot or breast wheels, made of iron rather than wood and improved bucket design allowed both much larger wheels to be employed, and at rates of efficiency reaching 90 percent. However, although the overshot wheel was the most efficient design, the breast wheel (where the water is delivered to the top left quadrant of the wheel, with the flow coming from the right) was preferred because it was better at handling variations in water level. The main period of transition seems to have been between the initial work of

[87] Reynolds (1983), pp. 172-4.

[88] This includes an allowance for imports. In practice not all the cereals consumed would have been milled, so the demand for milling is probably a little lower than presented in this example. Wrigley (2006), p. 458.

Smeaton in the 1750s, and the Napoleonic period. I have assumed an efficiency of 25 percent pertaining in 1750, rising to 50 percent by 1820, and 60 percent by 1900.[89] In other words, to get energy *inputs* at these dates one should multiply the energy consumption figures estimated at the shaft of the wheel by 4.2 and 1.67 respectively. Thus although capacity in industry continued to rise until 1907, actual energy consumed peaked in 1870.

Figure 1. *Waterpower in England and Wales (Capacity, Hp)*



Sources: see text.

2.7. Coal

The coal industry has been extremely well researched over a long period of time, culminating in the series of volumes commissioned by the National Coal Board. These volumes provide authoritative estimates on production and export for the period up until 1700 (Hatcher) and 1700-1830 (Flinn). More frequent statistics are provided by Mitchell from 1816 onward, and an annual series is pro-

[89] Reynolds (1983), pp. 178, 280-307, 319.

vided after 1853, based on the *Mineral Statistics* of Robert Hunt. However, between the 1830s and the mid-1860s I have employed the quinquennial data of David Church.[90] There are two main problems of disaggregation involved in using this data. Firstly, exports must be deducted from the production figure. Before 1922 this includes exports to Ireland from English and Welsh coalfields. Secondly, export statistics in the National Coal Board histories are provided for Great Britain as a whole, and from the mid-1860s the series on which the data used here is based gives data for the whole of Great Britain. Thus after 1775 it has been necessary to calculate output for the whole of Great Britain, deduct exports, and then remove the proportion consumed in Scotland. Because of the nature of export data this is the case even though it is possible to calculate the *output* of the English and Welsh coalfields separately. Note that we are concerned here with the coal *consumed* in Scotland, rather than excavated by the Scottish mining industry, as there may well have been coal exports from Scotland into England, or *vice versa.* As no statistics exist that record the heritage of the coal burned in different parts of the British Isles, it is assumed that the proportion of British coal burned in England and Wales is proportional to the proportion of the British population living in those two countries. The Scottish population has gradually sunk relative to that of its southern neighbours, from around 16-17 percent of the total in the late 18th century to 14 percent by 1851, 12 percent in 1901 and less than 9 percent today. Other methods could have been employed, for example taking the proportion of GDP, or more laboriously, the proportion of major consuming industries sited at different points in the United Kingdom. However, the first method makes only a marginal difference to the aggregate figures, as Scottish GDP has kept roughly in step with that of the island as a whole where

[90] Hatcher (1993), Flinn (1985), Mitchell (1962), Church (1986).

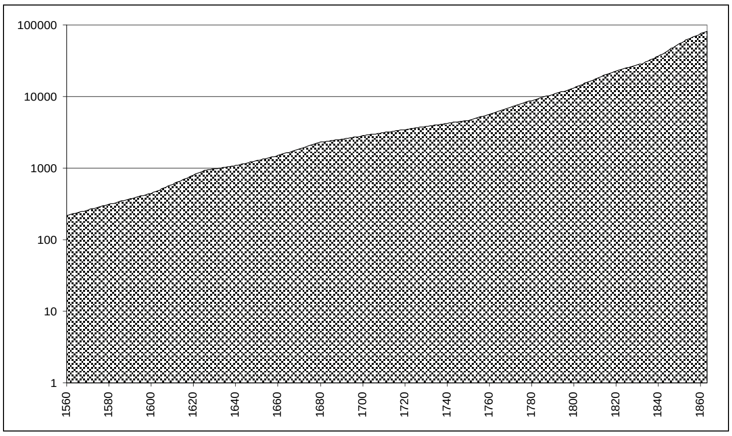
data is available. Given this, it is unlikely that the final method of calculation, sector-by-sector, would bring significant rewards given that the margin of error is relatively small. Before 1800 the proportion of Scottish consumption in the British whole has been treated as 15 percent, representing the lower per capita consumption of the poorer partner in the Union of 1707.[91] It has been assumed for convenience that Northern Ireland received its coal from Scotland.

Whilst commenting that quantifying the early output of the coal industry risked being a 'vainglorious attempt to conjure numbers', and an enterprise 'likely to prove damaging to [historians'] reputations', John Hatcher has provided meticulous assessments of the outputs of British coalfields in 1560 and 1700. However, he provides no benchmarks between these dates, although this is a period critical for our concerns, when coal shifted from providing around a tenth of total energy consumption to almost exactly 50 percent. The timing and indeed our analysis of the 'transition' thus rests on our assessment of what occurred in the intervening period. At risk of vainglory I have used Hatcher's work to provide benchmark estimates for 1600, 1625, 1640, 1660, 1680, and 1700. I have proceeded by establishing a range of possible outputs, the minimum resting largely upon established figures from available production sites, and the maximum resting upon estimates taken from production and consumption data, and other more qualitative indicators of trend. The results for each coalfield are then aggregated to provide an estimate for England and Wales, with a deduction for exports. I have chosen to use figures that lie close to the maximum of the results obtained. This is for two main reasons. Firstly, given that around half of consumption in 1700 was by domestic hearths, and that the population had been essentially static since the 1650s, any

[91] ONS (2004); Mitchell (1962), pp. 8-10; AAS (2005), p. 28.

figure much lower than the maximum estimates (which imply more rapid early growth of coalmining) would imply implausibly rapid growth in the second half of the 17th century: a trebling of consumption between the Interregnum and 1700, which would have had to be almost entirely taken up by industry, rapid urban growth notwithstanding. Secondly, the two probable largest industrial consumers, the salt and brewing industry, had already established high levels of production before 1640.

Figure 2. *Coal production of England and Wales (metric tonnes, log scale)*



The figures I employ imply a growth rate in coal consumption of 1.8 percent between 1560 and 1600, accelerating to 3 percent in the Jacobean era, when growth was to a large extent driven by the explosive expansion of the northeast coalfields. Growth was around 1.1 percent between 1625 and 1640, 1.6 percent in the Civil War and Interregnum period, 2.2 percent in the reign of Charles II, and falling to 1.1 percent as the late 17th century wars and slack domestic demand slowed the pace of expansion. The rate of growth was just over 1 percent for the first half of the 18th century, accelerating to over 2 percent before the next fifty years. It is clear that there has been no significant trend break at any point in the history of British coal consumption between 1550 and the First World War. However, the reign of the two more fortunate Stuart monarchs were period of relatively rapid growth, especially in a supposedly 'pre-industrial economy'. Growth rates also accelerated into the 19th century and were particularly high c.1830-1865.

2.8. Oil and Gas[92]

The import of crude petroleum began in 1856. Figures on *consumption* in the economy were not collected until 1964, so earlier consumption is derived from statistics on the import of crude and refined petroleum, and from 1939, domestic production, minus exports. Undoubtedly some of the oil was used for purposes other than the consumption of energy, so the earlier part of the series will slightly overestimate levels of consumption. This is compounded by the fact that an unknown proportion of oil would have been used as marine bunkers. The amount currently used in this way amounts to 1 percent of the primary energy supply.[93] While this would not affect overall energy trends bunkers may have accounted for a reasonable, if still quite small proportion of total petroleum use. The direct (i.e. not derived from other fuel sources such as coal) domestic consumption of gas reserves began in 1958, with actual consumption as opposed to production recorded from 1964. English and Welsh data for both these fuels has been disaggregated from the UK total by the population method.

[92] AAS (1965-2005).
[93] DTI (2006), p. 40.

2.9. Primary electricity

Electricity is always a secondary form of energy and technically should not appear in this analysis. Both thermal electricity - produced, that is, by means of coal or oil - or other forms of power such as hydro-, geo-, or nuclear-electricity are always secondary forms of energy. However, to assist economic analysis and following usual statistical practice, electricity that is generated by non-fossil fuel means has been grouped together. Thus hydro-power and wind power are not included under the sections ‘water’ and ‘wind’, although they could easily be so. This method facilitates an analysis that seeks to determine how much of England’s energy comes from these more modern sources of electricity generation. Statistics on nuclear power begin in 1964; hydro-electric power (in fact primarily generated in Scotland) from 1983, and wind power and other renewables from 1993. For consistency, we should also make estimates regarding the efficiency of water and wind turbines, but as these calculations would make almost negligible difference to the aggregate figures this calculation has not been attempted. In England and Wales, by far the most important sources of renewable power are biofuels and landfill gas. We must also account for net imports of electricity.[94]

2.10. Population

Censuses recording the total population resident are extant from 1801, and these have been employed, with extrapolation, from this date. I have used the mid-year estimates rather than the raw census figures. Inevitably there is some under-recording in such a procedure, though more recent censuses have attempted to correct for this error. Be-

[94] DTI (2006), p. 25.

fore 1801, we are reliant – and fortunate – to have the benefit of the vast amount of research done by Wrigley & Schofield and their collaborators on the the population history of England, which provides estimates reaching back to 1540 based on back projection from data sampled from the registers of births, marriages and deaths kept by Anglican parishes. The essential correctness of these results has been backed up by further studies.[95] However, before 1801 we have much less data on the Welsh population. In 1801, this stood at 6.7 percent of the English and Welsh total. This proportion has been used to estimate the Welsh population on the basis of trends outlined by Wrigley and Schofield, which obviously gives room for some error, although their research tended to suggest that regional trends in vital rates within England were not strongly divergent. Migration is an unknown factor though it seems likely that there was more out- and in-migration in the Welsh case. The resulting figures are lower than alternative estimates for Wales provided by Williams and Owen, but the error margin for the combined totals is small: probably no more than 1 percent.[96]

[95] It should be noted that Wrigley and Schofield provide slightly higher estimates of population than those from the censuses.

[96] Wrigley & Schofield (1981), Williams (1987), pp. 406-9.

2. Structure, trend, level

3. Structure, trend, level

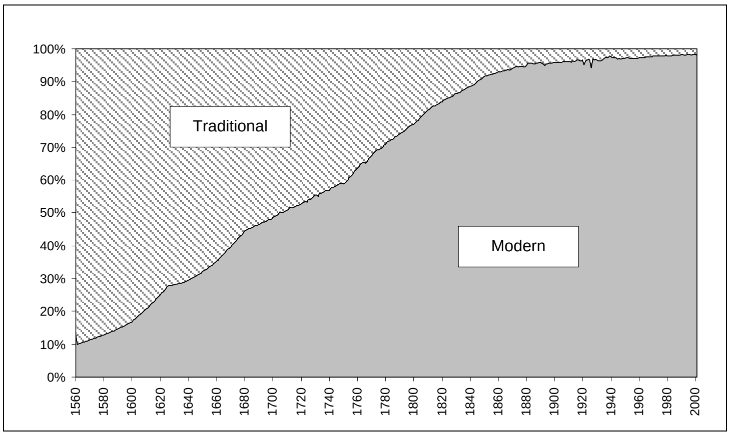
3.1. Structure

The methodologies described above make it clear that much of the earlier part of the data series, especially relating to traditional carriers, remains conjectural. However, we can be fairly sure that in order of magnitude they are broadly correct, and that only radical shifts in the assumptions employed would change the estimates of either the general level of energy consumption, or the structure of different carriers that made up that consumption.

Already by the end of Elizabeth I's reign, 'traditional' carriers made up only 81 percent of the total, and fossil fuels thus played a considerable role in the English economy. Although the choice of a precise date is clearly arbitrary, coal became a more important provider of thermal energy than wood around about, or a little earlier than 1620. By 1700 coal provided the majority share of all energy consumption and was completely dominant by the end of the 18th century. This dominance lasted until the late 1950s, after which coal has seen a steady and steep decline in relative importance.

Coal has played such an overwhelmingly important role in Britain's long-term energy history that the relative importance of other carriers largely mirrors its use. Around 1600, the energy consumption of the muscle power and brains of the economy, human and animal, made up the largest single share of energy consumption at some 53 percent. One and a half centuries later these still accounted for over a quarter of the total, but despite rapid advances in absolute numbers during the 19th century, progressively dwindled into insignificance. Perhaps of some surprise to economic historians, given their prominence in general literature and the history of technology, is that in aggregate terms water and wind power have been of negligible significance in English and Welsh energy history. This does not discount, however, a vital role in particular sectors, and possibly very high rates of energy productivity relative to other energy carriers. Before the widespread use of steam power for shipping from the 1860s, for example, Britain could not have functioned at all as a trading nation without harnessing wind power. Indeed, neither could it have developed important internal networks of supply such as the North Sea coastal coal trade.

Figure 3. *The transition from modern to traditional energy carriers, 1560-2001*



Source: Appendix.

Waterpower never accounted for more than 1 percent of aggregate energy consumption and has been in steady relative decline since the 16th century. Wind power enjoyed a brief flourishing as a result of the 18th century expansion of the merchant marine, from under 1 percent of the aggregate total before the 1740s to peak at 2.3 percent in 1816. As the figures for firewood are calculated from a maximal estimate of the supply-side, and the bulk of this was supplied from an only gradually shrinking area of woodland, we would expect its proportional importance to shrink steadily over time. It accounted for around a third of energy consumption in 1560, and was overtaken by coal as a thermal energy provider around 1619, at which point it provided about a quarter of the aggregate sum. By 1700 it provided only a little over a tenth of the total, and less than a 20th a century later.

Table 4. Composition of energy consumption in England and Wales 1600-2000 (%)

	1600	1700	1800	1900	1950	2000
Food	27.5	19.9	7.4	2.5	3	1.5
Firewood	28.7	13.4	4.4	0	0	0
Fodder (draught)	25.6	16.4	8.8	1.7	0	0
Wind	0.5	0.8	2.3	0.3	0	0
Water	1	0.6	0.2	0.03	0	0
Fossil fuels	16.7	48.6	77	95.5	97	90.6
Primary electricity	0	0	0	0	0	7.9

Source: Appendix 2.

By the beginning of the 20th century British energy consumption was almost entirely comprised of coal. The post-WWII period saw however a dramatic diversification in the employment of fossil fuels (including gas). Petroleum amounted to a little more than a tenth of total consumption in the 1940s but rose to become the dominant carrier, with over half of the total, by 1972. The oil crisis put only a temporary dent in its predominance. During most of the 1990s its share remained about 40 percent. The use of gas saw steady and rapid increases, largely substituting for coal, from the early 1970s to reach 38 percent of the total by 2000 and is now the largest carrier. The use of 'primary electricity', largely generated by nuclear power, saw a rapid advance in the 1980s and early 1990s to peak at 9.4 percent in 1993, its later lower relative importance owing to rapid absolute increases in the use of oil and gas. However in the 21st century the trend towards gas and nuclear may be reversing, with increased use of imported electricity where the UK has less control over its energy carrier mix. Since 2000 price trends have also promoted the use of coal for electricity generation. Indigenous energy production fell almost 10 percent between 2004 and 2005. In 2005-6 the UK has slipped into being a net importer of oil for the first time in many years.[1]

Table 5. Composition of 'modern' energy consumption in England & Wales, 1920-2000

	Coal	Oil	Natural Gas	Primary electricity
1920	97.7	2.3	-	-
1950	87.9	12.1	-	-
1970	48.1	47.2	4.7	-
2000	10.5	40.9	39.2	8.8

Source: see Appendix 2.

Table 6. Composition of energy consumption in 1850 (%)

	England & Wales	Sweden	Netherlands	Italy	Spain
Muscle	7	25	38	41	50
Firewood	0	73	11	51	46
Wind, Water	2	<1	10	1	2
Fossil fuels	91	2	41	7	2

Sources: Appendix 2; Malanima (2006), pp. 96-8; Kander (2002), p. 219-224; Gales et al (2007).

This data can be compared with a wider European experience, as displayed in the table above. Comparative data has been assembled from a range of northern and southern countries from 1850 onward. At this point in time, most

[1] DTI (2006), pp. 4, 8 & 13.

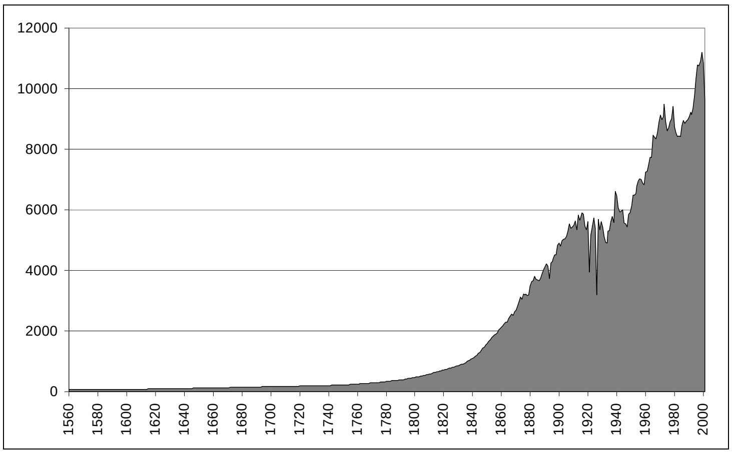
European economies were still firmly rooted in the 'organic' age. The profile of England and Wales' energy consumption was already markedly different from any other European country in the 17th century. Indeed, even around 1900 the Mediterranean and Scandinavian countries only used the same proportion of fossil fuel energy that England had reached at the time of Oliver Cromwell.

3.2. Trend

As we have seen, trends in aggregate energy consumption were largely driven by coal. Inevitably, when coal made up a small if rapidly expanding proportion of total energy consumption, the rate of growth in aggregate demand was perforce below the rate of increase in the use of coal. Aggregate energy demand accelerated after the middle of the 18th century, basically because coal had come to dominate consumption. Consumption grew at the still quite modest rate of around 1.6 percent per annum up until the 1830s. This equates very roughly with the rate of growth of industrial production, and is rather more than the rate of population growth except at the very end of the period. Thereafter energy consumption experienced rising growth of up to 3.5 percent per annum by the mid-1870s. This trend break is most likely explained by a sudden relative cheapening in the cost of coal attendant on the development of the railways. Rather slower growth persisted until the First World War, after which fossil fuel consumption (by now around 95 percent of the total) experienced relatively stable levels. Steady growth returned in the 1950s. Twin oil crisis shocks in 1973 and 1979 and industrial restructuring temporarily depressed consumption before growth resumed. This was particularly rapid in the period of economic recovery from 1993-9.

Britain has been developing as a fossil fuel economy since the 16th century, and it is thus not surprising that the trend breaks in growth have been few and have largely related to 'modern' crises in supply, often determined by political interventions. Comparison demonstrates that Britain has until recently been unusual by European standards. The very high level of energy consumption based on coal that already prevailed in 1800 means that English energy consumption rose by a factor of 19 between 1800 and the present, while Europe as a whole has seen a 35-fold rise. Per capita consumption, which rose by a factor of ten over the four centuries 1600-2000, rose by 3.5 times 1800-2000, in contrast to Europe as a whole where per capita energy consumption rose over 10 times in the latter period. In other words, it appears that the full transition from an 'organic economy' to the economy we have today entails roughly a tenfold increase in per capita energy consumption, but in the case of Britain this was drawn out over a long period of time.

Figure 4. *Total Energy Consumption in England & Wales (PJ)*



Source: Appendix 1.

England's per capita consumption of fossil fuels was probably almost 150 times the world average in 1800 (and probably quite a bit more still than the world average with Britain's consumption deducted). This fell rapidly to only eleven times the world average by 1900, a little under five times the world average by 1950, and under three times the world average today. These comparisons clearly illustrate how exceptional the English and Welsh economy were in the early modern and classic 'Industrial Revolution' period.

Table 7. Estimates of per capita energy consumption in Europe, per capita traditional energy carriers, the European population, total energy consumption, and per capita GDP.

	Per c. kcal. per day, Europe	Per c. kcal per day, England	Trad. Energy (%) Europe	Trad. Energy (%) England	Energy Consumption, Europe (1830=100)	Energy Consumption, England (1830=100)
1800	14,750	37,740	87	20	79	61
1830	15,150	41,000	80	14	100	100
1900	37,590	100,100	25	5	404	570
1950	47,430	90,540	15	3	678	697
1970	89,560	121,970	5	2	1504	1052
1989	106,700	116,100	5	2	1933	1036
2000	141,900	135,800	5	2	2709	1210

Sources: data on European energy are from Malanima (1996), p. 126; data on GDP in 12 Western European countries from Maddison (2003), pp. 58-65. English and Welsh data in Appendix 2.

Note: energy consumption is expressed in per c. kcal per day. traditional energy consumption – food for men, feed for animals, firewood, energy from water and wind – is a percentage of total consumption.

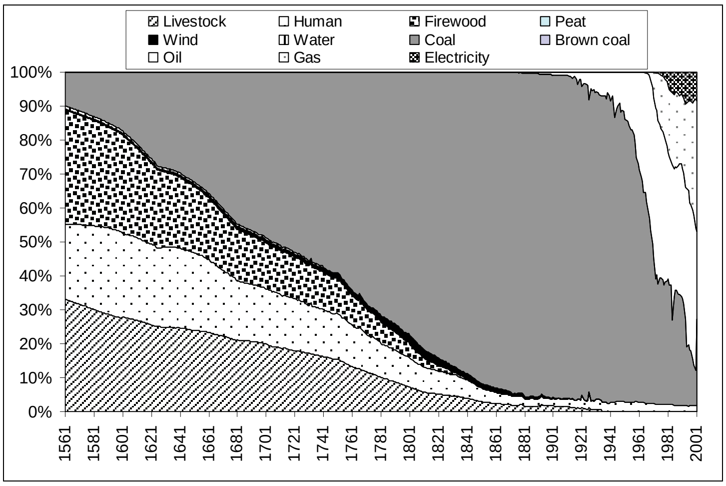
Before about 1750 aggregate energy consumption grew at a rate of 0.7-0.75 percent each year. After this date growth has been very consistent at around 1.6-2 percent each year. This long-term trend has only been broken by three phases:

1. A period of accelerated growth, reaching up to 3.5 percent, between the mid-1830s and mid-1870s.
2. Stagnation during the World Wars and the Great Depression.

3. A shorter period of stagnation between 1973 and the early 1990s.

The long-run energy history of England and Wales is thus one of continuity. Continuity, that is, of a gradual transition from 'traditional' energy carriers to the use of coal between the late 16th century and the 20th century. More radical shifts in the shares of total energy consumption taken up by each carrier are only apparent after 1950.

Figure 5. *Energy consumption in England and Wales by carrier*



Source: Appendix 2.

This data would seem to stand in agreement with recent work on growth rates in the classic 'Industrial Revolution' period that have tended to downplay any pronounced trend breaks in aggregate growth. Indeed, the peak rate of expansion in coal use (ca.1830-1870) matches well the peak rate of expansion in economic activity more generally.[2]

We have already seen that the period 1770-1830 did see a rapid expansion in the amount of fixed motive power

[2] Mokyr (2004), p. 4.

(ships, windmills and waterwheels) at the country's disposal. These are too small relative to coal use to make any difference to aggregate trends, but might they equal or be greater than growth in the use of steam engines (providing fixed motive power by the transformation of thermal energy) thought to be characteristic of this period? Testing this hypothesis brings us to a debate about the relative importance of steam and 'traditional' sources of fixed motive power during the Industrial Revolution, as some recent authors have sought to downplay the role of the former.[3]

Table 8. Sources of fixed motive power in England & Wales (Hp)

Year	Water (agriculture)	Water (Industry & Mining)	Water (Total)	Steam	Total fixed motive power
c.1800	35,000	20,000	55,000	30,000	85,000
c.1838	57,120	50,000	107,120	140,000	250,000
1870	50,400	70,000	120,400	1,100,000	1,220,000

Source: see text.

The process of estimating fixed steam power (i.e. excluding locomotives and steam ships) is as fraught as the process of estimating fixed waterpower. The discussion is generally couched in terms of the United Kingdom as a whole, although Britain was far more industrialized than Ireland and had the lion's share of steam power, especially at an early date. Following Kanefsky's estimate for 1870 I have assumed that around 70 percent of the total steam power of the United Kingdom was located in England and Wales.[4] The estimate of 1838 provides for a total amount of fixed steam power operating in the United Kingdom as being 200,000 Hp. This is conveniently situated between Musson's estimates of around 100,000 Hp in 1824 and 300,000 Hp in 1850.[5] Again, a rather conservative estimate of 70

[3] Crafts (2003a).
[4] Kanefksy (1979), p. 373.
[5] Musson (1976), pp. 423, 435.

percent of the UK total being English and Welsh at this date has been taken. The estimate from 1800 is rather arbitrarily situated between estimates of Harris and Kanfesky for this early period, based on numbers of steam engines. As these are based on estimates of capacity of the assumed average power of engines this figure may be rather higher than actual use.[6]

Kanefsky has estimated that steam engines accounted for around 30 percent of the coal consumption of the United Kingdom in 1870.[7] As British coal consumption was just under 100 million tons at this time, it implied that the equivalent of the entire coal consumption of 1830 had been added just to supply steam power in the intervening years (steam power having increased around tenfold). Thus a revolution in motive power did indeed have a very profound influence on the British energy economy, making a considerable impact on the elevated rate of growth in coal use between the mid-1830s and mid-1860s. In the 1830s around 10 percent of coal consumption went to steam engines, and certainly rather less than this in 1800. Steam power probably became more important than waterpower around 1820, the large growth in the use of waterpower notwithstanding.

Generally speaking, the increase in *final consumption* of *useful energy* was much higher than this data suggests, because of the great efficiency improvements in equipment over time, as well as the fundamental differences between energy carriers. For example, Malanima notes that it has been estimated that the efficiency of a working animal hardly reaches 10 percent. Most fodder is used for the metabolism and does not produce mechanical energy. In the case of a human being, efficiency is higher: about 20 percent. Traditional fireplaces and stoves employing firewood

[6] Greenberg (1983), p. 1252.
[7] Church (1986), p. 28.

usually had a very low efficiency, hardly reaching 25 percent. Today modern energy systems are credited with an efficiency of about 35 percent. In the UK in 2005, final consumption amounted to 70 percent of the statistically recorded primary energy supply. Most losses now occur during electricity production, and in practice there are further losses during the processes of use not captured in the statistics.[8] However, an exception to these trends is the shift from the use of water to steam power during early industrialization; in this case, steam power is far less efficient than water, and as we shall see, this helps to account for the falling energy efficiency, or put another way, rising energy intensity of the industrializing economy.

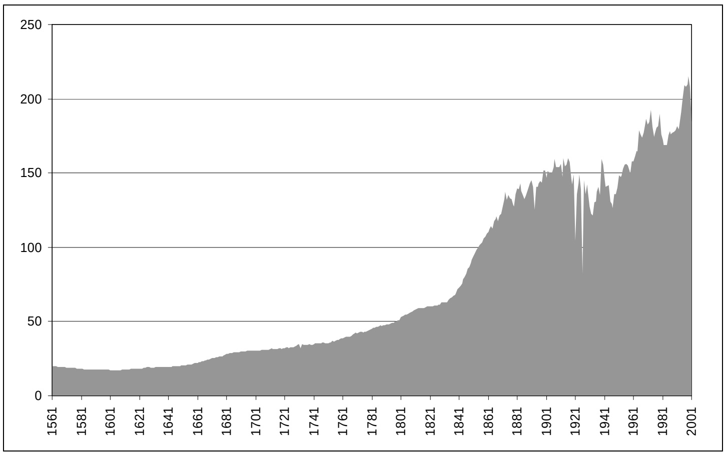
3.3. Level

From the middle of the 17th century a steady rise in per capita energy consumption began that would continue almost unbroken until the First World War. Somewhat accelerated phases can be observed during the reign of Charles II (1660-85), as coal consumption rose rapidly but population fell; and between 1750 and the Napoleonic wars. Its late 16th century level had already doubled by 1750 and the same value was added again in the next 50-60 years. The great acceleration in per capita consumption came, however between approximately 1830 and 1870 – along with much of the spread of an industrial and service sector workforce over much of the country; dramatic rises in per capita income; and the rapid extension of steam power, As with aggregate consumption, there was pronounced variability and stagnation in level between the onset of the First World War and 1945. Rapid post-war growth was cut off by another period of large fluctuations and stagnation in levels

[8] Malanima (2006), p. 70; DTI (2006), p. 40.

between 1973 and 1992. The rest of the 1990s saw exceptionally rapid increases in per capita consumption.

Figure 6. *Per Capita Energy Consumption in England & Wales (GJ)*



Source: see text.

However, at early stages of economic development England and Wales accompanied unusually high levels of per capita energy consumption with high energy intensity, or in other words, a low efficiency of energy use. Energy intensity measures energy consumption relative to income, or how much energy it takes to produce each unit of income. British exceptionalism can be illustrated by comparing energy consumption at given levels of per capita GDP, ranging from \$ 1,100 (roughly the level that all countries had achieved prior to growth associated with the fossil fuel age) to \$ 3,000. This last level of income was achieved by England and Wales in 1851, but in few other places until the 20th century; in Italy only in 1916 (though quite possibly later, as this year appears aberrant in Italian GDP statistics), and Spain in 1957.

Table 9. Per capita energy consumption at different per capita GDP levels (GJ)

GDP (1990$)	1100	1500	2000	2500	3000
England & Wales	19.01	30.59	57.41	85.45	88.3
Netherlands	-	-	26.5	35.4	43.1
Sweden	47.32	36.19	41.44	49.8	56.94
Germany	12.19	19.25	34.53	54.87	70.53
Italy		18.1	20.7	23.6	21.9
Spain	15	16	24.9	24.7	35.3

Note: These estimates use GDP data from Maddison (2003).

Source: Warde & Lindmark (2006).

Sweden's energy consumption levels are high because of very large firewood consumption (almost five times the English level!), largely for domestic hearths. At each level of income, English and Welsh consumption is very much higher than most of its neighbours'. This is in part because of a 'pioneer', and then 'vintage technology' effect. Reaching high levels of income at an early date is associated with relatively inefficient technology and high energy consumption rates. However, the development of a certain kind of capital stock means that these traits are carried over into later periods.[9] The divergences also result from radically different structures of the energy economy. At a GDP per capita level of $ 3,000 some 97 percent of energy came from 'modern carriers' in Britain, but only around two-thirds in Spain and the Netherlands, and less than a third in Italy. Despite the fact that in the long-run modern economies tend to be more energy efficient than traditional ones, the development of coal dependent heavy industry in England and Wales led to an energy-guzzling path to growth. As shown in table 10, the United Kingdom has only dipped below the European per capita average in 1990s, despite consistently enjoying relatively high income levels at which one might expect high levels of energy efficiency. Lower

[9] Lindmark (2004).

levels of per capita consumption relative to France and Germany were achieved in the 1960s and 1970s.

Table 10. Per capita energy consumption (modern carriers) in some developed countries, 1950-1990 (Toe per year)

	1950	1960	1970	1980	1990
Italy	0.336	0.805	2.112	2.517	2.730
Japan	0.380	1.020	2.905	3.261	3.536
United Kingdom	2.768	3.446	4.137	3.854	3.675
France	1.379	2.083	3.228	3.881	3.845
Germany*	1.825	2.883	4.254	4.809	4.351
The Netherlands	1.405	2.206	4.640	5.415	4.459
Canada	3.876	5.970	7.799	9.348	10.009
USA	5.531	6.119	8.058	8.221	7.882
URSS	1.102	2.196	3.294	4.578	5.014
EC**	1.231	2.141	3.622	3.972	3.410
World	0.707	1.089	1.422	1.575	1.567

* Fed. Germany until 1980. In 1990 Dem. Germany is included.
** 9 countries until 1980; 12 countries in 1990.

Source: Spinelli cited in Malanima (2006), p. 64.

4. Analysis

4. Analysis

4.1. Price and transitions

The purpose of this volume is to present data, and to explain the methodology underlying its production; it is not the place for a sustained analysis of what caused the levels or trends observed. However, a brief excursus into the relationships between energy consumption and the primary indicators utilised by economic historians – prices and GDP – can set the figures in some context, and provide some pointers for future research.

The strange thing about the price for energy is that the energy itself can hardly be said to have a price at all. It is effectively a free gift, and this goes a long way towards explaining its economic importance.

As with most commodities, the price of energy is determined by the sum of cost of the labour and capital utilised to produce it, and any rents that possessors of the commodity can charge.

$$P(E) = W + K + R.$$

What is immediately apparent in the case of *primary* energy, and indeed other natural resources, is that while there is a cost incurred in obtaining and consuming it, the cost does not bear on the production of the energy itself, but extraction costs: wages of miners or woodcutters, the cost of capital equipment, and rent. Given that what is being bought is the input of energy required to extract further useful energy, this relationship can also be expressed in energetic terms:

$$E = (f)z(E^{W}+E^{k})$$

That is, the energy obtained is a function of the energy inputs from labour and capital, multiplied by *z,* itself a function of the given state of technology and the organisation of extraction. Even in organic economies, z must be a relatively high number for the economy to function: most of the energetic gain in pre-industrial agriculture does not, after all, come from inputs of labour or capital, but from the 'free gift' of insolation and chemical processes.

Most economic processes can be described in this way. In most cases, however, z will tend towards unity at the very best, or incur a loss (the law of entropy). This is because when someone is put to work for a day, a substantial part of their wages simply goes towards reproducing their ability (or willingness) to work the next day. If one pays for the motive power of a man or a horse, you will get no more energy out than the energy they put in, generally with conversion losses. Economic value is not simply a function of energy of course but in this situation it is difficult to increase material well-being. Predominately agricultural economies will tend towards this situation outside of the agricultural sector – something familiar to the Physiocrats.

If we express the energy relationship more clearly in terms of prices the nature and importance of the 'free gift' becomes clearer;

$P(E) = P(E^w)+P(E^k)+R.$

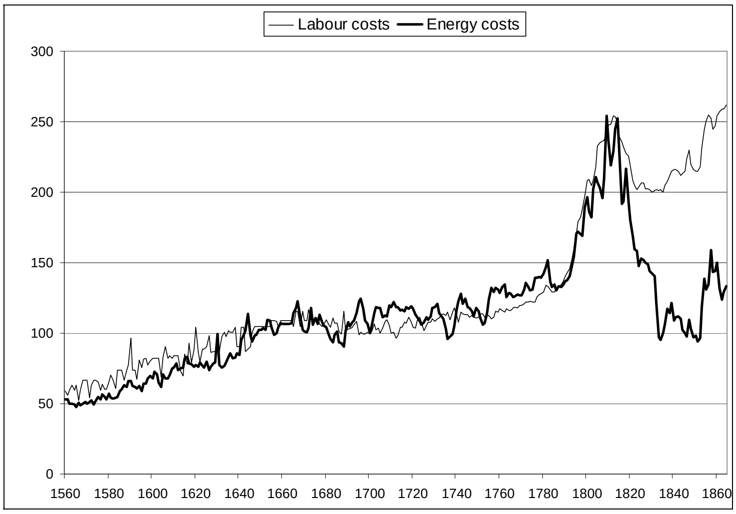
We know that E is larger than E^w+E^k by the multiplier z. Thus unless R (rents) amount to $(z(P^k+P^w))-(P^k+P^w)$ the 'user' of the energy is not in fact bearing any cost for a significant part of her or his consumption. The surplus energy is pure profit. Unless the producer exercises a monopoly position, or the price of each unit of energy only covers and no more the cost of energy embodied as labour and capital (in which case both z=1 and rents are zero), then the net balance of energy obtained in the production process is a 'free gift'. In other words, only if energy is entirely recycled within the system and there is no net gain beyond that expended by the factors of production; or, if rents correctly discount for future disappearance of the stock of energy, will some energy obtained not be a 'free gift'. Of course, we must remember that the energy extracted also requires labour and capital for its utilisation. The 'free gift' is only meaningful in the context of *effective demand* for it. Without this it would be of no value: countries with huge natural resource endowments are not rich if they do not have the means to exploit them, which is why more developed economies tend to reap the bulk of the benefits from trade in such things.

This simple model helps us distinguish between the properties of different energy carriers. Let us compare wood and coal in the 18th century. A single woodcutter could cut and prepare about 1.1 tonnes of firewood in a day (3.3 million Kcal) compared with a coal miner who could extract as much as 2.5 tonnes (17.5 million Kcal). Given that a man working in these trades might consume 4,000 Kcal per day, this represents an extremely good return: of 1:825 in the case of wood, or 1:4375 in the case of coal. In contrast the energetic return from growing wheat was about 1:100. Clearly an economy that could usefully harness thermal instead of muscle energy was at a massive advantage; and while the proportional gain from shifting from wood to coal was less, in absolute terms it was much larger. Technological improvements that could also improve the efficiency of energy extraction (i.e. raise 'z', and produce more energy for each input of labour and capital) were also concentrated in the coal-using sector. Other things being equal, if access to coal and wood were largely a question of labour costs, coal had a considerable advantage over wood.

However, until the 1820s neither coal nor wood could effectively be used to provide motive power. This meant that for travel over land energy supplies remained dependent on the 'organic' economy that supplied muscle power, and where the 'free gift' to labour was approximately 40 times less than in the case of coal. Most consumers, of course, did not reside immediately in the vicinity of pits or forests. Given that we have described the cost of energy consumption for the end user with the equation $P(E) = P(E^w)+P(E^k)+R$, and the energy embodied in labour and capital was of organic origin, this meant that in practice obtaining coal at any distance from the coalfield was largely determined by the price of food, and fossil energy supplies did not enjoy a very great price advantage over muscle energy or wood. Indeed, the primary difference in price between wood and coal was probably determined by rents, because wood competed for space with other uses and had to pay the rent consequent upon that, while there were no competing uses for mineral seams. The changing point at which coal-use became more economic than wood use was probably thus determined by the general level of land rents, and these in turn were determined by the necessity of producing by far the least efficient output in energetic terms, food. It is likely that it was not the scarcity of wood but the relative scarcity of food that made coal a more attractive fuel, although of course improvements in infrastructure would have the effect of raising the multiplier 'z' to the end user and encouraging the use of coal.

These matters require much further investigation. But it is perhaps not surprising that rapid increase in the use of coal came in the Elizabethan and Jacobean periods, when rents were also steeply advancing. The true break, however, come after the 1820s. For the entire period previously the price of coal and the price of labour were closely correlated, hardly surprisingly as one was effectively paying for the same thing: food energy. From the 1820s, as shown in Figure 5, these prices radically and permanently diverged, and per capita consumption of coal rose rapidly, largely used to supply steam engines.

Figure 7. *Labour and Energy Costs compared, 1560-1864 (1700=100, nominal prices)*



Source: Energy prices from Phelps-Brown & Hopkins (1981). Nominal wages from Officer (2004).

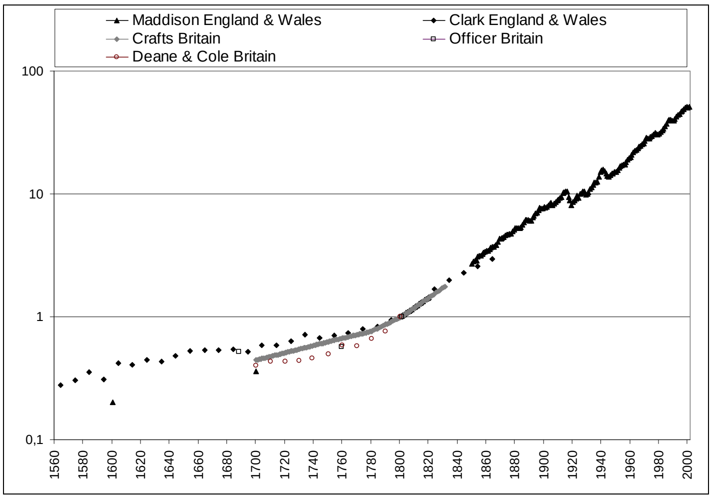
4.2 Energy and GDP

Finally, we will look at energy consumption relative to GDP. For the modern era, this presents the problem of disaggregating English and Welsh GDP from that of the United Kingdom. For the long period before 1830 there is a more profound difficulty in calculating GDP at all. Post-1830 I disaggregate English and Welsh GDP from British via the 'population method'. It is likely that this slightly understates English and Welsh GDP throughout the period under observation, as Scottish GDP, that has only been officially calculated very recently, was probably below the British average over the long-term.[1] For the 18th century there is the difficulty that we do not have many estimates of

[1] See note 100.

the Scottish population of the quality supplied by Wrigley and Schofield for England, yet some GDP estimates (such as those of Deane and Cole and Crafts) are of British GDP. It has simply been assumed here, for the sake of convenience and in lieu of any better estimates, that the *trends* in these series can stand as a proxy of those of England and Wales. This factor may however explain a small amount of the differences between the GDP levels calculated by Clark (for England) and estimates of British trends.[2]

Figure 8. *Estimates of British GDP, 1560-2001 (1800=1, log scale)*



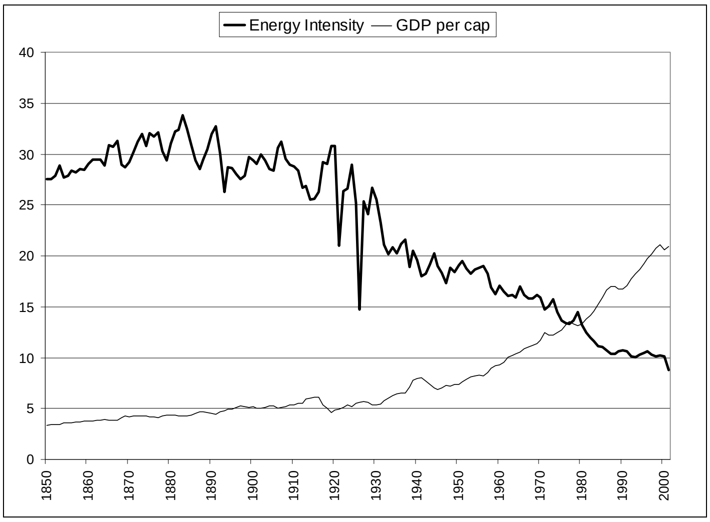
Sources: Maddison (2003); Clark (2001); Crafts (1985); Officer (2003); Deane & Cole (1962).

This is not the place to engage in a very detailed discussion of GDP estimates, about which there is an extensive literature, although any such discussion is clearly highly germane to our understanding of the energy economy. We can, however, apply a further and original test to these estimates by examining trends in the energy intensity of the

[2] Deane & Cole (1962); Crafts (1985); Clark (2001).

economy (energy consumption divided by GDP). Estimates of GDP per capita prior to the mid-19th century vary very widely, implying that the error in some estimates is large. It is unlikely that the margins for error in the estimates of energy consumption are of nearly such a magnitude, even if the component estimates are uniformly biased in one direction. Given that through international comparison we can develop reasonable expectations of energy intensity levels at given technologies and levels of income, the energy data can thus be used as a test for the plausibility of GDP estimates.

Figure 9. *English and Welsh Energy Intensity 1850-2001 (MJ per year/GDP in 1990$) and GDP per capita (in 1000 1990$)*



Sources: Maddison (2003); Appendix 3.

The 19th and 20th century trend in Energy Intensity is uncontroversial. The trend was steadily upwards until a peak was reached in 1883, showing a classic 'Environmental Kuznets Curve'.[3] After 1883, with a few outliers (such as

[3] Kander (2002).

1926, the year of the general strike) Energy Intensity showed a steadily declining level until the 1990s, with particularly rapid falls in eras when traditional manufacturing industry struggled: the early 1930s and 1973-88.

The estimated trends diverge widely prior to 1850, depending on which estimates for GDP we choose. Those of Clark imply a very rapid rise in energy intensity from the 1830s, at the same time that per capita energy consumption also rose dramatically. However, contrary to Clark it is usually argued that wages and per capita income also rose rapidly in this period.[4] If Clark is right the large expansion in coal use brought virtually no economic benefit. The more generally accepted estimates of Crafts imply a rather smooth upward trend in Energy Intensity starting in the middle of the 18th century and lasting until 1883.

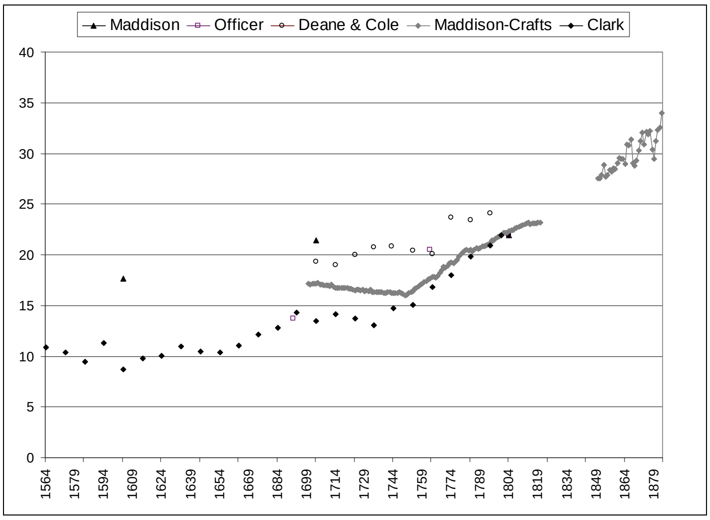
The pre-1800 picture gives further reason to doubt any estimates that give England a very high per capita income in the 16th and 17th centuries. Clark's figures for GDP imply an Energy Intensity level lower than 15 MJ/$ until the 1770s, and a level as low as 7-8 MJ/$ in the late 16th century. Yet 18th century per capita energy consumption was already very high by 'pre-industrial' standards, and it is hard to reconcile this fact with the implication that English energy use was also extraordinarily efficient. According to Clark, until the middle of the 18th century, British Energy Intensity would approximate to that of Mediterranean economies before the extensive use of fossil fuel, and would still have been low in 1700 despite the fact that half of energy came from fossil fuels and that these fuels were nearly entirely employed to *supplement,* rather than *substitute for* the traditional carriers that dominated in the middle of the 16th century.[5] There is indeed a classic 'Industrial Revolution' in the Clark story,

[4] Athough the 'standards of living' debate has its own vast literature that it is not possible to gloss here.

[5] Warde & Lindmark, (2006); Gales at el (2007).

but it is an enormous revolution in energy inefficiency for little material gain.

Figure 10. *English and Welsh Energy Intensity 1564-1883 (MJ per year/GDP in 1990$)*

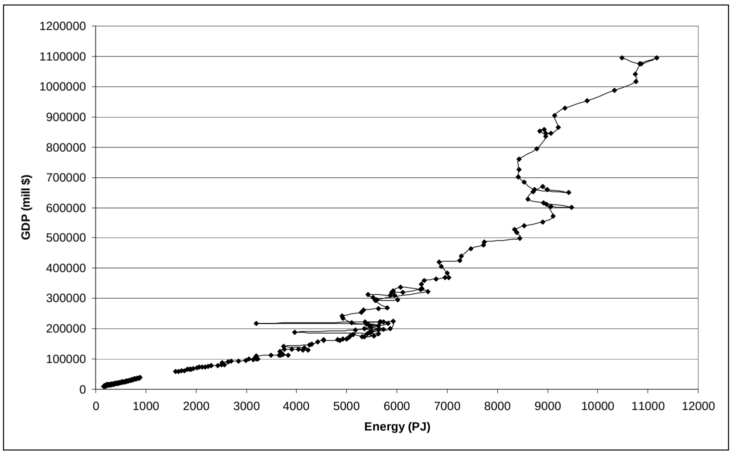


Source: see Figure 7.

In contrast, the Crafts story, assuming by 1700 that GDP was probably a little above the low levels also estimated by Maddison for 1600, would imply by western and southern European standards a relatively energy intense economy (> 15 Mj/$) in the late 16th century that succeeded in growing gradually across the 17th century without decreasing energy efficiency, and indeed somewhat improving it between 1700 and 1750. This age was marked by modest gains in per capita income of around 0.4 percent per annum, and possibly slightly larger gains to overall GDP supported by increases in the use of coal of 1-3 percent per annum. Put another way, over the 17th century per capita income may have risen by a third to a half, national income roughly doubled, coal consumption gone up by a factor of nearly seven and aggregate energy consumption doubled (largely because of coal).

This would in turn be a surprising and notable achievement, but rather more plausible than the picture painted by Clark. The period after 1750 or perhaps 1770 was then marked by technological change that allowed new applications of coal (notably in the application of motive power and in the iron production process), pushing the production possibility curve rapidly outwards but at the cost of rising Energy Intensity.

Figure 11. *GDP (1990$) and Energy Consumption*



This *could* suggest that 17th century growth required in part the development of much more energy intense sectors that helped drive aggregate growth even though the overall trend in Energy Intensity remained rather flat. It will be an important area of investigation to see if it can be determined that overall growth was disproportionately driven by those sectors of the economy, and regions of domestic consumption, that were dependent on the much faster rate of increase in the use of coal.

Another way of examining the same problem is to remove the data from a chronological series and simply examine the relationship between GDP and energy consumption, treating energy consumption as a function of GDP. We can perceive in the figure below three phases in this relationship.

1. A first stage before energy consumption reaches around 5,000 PJ where economic growth requires quite rapid accoutrements of energy. This is energy intense growth and appears to have characterised English economic development from the start point of this part analysis, c.1700 (using the Crafts-Maddison series).
2. A second clear phase between levels of total energy consumption of 6,000 PJ and 8,500 PJ, where the energy intensity of growth is relatively stable but at a slower rate to the previous phase. In chronological terms, this is characteristic of post-WWII British growth.
3. A final phase where the energy intensity of development is similar to that in the second phase, but at a higher level of income. This characterises the 1990s.

Between these three periods are two zones that we might characterise as 'noise' or a change of phase in the energy basis of growth. Within these phases the same level of energy consumption can result in rather different levels of GDP. This seems to characterise much of the first half of the 20th century and the period 1970-1984. These mark periods of profound transition in the energy economy, the first with a rapidly increasing share of oil in the aggregate total, and the second corresponding very closely to the rapid expansion in the use of gas. These thus appear as significant energy-economising periods of transition.

5. Conclusions

5. Conclusion

The primary aim of this booklet is simply to present estimates of the energy consumption of England and Wales between 1550 and the present. Given the preliminary nature of this attempt, it would be surprising indeed, if gratifying, should they turn out to be very accurate. As the aggregate figures are provided in appendices, the assumptions and methods that I have employed may be altered as the reader pleases, to provide new estimates or further test the implications of the data presented here. It is moreover hoped that the data may facilitate international comparison with countries where equivalent data exists. This data in itself reinforces an impression that is widespread among economic historians, but rarely examined in detail. Already by the late 18th century (and in truth, a century before this), English energy consumption was extraordinary by world standards. This was not because coal substituted traditional energy carriers, but supplemented them and vastly expanded the per capita energy supply. One could surmise that had this not led to relatively high levels of income, the British would have been guilty of some of the most profligate behaviour in history. Indeed, this is precisely the implication of those analyses that argue that the English were *already* relatively rich long before the Industrial Revolution, and that the vast growth in the use of coal made little difference to their level of incomes.

Before about 1750 England and Wales gradually increased a level of energy consumption that was probably already relatively high by European standards, largely through the growth in the use of coal. This went hand in hand with gradual aggregate and per capita growth that meant the energy intensity of the economy changed little, if at all. Between around 1750 and 1880 England followed an energy-intense course of development. Initially this seems to have largely kept economic growth in step with population growth, but by the middle of the 19th century per capita consumption of coal, wage levels and per capita income levels expanded more markedly.

After the mid-1880s the rate of increase in coal consumption slowed, and by the turn of the century the very earliest stages of the 'second industrial revolution', the turn to oil and electricity, began to make their mark. The rates of growth in this 'true factory age' of the unit drive were however unsettled by world wars, industrial unrest and depression. By the end of this technological revolution, by which time nearly every sector of the economy was thoroughly mechanized or employing 'secondary' forms of energy such as electricity dependent on a large technical infrastructure, dramatic efficiency improvements had been achieved. Income was significantly higher, but per capita levels of energy consumption did not again reach pre-WWI levels until the 1960s, while energy intensity was back to the level of the late 18th century.

From the 1950s Britain shared, though to a lesser degree than some nations, in the 'European miracle' that saw rapid growth rates and a general convergence in energy consumption levels. Energy intensity continued to fall but per capita consumption levels increased rapidly. From around 1970 the country entered into a period of economic restructuring, energy price shocks and the advent of North Sea gas. It is not clear, however, that this represents a profound break in the relationship between energy use and economic development. One might speculate that it rather represented a kind of final completion of the 'second industrial revolution', as electricity, gas and especially petrol-fuelled transport came to dominate energy consumption. These contributed in particular to continued falls in the Energy Intensity of the industrial sector. Rapid growth in consumption levels resumed in the 1990s, and Energy Intensity's long decline was arrested as domestic and transport use, both of which still demonstrate rising Energy Intensity, have become the largest sectors. This trend shows no sign of altering.[1]

[1] DTI (2006), pp. 2 & 4. Coal use was considerably up, however, at the expense of gas and nuclear electricity generation.

List of Abbreviations

AAS	Annual Abstract of Statistics
BPP	British Parliamentary Papers
DEFRA	Department for Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
HCJ	House of Commons Journal
ONS	Office for National Statistics

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APPENDIX

I

Aggregate Series

1. Energy consumption in England & Wales, 1560-2001 Petajoules)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1560	21.1	14.1	21.4	0.2	0.5	6.3				63.7
1561	21.1	14.2	21.4	0.2	0.5	6.4				63.9
1562	21.1	14.4	21.5	0.2	0.5	6.5				64.2
1563	21.1	14.5	21.5	0.2	0.5	6.6				64.5
1564	21.1	14.6	21.5	0.2	0.5	6.7				64.6
1565	21.1	14.8	21.5	0.2	0.5	6.9				65.0
1566	21.1	14.9	21.5	0.2	0.6	7.0				65.2
1567	21.1	15.0	21.5	0.2	0.6	7.1				65.5
1568	21.1	15.3	21.5	0.2	0.6	7.2				65.8
1569	21.1	15.4	21.5	0.2	0.6	7.4				66.1
1570	21.1	15.5	21.5	0.2	0.6	7.5				66.4
1571	21.1	15.6	21.5	0.2	0.6	7.6				66.6
1572	21.1	15.7	21.5	0.2	0.6	7.8				66.9
1573	21.0	15.8	21.5	0.2	0.6	7.9				67.1
1574	21.0	15.9	21.6	0.2	0.6	8.1				67.4
1575	21.0	16.1	21.6	0.2	0.6	8.2				67.7
1576	21.0	16.3	21.6	0.2	0.6	8.3				68.0
1577	21.0	16.5	21.6	0.2	0.6	8.5				68.4
1578	21.0	16.6	21.6	0.2	0.6	8.6				68.7
1579	21.0	16.8	21.6	0.3	0.6	8.8				69.0
1580	21.0	17.0	21.6	0.3	0.6	9.0				69.4
1581	21.0	17.1	21.6	0.3	0.6	9.1				69.7
1582	21.0	17.3	21.6	0.3	0.6	9.3				70.1
1583	21.0	17.6	21.6	0.3	0.6	9.5				70.5
1584	21.0	17.8	21.6	0.3	0.6	9.6				70.9
1585	21.0	17.9	21.6	0.3	0.6	9.8				71.2
1586	21.0	18.1	21.7	0.3	0.6	10.0				71.6
1587	21.0	18.2	21.7	0.3	0.6	10.2				71.9
1588	20.9	18.2	21.7	0.3	0.6	10.3				72.0
1589	20.9	18.3	21.7	0.3	0.6	10.5				72.4
1590	20.9	18.6	21.7	0.3	0.6	10.7				72.8
1591	20.9	18.6	21.7	0.3	0.6	10.9				73.0
1592	20.9	18.6	21.7	0.3	0.6	11.1				73.3
1593	20.9	18.6	21.7	0.3	0.6	11.3				73.5
1594	20.9	18.8	21.7	0.3	0.7	11.5				73.9
1595	20.9	19.0	21.7	0.3	0.7	11.7				74.3
1596	20.9	19.1	21.7	0.3	0.7	11.9				74.6
1597	20.9	19.1	21.8	0.3	0.7	12.1				74.9
1598	20.9	19.0	21.8	0.3	0.7	12.3				75.0
1599	20.9	19.1	21.8	0.3	0.7	12.6				75.4
1600	20.9	19.4	21.8	0.3	0.7	12.7				75.8
1601	21.0	18.5	21.8	0.4	0.7	13.1				75.4
1602	21.1	18.7	21.8	0.4	0.7	13.5				76.1
1603	21.2	18.8	21.8	0.4	0.7	13.9				76.8
1604	21.4	18.9	21.8	0.4	0.7	14.3				77.4
1605	21.5	19.1	21.8	0.4	0.7	14.7				78.2
1606	21.6	19.3	21.8	0.4	0.7	15.1				78.9
1607	21.7	19.5	21.8	0.4	0.7	15.6				79.8
1608	21.9	19.7	21.8	0.4	0.7	16.0				80.6
1609	22.0	20.0	21.9	0.4	0.7	16.5				81.4
1610	22.1	20.1	21.9	0.4	0.7	17.0				82.1
1611	22.2	20.2	21.9	0.4	0.7	17.5				82.9
1612	22.4	20.3	21.9	0.4	0.7	18.0				83.7
1613	22.5	20.5	21.9	0.4	0.7	18.6				84.5
1614	22.6	20.5	21.9	0.4	0.7	19.1				85.3
1615	22.7	20.7	21.9	0.4	0.7	19.7				86.2

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1616	22.9	20.8	21.9	0.4	0.7	20.3				87.0
1617	23.0	20.9	21.9	0.4	0.7	20.9				87.8
1618	23.1	21.1	21.9	0.4	0.7	21.5				88.8
1619	23.2	21.3	21.9	0.4	0.7	22.2				89.8
1620	23.4	21.5	21.9	0.4	0.7	22.8				90.9
1621	23.5	21.9	22.0	0.4	0.7	23.5				92.0
1622	23.6	22.2	22.0	0.4	0.8	24.2				93.2
1623	23.7	22.3	22.0	0.4	0.8	24.9				94.2
1624	23.9	22.3	22.0	0.4	0.8	25.7				95.0
1625	24.0	22.3	22.0	0.5	0.8	26.5				96.0
1626	24.1	22.3	22.0	0.5	0.8	26.7				96.4
1627	24.2	22.5	22.0	0.5	0.8	27.0				96.9
1628	24.4	22.8	22.0	0.5	0.8	27.3				97.7
1629	24.5	23.0	22.0	0.5	0.8	27.6				98.3
1630	24.6	23.3	22.0	0.5	0.8	27.8				99.0
1631	24.7	23.4	22.0	0.5	0.8	28.1				99.6
1632	24.9	23.5	22.0	0.5	0.8	28.4				100.1
1633	25.0	23.7	22.1	0.5	0.8	28.7				100.8
1634	25.1	24.0	22.1	0.5	0.8	29.0				101.5
1635	25.3	24.2	22.1	0.6	0.8	29.3				102.1
1636	25.4	24.4	22.1	0.6	0.8	29.6				102.8
1637	25.5	24.5	22.1	0.6	0.8	29.9				103.4
1638	25.6	24.6	22.1	0.6	0.8	30.2				103.9
1639	25.8	24.5	22.1	0.6	0.8	30.5				104.3
1640	25.9	24.5	22.1	0.6	0.8	30.9				104.9
1641	26.0	24.7	22.1	0.7	0.8	31.4				105.8
1642	26.1	24.9	22.1	0.7	0.8	31.9				106.6
1643	26.3	25.0	22.1	0.7	0.8	32.5				107.4
1644	26.4	25.0	22.1	0.7	0.8	33.0				108.0
1645	26.5	25.1	22.2	0.7	0.8	33.5				108.8
1646	26.6	25.4	22.2	0.7	0.8	34.1				109.8
1647	26.8	25.6	22.2	0.7	0.8	34.6				110.7
1648	26.9	25.7	22.2	0.8	0.8	35.2				111.5
1649	27.0	25.8	22.2	0.8	0.8	35.7				112.3
1650	27.1	25.8	22.2	0.8	0.9	36.3				113.0
1651	27.3	25.9	22.2	0.8	0.9	36.9				114.0
1652	27.4	26.0	22.2	0.8	0.9	37.5				114.8
1653	27.5	26.1	22.2	0.8	0.9	38.1				115.6
1654	27.6	26.0	22.2	0.9	0.9	38.7				116.3
1655	27.8	26.2	22.2	0.9	0.9	39.3				117.2
1656	27.9	26.4	22.2	0.9	0.9	40.0				118.3
1657	28.0	26.5	22.2	0.9	0.9	40.6				119.1
1658	28.1	26.1	22.2	0.9	0.9	41.3				119.6
1659	28.3	25.8	22.2	0.9	0.9	41.9				120.1
1660	28.4	25.9	22.2	1.0	0.9	42.8				121.1
1661	28.5	26.2	22.3	1.0	0.9	43.7				122.5
1662	28.6	26.1	22.3	1.0	0.9	44.6				123.5
1663	28.8	26.1	22.3	1.0	0.9	45.6				124.6
1664	28.9	26.2	22.3	1.0	0.9	46.6				125.9
1665	29.0	26.2	22.3	1.0	0.9	47.6				127.0
1666	29.1	26.0	22.3	1.0	0.9	48.6				128.0
1667	29.3	26.0	22.3	1.1	0.9	49.6				129.1
1668	29.4	26.0	22.3	1.1	0.9	50.7				130.3
1669	29.5	26.0	22.3	1.1	0.9	51.7				131.5
1670	29.6	26.0	22.3	1.1	0.9	52.8				132.7
1671	29.8	25.9	22.3	1.1	0.9	53.9				133.9
1672	29.9	25.8	22.3	1.1	0.9	55.1				135.1

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1673	30.0	26.0	22.3	1.2	0.9	56.2				136.6
1674	30.1	26.1	22.3	1.2	0.9	57.4				138.1
1675	30.3	26.2	22.3	1.2	0.9	58.6				139.5
1676	30.4	26.0	22.3	1.2	0.9	59.9				140.7
1677	30.5	26.2	22.3	1.2	0.9	61.2				142.3
1678	30.6	26.4	22.3	1.2	0.9	62.5				144.0
1679	30.8	26.3	22.3	1.2	0.9	63.8				145.3
1680	30.9	26.1	22.3	1.3	0.9	65.3				146.8
1681	31.0	25.8	22.3	1.3	0.9	65.9				147.3
1682	31.1	25.7	22.4	1.3	0.9	66.5				148.0
1683	31.3	25.7	22.4	1.3	0.9	67.2				148.7
1684	31.4	25.7	22.4	1.3	0.9	67.8				149.6
1685	31.5	25.7	22.4	1.3	0.9	68.5				150.4
1686	31.6	25.7	22.4	1.4	0.9	69.2				151.2
1687	31.8	25.8	22.4	1.4	0.9	69.9				152.1
1688	31.9	25.9	22.4	1.3	0.9	70.6				153.1
1689	32.0	26.1	22.4	1.3	0.9	71.4				154.1
1690	32.1	26.1	22.4	1.3	0.9	72.1				155.0
1691	32.3	26.1	22.4	1.3	0.9	72.8				155.9
1692	32.4	26.2	22.4	1.3	0.9	73.6				156.9
1693	32.5	26.3	22.4	1.3	0.9	74.3				157.8
1694	32.6	26.4	22.4	1.3	0.9	75.1				158.8
1695	32.7	26.4	22.4	1.3	0.9	75.9				159.6
1696	32.7	26.4	22.4	1.3	0.9	76.6				160.4
1697	32.7	26.5	22.4	1.3	0.9	77.4				161.3
1698	32.7	26.7	22.4	1.3	0.9	77.3				161.4
1699	32.7	26.8	22.4	1.3	0.9	78.4				162.6
1700	32.7	26.9	22.4	1.3	0.9	79.8				164.1
1701	32.7	27.0	22.4	1.3	1.0	80.4				164.8
1702	32.7	27.1	22.5	1.3	1.0	81.8				166.4
1703	32.8	27.3	22.5	1.3	1.0	82.9				167.7
1704	32.8	27.4	22.5	1.3	1.0	83.6				168.6
1705	32.8	27.4	22.5	1.4	1.0	85.9				171.0
1706	32.8	27.5	22.5	1.4	1.0	85.4				170.5
1707	32.8	27.5	22.5	1.4	1.0	86.0				171.2
1708	32.8	27.6	22.5	1.4	1.0	86.8				172.1
1709	32.9	27.6	22.5	1.5	1.0	87.4				172.8
1710	32.9	27.6	22.5	1.5	1.0	88.4				174.0
1711	32.9	27.6	22.5	1.5	1.0	89.3				174.8
1712	32.9	27.5	22.5	1.5	1.0	92.1				177.6
1713	32.9	27.5	22.5	1.5	1.0	90.7				176.3
1714	33.0	27.6	22.5	1.6	1.1	91.0				176.7
1715	33.0	27.6	22.5	1.6	1.1	92.1				177.8
1716	33.0	27.8	22.5	1.6	1.1	93.0				178.9
1717	33.0	27.9	22.6	1.6	1.1	94.3				180.5
1718	33.0	28.1	22.6	1.7	1.1	95.0				181.4
1719	33.0	28.2	22.6	1.7	1.1	95.8				182.4
1720	33.1	28.2	22.6	1.7	1.1	97.1				183.7
1721	33.1	28.1	22.6	1.7	1.1	97.7				184.3
1722	33.1	28.0	22.6	1.7	1.1	98.7				185.3
1723	33.1	28.1	22.6	1.8	1.1	99.7				186.4
1724	33.1	28.2	22.6	1.8	1.1	99.0				185.8
1725	33.1	28.2	22.6	1.8	1.1	101.9				188.9
1726	33.2	28.3	22.6	1.8	1.1	102.4				189.4
1727	33.2	28.4	22.6	1.9	1.1	103.1				190.4
1728	33.2	28.1	22.6	1.9	1.2	105.1				192.1
1729	33.2	27.6	22.6	1.9	1.2	105.4				192.0

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1730	33.2	27.3	22.6	1.9	1.2	107.6				193.9
1731	33.2	27.3	22.7	2.0	1.2	107.8				194.1
1732	33.3	30.2	22.7	2.0	1.2	108.6				197.9
1733	33.3	27.5	22.7	2.0	1.2	109.9				196.6
1734	33.3	27.7	22.7	2.0	1.2	110.7				197.7
1735	33.3	27.9	22.7	2.1	1.2	111.8				199.0
1736	33.3	28.0	22.7	2.1	1.2	112.8				200.1
1737	33.3	28.2	22.7	2.1	1.2	114.2				201.8
1738	33.4	28.3	22.7	2.1	1.2	115.4				203.1
1739	33.4	28.4	22.7	2.2	1.2	116.0				203.9
1740	33.4	28.5	22.7	2.2	1.2	116.5				204.6
1741	33.4	28.5	22.7	2.2	1.3	118.8				206.9
1742	33.4	28.2	22.7	2.3	1.3	120.4				208.2
1743	33.4	28.1	22.7	2.3	1.3	121.0				208.9
1744	33.5	28.3	22.7	2.3	1.3	122.7				210.8
1745	33.5	28.5	22.7	2.3	1.3	123.9				212.3
1746	33.5	28.6	22.8	2.4	1.3	124.9				213.4
1747	33.5	28.6	22.8	2.4	1.3	126.8				215.5
1748	33.5	28.7	22.8	2.4	1.3	127.4				216.1
1749	33.5	28.8	22.8	2.4	1.3	128.1				217.0
1750	33.6	29.0	22.8	2.5	1.3	127.4				216.5
1751	33.6	29.2	22.7	2.5	1.3	128.8				218.1
1752	33.6	29.4	22.7	2.7	1.3	132.2				221.8
1753	33.6	29.6	22.6	2.8	1.3	135.1				225.1
1754	33.6	29.2	22.6	2.8	1.3	138.7				228.2
1755	33.6	29.9	22.5	2.9	1.3	142.1				232.4
1756	33.7	30.1	22.5	2.9	1.3	145.3				235.8
1757	33.7	30.2	22.4	3.0	1.3	149.4				240.0
1758	33.7	30.3	22.4	3.0	1.3	152.7				243.4
1759	33.7	30.4	22.4	3.0	1.3	156.4				247.2
1760	33.7	30.5	22.3	3.1	1.3	159.9				250.9
1761	33.7	30.7	22.3	3.1	1.3	162.4				253.5
1762	33.8	30.8	22.2	3.1	1.3	166.1				257.3
1763	33.8	30.7	22.2	3.2	1.3	169.5				260.6
1764	33.8	30.8	22.1	3.4	1.3	172.9				264.3
1765	33.8	31.0	22.1	3.5	1.3	174.1				265.9
1766	33.8	32.2	22.0	3.7	1.3	173.3				266.3
1767	33.9	32.3	22.0	3.7	1.3	177.9				270.9
1768	33.9	32.3	21.9	3.6	1.3	184.9				278.0
1769	33.9	32.5	21.9	3.8	1.3	190.0				283.4
1770	33.9	32.7	21.8	4.0	1.3	195.8				289.5
1771	33.9	31.8	21.8	3.9	1.3	197.9				290.6
1772	33.9	32.1	21.7	4.0	1.3	202.6				295.5
1773	34.0	32.3	21.7	4.0	1.3	207.9				301.1
1774	34.0	32.5	21.6	4.0	1.2	211.3				304.7
1775	34.0	32.8	21.6	4.2	1.2	210.4				304.2
1776	34.0	33.0	21.5	4.5	1.2	214.5				308.7
1777	34.0	33.3	21.5	4.7	1.2	219.1				313.8
1778	34.0	33.6	21.4	5.0	1.2	225.5				320.8
1779	34.1	33.9	21.4	5.3	1.2	231.3				327.1
1780	34.1	34.1	21.3	5.5	1.2	236.2				332.4
1781	34.1	34.2	21.3	5.8	1.2	243.3				339.9
1782	34.1	34.3	21.2	6.1	1.2	248.5				345.4
1783	34.1	34.5	21.2	6.4	1.2	250.4				347.8
1784	34.1	34.6	21.1	6.6	1.2	256.1				353.8
1785	34.2	34.9	21.1	6.9	1.2	258.6				356.9
1786	34.2	35.2	21.0	7.2	1.2	265.5				364.3

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1787	34.2	35.5	21.0	7.5	1.2	272.8				372.1
1788	34.2	35.9	21.0	7.8	1.2	275.0				375.0
1789	34.2	36.3	20.9	7.8	1.1	282.0				382.3
1790	34.2	36.7	20.9	8.3	1.1	287.8				389.0
1791	34.3	37.0	20.8	8.5	1.1	293.7				395.4
1792	34.3	37.5	20.8	8.7	1.1	299.4				401.8
1793	34.3	37.9	20.7	8.8	1.1	305.7				408.5
1794	34.3	38.3	20.7	8.9	1.1	314.7				418.0
1795	34.3	38.6	20.6	8.7	1.1	324.1				427.4
1796	34.3	38.9	20.6	8.4	1.1	329.4				432.7
1797	34.4	39.3	20.5	9.0	1.1	338.7				443.0
1798	34.4	39.8	20.5	9.3	1.1	346.3				451.3
1799	34.4	40.2	20.4	9.7	1.1	353.7				459.5
1800	34.4	41.0	20.4	10.7	1.1	359.8				467.3
1801	34.4	40.5	20.0	11.4	1.1	371.2				478.5
1802	34.4	40.7	19.6	12.0	1.1	379.4				487.1
1803	34.3	41.0	19.2	12.6	1.1	390.0				498.1
1804	34.3	41.4	18.7	13.1	1.1	401.2				509.8
1805	34.3	41.9	18.3	13.2	1.1	412.8				521.6
1806	34.2	42.3	17.9	13.1	1.1	423.6				532.2
1807	34.2	42.7	17.5	13.3	1.1	437.9				546.7
1808	34.2	43.1	17.1	13.5	1.1	448.8				557.8
1809	34.2	43.5	16.7	13.7	1.1	462.1				571.3
1810	34.1	43.8	16.3	14.0	1.1	474.8				584.2
1811	34.1	44.2	15.9	14.2	1.1	487.9				597.4
1812	35.0	44.7	15.5	14.3	1.1	501.2				611.8
1813	34.8	45.3	15.1	14.9	1.1	514.9				626.2
1814	35.0	45.8	14.7	15.3	1.1	526.6				638.5
1815	35.4	46.4	14.3	15.7	1.1	534.4				647.3
1816	35.8	46.9	13.9	15.8	1.2	546.8				660.3
1817	36.1	47.5	13.4	15.3	1.2	560.1				673.6
1818	36.5	48.1	13.0	15.5	1.2	573.1				687.4
1819	36.8	48.6	12.6	15.5	1.2	587.5				702.2
1820	37.2	49.1	12.2	15.4	1.2	599.9				715.0
1821	37.3	49.7	11.8	14.9	1.2	613.3				728.2
1822	37.7	50.4	11.4	14.6	1.2	626.6				741.9
1823	38.0	51.0	11.0	14.5	1.3	641.3				757.1
1824	38.4	51.5	10.6	14.8	1.3	654.4				770.9
1825	38.8	52.0	10.2	14.6	1.3	665.8				782.7
1826	39.1	52.4	9.8	15.1	1.3	678.6				796.3
1827	39.5	52.8	9.4	13.6	1.3	691.6				808.3
1828	39.8	53.3	9.0	13.7	1.4	705.7				822.9
1829	40.2	53.8	8.6	13.7	1.4	737.0				854.7
1830	40.5	54.3	8.2	13.7	1.4	747.3				865.4
1831	40.9	54.9	7.7	13.9	1.4	760.9				879.8
1832	41.3	55.3	7.3	14.1	1.5	772.6				892.1
1833	41.6	55.7	6.9	14.1	1.5	785.2				905.1
1834	42.0	56.2	6.5	14.3	1.5	815.1				935.7
1835	42.3	56.7	6.1	14.6	1.5	841.7				962.9
1836	42.7	57.4	5.7	14.5	1.5	866.6				988.5
1837	43.1	57.8	5.3	14.3	1.6	891.0				1013.1
1838	43.4	58.2	4.9	14.8	1.6	915.5				1038.5
1839	43.8	58.8	4.5	15.8	1.6	947.4				1071.8
1840	44.1	58.8	4.1	16.9	1.6	974.6				1100.2
1841	44.6	60.5	3.7	17.9	1.6	1003.8				1132.1
1842	45.0	61.2	3.3	18.5	1.6	1035.2				1164.8
1843	45.4	61.7	2.9	18.3	1.6	1074.0				1203.9

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1844	45.8	62.2	2.4	18.5	1.6	1133.7				1264.3
1845	46.2	62.7	2.0	19.0	1.6	1171.7				1303.2
1846	46.6	63.1	1.6	19.4	1.6	1229.7				1362.1
1847	47.0	63.6	1.2	20.0	1.6	1296.4				1429.8
1848	47.4	64.0	0.8	20.5	1.6	1335.5				1470.0
1849	47.8	64.5	0.4	21.0	1.6	1398.0				1533.4
1850	48.2	64.9	0.0	21.5	1.7	1449.2				1585.5
1851	48.7	65.5		21.2	1.7	1510.3				1647.3
1852	49.1	66.7		22.4	1.7	1569.9				1709.8
1853	49.5	67.2		23.9	1.7	1627.1				1769.3
1854	49.9	67.7		24.9	1.7	1677.8				1822.0
1855	50.3	68.2		25.1	1.7	1721.5				1866.7
1856	50.7	68.7		25.1	1.7	1759.3				1905.6
1857	51.1	69.2		26.2	1.7	1798.0	0.1			1946.3
1858	51.5	69.7		26.6	1.7	1862.9	0.1			2012.5
1859	51.9	70.2		26.7	1.7	1915.0	0.0			2065.5
1860	52.3	70.7		26.6	1.7	1972.9	0.0			2124.2
1861	52.8	71.2		27.5	1.7	2024.7	0.0			2177.9
1862	53.2	71.8		27.8	1.7	2077.0	0.7			2232.2
1863	53.6	72.5		29.9	1.7	2140.8	1.1			2299.5
1864	54.0	73.1		27.7	1.7	2135.3	0.6			2292.4
1865	54.4	73.8		31.2	1.7	2264.8	0.4			2426.3
1866	54.8	74.4		31.0	1.7	2332.4	0.9			2495.2
1867	55.2	75.0		30.6	1.7	2396.3	0.7			2559.6
1868	55.6	75.7		30.8	1.7	2350.5	0.6			2515.0
1869	56.0	76.4		30.1	1.7	2467.5	0.8			2632.5
1870	56.4	77.0		28.5	1.7	2521.2	1.0			2685.9
1871	56.9	77.5		27.6	1.7	2673.7	1.3			2838.8
1872	57.8	78.3		26.6	1.7	2816.5	0.9			2981.8
1873	58.8	79.0		25.8	1.7	2965.4	2.4			3133.3
1874	59.8	79.8		25.9	1.7	2879.9	3.2			3050.3
1875	60.8	80.6		26.6	1.7	3041.4	2.9			3213.9
1876	61.7	81.3		26.9	1.7	3019.3	3.7			3194.6
1877	62.7	82.1		26.9	1.7	3043.6	5.0			3222.0
1878	63.7	82.9		26.8	1.7	3000.9	4.4			3180.4
1879	64.7	83.7		25.7	1.7	3011.2	6.4			3193.4
1880	65.7	84.5		24.3	1.7	3302.8	5.7			3484.7
1881	51.2	85.0		23.3	1.7	3465.9	8.7			3635.9
1882	52.1	85.6		22.9	1.7	3496.4	8.8			3667.5
1883	53.1	86.5		22.2	1.7	3637.6	10.4			3811.5
1884	54.1	86.5		21.9	1.7	3547.3	7.8			3719.4
1885	55.1	87.1		21.8	1.7	3503.8	10.9			3680.5
1886	56.1	87.7		21.5	1.7	3472.1	10.5			3649.5
1887	57.0	88.3		20.5	1.7	3562.1	11.4			3741.1
1888	58.0	88.9		19.7	1.7	3703.0	14.0			3885.2
1889	59.0	89.5		19.2	1.7	3836.3	15.2			4020.9
1890	60.0	90.1		18.5	1.7	3927.2	15.6			4113.0
1891	76.4	91.6		18.8	1.7	4009.8	19.4			4217.5
1892	77.1	92.2		19.5	1.7	3926.4	19.3			4136.2
1893	77.8	92.9		19.2	1.7	3511.3	23.0			3725.8
1894	78.5	93.6		18.9	1.7	4024.5	24.2			4241.3
1895	79.2	94.3		18.1	1.6	4061.9	26.3			4281.4
1896	79.9	95.9		17.3	1.6	4177.3	28.2			4400.1
1897	80.6	96.5		16.4	1.6	4288.2	27.5			4510.8
1898	81.2	97.2		15.1	1.6	4296.4	32.5			4524.2
1899	81.9	97.9		14.2	1.6	4602.6	35.6			4833.9
1900	82.6	98.6		13.2	1.6	4659.7	37.8			4893.7

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1901	83.3	101.5		12.6	1.6	4557.8	37.6			4794.5
1902	82.7	104.4		12.3	1.6	4735.4	42.3			4978.8
1903	82.1	107.2		11.8	1.6	4774.0	42.5			5019.2
1904	81.5	110.2		11.4	1.6	4796.7	44.9			5046.3
1905	80.9	113.2		10.6	1.6	4862.8	44.6			5113.7
1906	80.3	116.2		9.8	1.6	5042.4	44.5			5294.9
1907	79.7	120.1		9.2	1.6	5269.1	45.3			5525.0
1908	79.1	123.3		8.9		5136.0	51.1			5398.4
1909	78.4	126.5		8.2		5184.0	53.3			5450.4
1910	77.8	129.7		7.0		5227.3	51.5			5493.4
1911	77.2	132.9		6.2		5358.5	54.5			5629.4
1912	74.5	135.8		5.7		5066.7	61.8			5344.5
1913	71.8	138.9		5.4		5534.9	72.8			5823.7
1914	69.0	142.7		5.0		5346.5	96.5			5659.7
1915	66.3	135.6		4.9		5425.8	87.8			5720.5
1916	63.6	134.0		4.5		5644.3	67.4			5913.8
1917	60.8	133.3		4.0		5528.2	123.5			5849.8
1918	58.1	134.2		3.8		5075.0	197.8			5469.0
1919	55.4	134.9		3.7		5040.2	106.6			5340.9
1920	52.6	135.7		3.7		5301.1	122.3			5615.4
1921	49.9	136.4		3.9		3593.6	169.0			3952.8
1922	47.2	137.3		3.6		4809.2	166.7			5163.9
1923	44.4	138.1		3.5		5101.7	179.1			5466.8
1924	41.7	138.9		3.3		5336.6	210.1			5730.6
1925	40.4	139.8		3.3		5000.7	207.5			5391.7
1926	39.2	140.6		3.3		2749.5	259.6			3192.1
1927	37.9	141.4		3.2		5207.0	281.3			5670.9
1928	36.6	142.3		3.1		4882.3	285.7			5350.0
1929	35.3	143.1		3.0		5151.0	289.2			5621.6
1930	34.1	143.9		3.0		4929.9	323.7			5434.6
1931	32.8	144.8		2.9		4612.7	299.5			5092.7
1932	31.5	145.6		3.0		4432.4	305.1			4917.6
1933	30.3	146.4		2.9		4387.2	333.0			4899.7
1934	29.0	147.1		2.7		4727.9	374.2			5280.9
1935	0.0	147.9		2.6		4795.5	376.0			5322.1
1936	0.0	148.7		2.6		5068.1	395.9			5615.4
1937	0.0	149.5		2.6		5228.2	410.9			5791.2
1938	0.0	150.3		2.5		4996.2	434.1			5583.1
1939	0.0	151.1				6047.1	406.7			6604.9
1940	0.0	163.9				5865.4	445.8			6475.0
1941	0.0	163.5				5395.8	511.4			6070.8
1942	0.0	159.4				5360.4	407.8			5927.5
1943	0.0	160.3				5204.5	590.9			5955.7
1944	0.0	169.2				5043.3	796.1			6008.6
1945	0.0	169.1				4785.2	615.3			5569.6
1946	0.0	165.0				4809.7	552.3			5527.0
1947	0.0	165.8				4771.4	489.9			5427.1
1948	0.0	172.2				5002.9	689.2			5864.2
1949	0.0	175.7				5051.0	670.0			5896.7
1950	0.0	180.0				5227.6	707.3			6115.0
1951	0.0	180.2				5409.5	909.0			6498.6
1952	0.0	179.8				5382.7	920.5			6483.0
1953	0.0	186.2				5400.5	961.2			6547.9
1954	0.0	195.0				5531.1	1059.5			6785.6
1955	0.0	197.2				5570.0	1187.1			6954.3
1956	0.0	199.6				5632.4	1196.6			7028.7
1957	0.0	197.7				5513.7	1284.2			6995.6

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Total
1958	0.0	199.5				5242.4	1436.8	0.0		6878.7
1959	0.0	199.7				4907.8	1729.2	0.1		6836.8
1960	0.0	201.5				5096.3	1950.0	0.5		7248.3
1961	0.0	202.5				4971.8	2098.1	3.2		7275.6
1962	0.0	204.7				4958.8	2306.5	6.3		7476.2
1963	0.0	206.8				5035.2	2468.4	9.5		7719.9
1964	0.0	204.2				4790.0	2729.3	9.5	0.1	7733.1
1965	0.0	204.7				5239.1	2978.4	30.1	0.2	8452.6
1966	0.0	203.7				4986.2	3169.7	29.3	0.5	8389.5
1967	0.0	207.4				4677.4	3402.7	49.4	1.0	8338.0
1968	0.0	206.3				4657.8	3554.8	111.6	1.8	8532.2
1969	0.0	208.4				4533.3	3934.7	217.5	2.9	8896.9
1970	0.0	208.9				4283.7	4199.6	414.8	4.7	9111.6
1971	0.0	204.4				3844.4	4257.6	669.1	8.0	8983.5
1972	0.0	199.7				3339.5	4560.5	949.6	13.9	9063.2
1973	0.0	197.4				3615.4	4621.0	1027.5	22.5	9483.9
1974	0.0	191.0				3167.5	4291.0	1229.4	38.0	8917.0
1975	0.0	187.8				3191.0	3881.8	1288.0	54.6	8603.3
1976	0.0	186.8				3247.3	3825.8	1367.0	86.1	8712.9
1977	0.0	186.0				3258.0	3893.7	1453.2	118.9	8909.7
1978	0.0	186.6				3173.9	3976.4	1507.6	148.8	8993.3
1979	0.0	187.1				3411.8	3970.7	1647.6	196.4	9413.6
1980	0.0	185.0				3171.4	3483.1	1647.5	251.4	8738.4
1981	0.0	183.8				3154.2	3189.6	1670.2	334.8	8532.6
1982	0.0	181.4				2941.8	3199.0	1662.5	428.6	8413.3
1983	0.0	178.7				2969.1	3070.5	1733.6	478.4	8430.4
1984	0.0	172.9				2109.8	3852.8	1774.3	516.6	8426.4
1985	0.0	169.1				2806.1	3313.8	1909.0	581.4	8779.4
1986	0.0	173.7				3030.3	3263.3	1941.5	547.4	8956.2
1987	0.0	171.8				2995.6	3178.3	1994.8	509.6	8850.1
1988	0.0	168.7				2925.4	3373.8	1900.5	563.0	8931.4
1989	0.0	164.4				2939.0	3440.1	1790.8	635.5	8969.8
1990	0.0	159.4				2928.5	3523.7	1862.5	590.1	9064.1
1991	0.0	157.6				2905.8	3531.1	1992.9	632.2	9219.6
1992	0.0	173.2				2746.6	3518.3	2023.3	681.9	9143.3
1993	0.0	171.1				2386.4	3604.4	2305.6	880.3	9347.9
1994	0.0	167.4				1703.8	4569.4	2462.7	884.4	9787.7
1995	0.0	168.0				1881.6	4695.9	2699.9	892.3	10337.7
1996	0.0	187.9				1784.1	4677.6	3211.9	923.1	10784.6
1997	0.0	197.4				1738.2	4623.1	3277.8	923.4	10759.9
1998	0.0	193.0				1480.0	4786.0	3442.9	988.6	10890.5
1999	0.0	188.0				1330.9	4948.9	3783.8	946.9	11198.5
2000	0.0	184.5				1124.4	4558.2	4140.2	851.7	10858.9
2001	0.0	184.3				2438.0	2502.3	3690.6	822.6	9637.9

2. The Structure of Energy Consumption in England & Wales, 1560-2001 (Total = 1)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1560	0.333	0.220	0.338	0.003	0.008	0.128				0.128
1561	0.331	0.222	0.336	0.003	0.008	0.100				0.100
1562	0.329	0.224	0.334	0.003	0.008	0.101				0.101
1563	0.328	0.225	0.333	0.003	0.008	0.103				0.103
1564	0.327	0.226	0.332	0.003	0.008	0.104				0.104
1565	0.325	0.227	0.331	0.003	0.008	0.106				0.106
1566	0.323	0.228	0.329	0.003	0.008	0.107				0.107
1567	0.322	0.230	0.328	0.003	0.008	0.109				0.109
1568	0.320	0.232	0.327	0.003	0.008	0.110				0.110
1569	0.319	0.233	0.325	0.003	0.009	0.111				0.111
1570	0.317	0.234	0.324	0.003	0.009	0.113				0.113
1571	0.316	0.234	0.323	0.003	0.009	0.115				0.115
1572	0.315	0.235	0.322	0.003	0.009	0.116				0.116
1573	0.314	0.236	0.321	0.003	0.009	0.118				0.118
1574	0.312	0.236	0.320	0.003	0.009	0.119				0.119
1575	0.311	0.238	0.319	0.003	0.009	0.121				0.121
1576	0.309	0.239	0.317	0.003	0.009	0.123				0.123
1577	0.307	0.241	0.316	0.004	0.009	0.124				0.124
1578	0.306	0.242	0.314	0.004	0.009	0.126				0.126
1579	0.304	0.243	0.313	0.004	0.009	0.127				0.127
1580	0.302	0.245	0.311	0.004	0.009	0.129				0.129
1581	0.301	0.246	0.310	0.004	0.009	0.131				0.131
1582	0.299	0.247	0.308	0.004	0.009	0.132				0.132
1583	0.297	0.249	0.307	0.004	0.009	0.134				0.134
1584	0.296	0.251	0.305	0.004	0.009	0.136				0.136
1585	0.294	0.252	0.304	0.004	0.009	0.138				0.138
1586	0.293	0.253	0.302	0.004	0.009	0.139				0.139
1587	0.291	0.253	0.301	0.004	0.009	0.141				0.141
1588	0.291	0.252	0.301	0.004	0.009	0.143				0.143
1589	0.289	0.253	0.299	0.004	0.009	0.145				0.145
1590	0.287	0.255	0.298	0.004	0.009	0.147				0.147
1591	0.286	0.254	0.297	0.004	0.009	0.149				0.149
1592	0.285	0.254	0.296	0.004	0.009	0.151				0.151
1593	0.285	0.253	0.296	0.004	0.009	0.154				0.154
1594	0.283	0.254	0.294	0.004	0.009	0.156				0.156
1595	0.281	0.255	0.293	0.004	0.009	0.158				0.158
1596	0.280	0.256	0.291	0.004	0.009	0.160				0.160
1597	0.279	0.255	0.291	0.004	0.009	0.162				0.162
1598	0.278	0.253	0.290	0.005	0.009	0.165				0.165
1599	0.277	0.254	0.289	0.005	0.009	0.167				0.167
1600	0.275	0.256	0.287	0.005	0.009	0.168				0.168
1601	0.278	0.246	0.289	0.005	0.009	0.174				0.174
1602	0.277	0.245	0.286	0.005	0.009	0.177				0.177
1603	0.277	0.245	0.284	0.005	0.009	0.181				0.181
1604	0.276	0.244	0.282	0.005	0.009	0.184				0.184
1605	0.275	0.245	0.279	0.005	0.009	0.188				0.188
1606	0.274	0.244	0.277	0.005	0.009	0.192				0.192
1607	0.273	0.245	0.274	0.005	0.009	0.195				0.195
1608	0.271	0.245	0.271	0.005	0.009	0.199				0.199
1609	0.270	0.245	0.268	0.005	0.009	0.203				0.203
1610	0.269	0.244	0.266	0.005	0.009	0.207				0.207
1611	0.268	0.243	0.264	0.005	0.009	0.211				0.211
1612	0.267	0.243	0.261	0.005	0.009	0.216				0.216
1613	0.266	0.242	0.259	0.005	0.009	0.220				0.220
1614	0.265	0.240	0.257	0.005	0.008	0.224				0.224
1615	0.264	0.240	0.254	0.005	0.008	0.229				0.229

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1616	0.263	0.239	0.252	0.005	0.008	0.233				0.233
1617	0.262	0.238	0.250	0.005	0.008	0.238				0.238
1618	0.260	0.237	0.247	0.005	0.008	0.243				0.243
1619	0.259	0.237	0.244	0.005	0.008	0.247				0.247
1620	0.257	0.237	0.242	0.005	0.008	0.251				0.251
1621	0.255	0.238	0.239	0.005	0.008	0.256				0.256
1622	0.253	0.238	0.236	0.005	0.008	0.260				0.260
1623	0.252	0.237	0.233	0.005	0.008	0.265				0.265
1624	0.251	0.235	0.231	0.005	0.008	0.270				0.270
1625	0.250	0.233	0.229	0.005	0.008	0.276				0.276
1626	0.250	0.232	0.228	0.005	0.008	0.277				0.277
1627	0.250	0.232	0.227	0.005	0.008	0.279				0.279
1628	0.250	0.233	0.225	0.005	0.008	0.279				0.279
1629	0.249	0.234	0.224	0.005	0.008	0.280				0.280
1630	0.249	0.235	0.222	0.005	0.008	0.281				0.281
1631	0.249	0.235	0.221	0.005	0.008	0.283				0.283
1632	0.249	0.234	0.220	0.005	0.008	0.284				0.284
1633	0.248	0.236	0.219	0.005	0.008	0.285				0.285
1634	0.248	0.236	0.217	0.005	0.008	0.286				0.286
1635	0.247	0.237	0.216	0.005	0.008	0.286				0.286
1636	0.247	0.237	0.215	0.006	0.008	0.288				0.288
1637	0.247	0.237	0.214	0.006	0.008	0.289				0.289
1638	0.247	0.237	0.213	0.006	0.008	0.291				0.291
1639	0.247	0.235	0.212	0.006	0.008	0.293				0.293
1640	0.247	0.234	0.211	0.006	0.008	0.295				0.295
1641	0.246	0.234	0.209	0.006	0.008	0.297				0.297
1642	0.245	0.233	0.208	0.006	0.008	0.300				0.300
1643	0.244	0.233	0.206	0.006	0.008	0.302				0.302
1644	0.244	0.231	0.205	0.006	0.008	0.305				0.305
1645	0.244	0.231	0.204	0.007	0.008	0.308				0.308
1646	0.243	0.231	0.202	0.007	0.008	0.310				0.310
1647	0.242	0.231	0.200	0.007	0.008	0.313				0.313
1648	0.241	0.230	0.199	0.007	0.008	0.315				0.315
1649	0.240	0.229	0.198	0.007	0.008	0.318				0.318
1650	0.240	0.228	0.196	0.007	0.008	0.321				0.321
1651	0.239	0.228	0.195	0.007	0.007	0.324				0.324
1652	0.239	0.227	0.193	0.007	0.007	0.326				0.326
1653	0.238	0.225	0.192	0.007	0.007	0.330				0.330
1654	0.238	0.224	0.191	0.007	0.007	0.333				0.333
1655	0.237	0.224	0.190	0.007	0.007	0.335				0.335
1656	0.236	0.224	0.188	0.008	0.007	0.338				0.338
1657	0.235	0.222	0.187	0.008	0.007	0.341				0.341
1658	0.235	0.219	0.186	0.008	0.007	0.345				0.345
1659	0.235	0.215	0.185	0.008	0.007	0.349				0.349
1660	0.234	0.214	0.184	0.008	0.007	0.353				0.353
1661	0.233	0.214	0.182	0.008	0.007	0.357				0.357
1662	0.232	0.211	0.180	0.008	0.007	0.361				0.361
1663	0.231	0.209	0.179	0.008	0.007	0.366				0.366
1664	0.229	0.208	0.177	0.008	0.007	0.370				0.370
1665	0.228	0.206	0.175	0.008	0.007	0.375				0.375
1666	0.228	0.203	0.174	0.008	0.007	0.380				0.380
1667	0.227	0.202	0.173	0.008	0.007	0.384				0.384
1668	0.226	0.200	0.171	0.008	0.007	0.389				0.389
1669	0.224	0.198	0.169	0.008	0.007	0.393				0.393
1670	0.223	0.196	0.168	0.008	0.007	0.398				0.398
1671	0.222	0.193	0.167	0.008	0.007	0.403				0.403
1672	0.221	0.191	0.165	0.008	0.007	0.408				0.408

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1673	0.220	0.190	0.163	0.008	0.007	0.412				0.412
1674	0.218	0.189	0.162	0.008	0.007	0.416				0.416
1675	0.217	0.188	0.160	0.008	0.006	0.421				0.421
1676	0.216	0.185	0.159	0.009	0.006	0.426				0.426
1677	0.214	0.184	0.157	0.009	0.006	0.430				0.430
1678	0.213	0.183	0.155	0.009	0.006	0.434				0.434
1679	0.212	0.181	0.154	0.009	0.006	0.439				0.439
1680	0.210	0.178	0.152	0.009	0.006	0.445				0.445
1681	0.211	0.175	0.152	0.009	0.006	0.447				0.447
1682	0.210	0.174	0.151	0.009	0.006	0.450				0.450
1683	0.210	0.173	0.150	0.009	0.006	0.452				0.452
1684	0.210	0.172	0.150	0.009	0.006	0.454				0.454
1685	0.210	0.171	0.149	0.009	0.006	0.456				0.456
1686	0.209	0.170	0.148	0.009	0.006	0.458				0.458
1687	0.209	0.170	0.147	0.009	0.006	0.460				0.460
1688	0.208	0.169	0.146	0.009	0.006	0.461				0.461
1689	0.208	0.169	0.145	0.009	0.006	0.463				0.463
1690	0.207	0.168	0.144	0.009	0.006	0.465				0.465
1691	0.207	0.168	0.144	0.009	0.006	0.467				0.467
1692	0.207	0.167	0.143	0.008	0.006	0.469				0.469
1693	0.206	0.167	0.142	0.008	0.006	0.471				0.471
1694	0.206	0.166	0.141	0.008	0.006	0.473				0.473
1695	0.205	0.166	0.140	0.008	0.006	0.475				0.475
1696	0.204	0.165	0.140	0.008	0.006	0.478				0.478
1697	0.203	0.165	0.139	0.008	0.006	0.480				0.480
1698	0.203	0.165	0.139	0.008	0.006	0.479				0.479
1699	0.201	0.165	0.138	0.008	0.006	0.482				0.482
1700	0.199	0.164	0.137	0.008	0.006	0.486				0.486
1701	0.199	0.164	0.136	0.008	0.006	0.488				0.488
1702	0.197	0.163	0.135	0.008	0.006	0.492				0.492
1703	0.195	0.163	0.134	0.008	0.006	0.494				0.494
1704	0.194	0.163	0.133	0.008	0.006	0.496				0.496
1705	0.192	0.161	0.131	0.008	0.006	0.502				0.502
1706	0.192	0.161	0.132	0.008	0.006	0.501				0.501
1707	0.192	0.161	0.131	0.008	0.006	0.502				0.502
1708	0.191	0.160	0.131	0.008	0.006	0.504				0.504
1709	0.190	0.160	0.130	0.008	0.006	0.506				0.506
1710	0.189	0.159	0.129	0.008	0.006	0.508				0.508
1711	0.188	0.158	0.129	0.009	0.006	0.511				0.511
1712	0.185	0.155	0.127	0.009	0.006	0.519				0.519
1713	0.187	0.156	0.128	0.009	0.006	0.515				0.515
1714	0.187	0.156	0.128	0.009	0.006	0.515				0.515
1715	0.185	0.155	0.127	0.009	0.006	0.518				0.518
1716	0.184	0.155	0.126	0.009	0.006	0.520				0.520
1717	0.183	0.155	0.125	0.009	0.006	0.522				0.522
1718	0.182	0.155	0.124	0.009	0.006	0.524				0.524
1719	0.181	0.155	0.124	0.009	0.006	0.525				0.525
1720	0.180	0.153	0.123	0.009	0.006	0.528				0.528
1721	0.179	0.152	0.123	0.009	0.006	0.530				0.530
1722	0.179	0.151	0.122	0.009	0.006	0.533				0.533
1723	0.178	0.151	0.121	0.010	0.006	0.535				0.535
1724	0.178	0.152	0.122	0.010	0.006	0.533				0.533
1725	0.175	0.150	0.120	0.010	0.006	0.540				0.540
1726	0.175	0.149	0.119	0.010	0.006	0.540				0.540
1727	0.174	0.149	0.119	0.010	0.006	0.542				0.542
1728	0.173	0.146	0.118	0.010	0.006	0.547				0.547
1729	0.173	0.144	0.118	0.010	0.006	0.549				0.549

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1730	0.171	0.141	0.117	0.010	0.006	0.555				0.555
1731	0.171	0.141	0.117	0.010	0.006	0.555				0.555
1732	0.168	0.152	0.115	0.010	0.006	0.549				0.549
1733	0.169	0.140	0.115	0.010	0.006	0.559				0.559
1734	0.168	0.140	0.115	0.010	0.006	0.560				0.560
1735	0.167	0.140	0.114	0.010	0.006	0.562				0.562
1736	0.167	0.140	0.113	0.010	0.006	0.563				0.563
1737	0.165	0.140	0.112	0.011	0.006	0.566				0.566
1738	0.164	0.139	0.112	0.011	0.006	0.568				0.568
1739	0.164	0.139	0.111	0.011	0.006	0.569				0.569
1740	0.163	0.139	0.111	0.011	0.006	0.570				0.570
1741	0.161	0.138	0.110	0.011	0.006	0.574				0.574
1742	0.161	0.135	0.109	0.011	0.006	0.578				0.578
1743	0.160	0.135	0.109	0.011	0.006	0.579				0.579
1744	0.159	0.134	0.108	0.011	0.006	0.582				0.582
1745	0.158	0.134	0.107	0.011	0.006	0.584				0.584
1746	0.157	0.134	0.107	0.011	0.006	0.585				0.585
1747	0.156	0.133	0.106	0.011	0.006	0.589				0.589
1748	0.155	0.133	0.105	0.011	0.006	0.590				0.590
1749	0.155	0.133	0.105	0.011	0.006	0.590				0.590
1750	0.155	0.134	0.105	0.011	0.006	0.588				0.588
1751	0.154	0.134	0.104	0.011	0.006	0.590				0.590
1752	0.151	0.132	0.102	0.012	0.006	0.596				0.596
1753	0.149	0.131	0.101	0.013	0.006	0.600				0.600
1754	0.147	0.128	0.099	0.012	0.006	0.608				0.608
1755	0.145	0.129	0.097	0.012	0.006	0.611				0.611
1756	0.143	0.128	0.095	0.012	0.006	0.616				0.616
1757	0.140	0.126	0.094	0.012	0.005	0.622				0.622
1758	0.138	0.124	0.092	0.012	0.005	0.627				0.627
1759	0.136	0.123	0.090	0.012	0.005	0.633				0.633
1760	0.134	0.122	0.089	0.012	0.005	0.637				0.637
1761	0.133	0.121	0.088	0.012	0.005	0.641				0.641
1762	0.131	0.120	0.086	0.012	0.005	0.646				0.646
1763	0.130	0.118	0.085	0.012	0.005	0.650				0.650
1764	0.128	0.117	0.084	0.013	0.005	0.654				0.654
1765	0.127	0.117	0.083	0.013	0.005	0.655				0.655
1766	0.127	0.121	0.083	0.014	0.005	0.651				0.651
1767	0.125	0.119	0.081	0.014	0.005	0.657				0.657
1768	0.122	0.116	0.079	0.013	0.005	0.665				0.665
1769	0.120	0.115	0.077	0.013	0.004	0.670				0.670
1770	0.117	0.113	0.075	0.014	0.004	0.676				0.676
1771	0.117	0.110	0.075	0.013	0.004	0.681				0.681
1772	0.115	0.108	0.074	0.013	0.004	0.686				0.686
1773	0.113	0.107	0.072	0.013	0.004	0.691				0.691
1774	0.111	0.107	0.071	0.013	0.004	0.694				0.694
1775	0.112	0.108	0.071	0.014	0.004	0.692				0.692
1776	0.110	0.107	0.070	0.014	0.004	0.695				0.695
1777	0.108	0.106	0.068	0.015	0.004	0.698				0.698
1778	0.106	0.105	0.067	0.016	0.004	0.703				0.703
1779	0.104	0.104	0.065	0.016	0.004	0.707				0.707
1780	0.102	0.102	0.064	0.017	0.004	0.711				0.711
1781	0.100	0.101	0.063	0.017	0.004	0.716				0.716
1782	0.099	0.099	0.062	0.018	0.003	0.719				0.719
1783	0.098	0.099	0.061	0.018	0.003	0.720				0.720
1784	0.096	0.098	0.060	0.019	0.003	0.724				0.724
1785	0.096	0.098	0.059	0.019	0.003	0.725				0.725
1786	0.094	0.097	0.058	0.020	0.003	0.729				0.729

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1787	0.092	0.095	0.056	0.020	0.003	0.733				0.733
1788	0.091	0.096	0.056	0.021	0.003	0.733				0.733
1789	0.090	0.095	0.055	0.020	0.003	0.738				0.738
1790	0.088	0.094	0.054	0.021	0.003	0.740				0.740
1791	0.087	0.094	0.053	0.022	0.003	0.743				0.743
1792	0.085	0.093	0.052	0.022	0.003	0.745				0.745
1793	0.084	0.093	0.051	0.022	0.003	0.748				0.748
1794	0.082	0.092	0.049	0.021	0.003	0.753				0.753
1795	0.080	0.090	0.048	0.020	0.003	0.758				0.758
1796	0.079	0.090	0.048	0.019	0.003	0.761				0.761
1797	0.078	0.089	0.046	0.020	0.002	0.765				0.765
1798	0.076	0.088	0.045	0.021	0.002	0.767				0.767
1799	0.075	0.088	0.044	0.021	0.002	0.770				0.770
1800	0.074	0.088	0.044	0.023	0.002	0.770				0.770
1801	0.072	0.085	0.042	0.024	0.002	0.776				0.776
1802	0.071	0.083	0.040	0.025	0.002	0.779				0.779
1803	0.069	0.082	0.038	0.025	0.002	0.783				0.783
1804	0.067	0.081	0.037	0.026	0.002	0.787				0.787
1805	0.066	0.080	0.035	0.025	0.002	0.791				0.791
1806	0.064	0.079	0.034	0.025	0.002	0.796				0.796
1807	0.063	0.078	0.032	0.024	0.002	0.801				0.801
1808	0.061	0.077	0.031	0.024	0.002	0.805				0.805
1809	0.060	0.076	0.029	0.024	0.002	0.809				0.809
1810	0.058	0.075	0.028	0.024	0.002	0.813				0.813
1811	0.057	0.074	0.027	0.024	0.002	0.817				0.817
1812	0.057	0.073	0.025	0.023	0.002	0.819				0.819
1813	0.056	0.072	0.024	0.024	0.002	0.822				0.822
1814	0.055	0.072	0.023	0.024	0.002	0.825				0.825
1815	0.055	0.072	0.022	0.024	0.002	0.826				0.826
1816	0.054	0.071	0.021	0.024	0.002	0.828				0.828
1817	0.054	0.071	0.020	0.023	0.002	0.831				0.831
1818	0.053	0.070	0.019	0.023	0.002	0.834				0.834
1819	0.052	0.069	0.018	0.022	0.002	0.837				0.837
1820	0.052	0.069	0.017	0.022	0.002	0.839				0.839
1821	0.051	0.068	0.016	0.020	0.002	0.842				0.842
1822	0.051	0.068	0.015	0.020	0.002	0.845				0.845
1823	0.050	0.067	0.015	0.019	0.002	0.847				0.847
1824	0.050	0.067	0.014	0.019	0.002	0.849				0.849
1825	0.050	0.066	0.013	0.019	0.002	0.851				0.851
1826	0.049	0.066	0.012	0.019	0.002	0.852				0.852
1827	0.049	0.065	0.012	0.017	0.002	0.856				0.856
1828	0.048	0.065	0.011	0.017	0.002	0.858				0.858
1829	0.047	0.063	0.010	0.016	0.002	0.862				0.862
1830	0.047	0.063	0.009	0.016	0.002	0.864				0.864
1831	0.046	0.062	0.009	0.016	0.002	0.865				0.865
1832	0.046	0.062	0.008	0.016	0.002	0.866				0.866
1833	0.046	0.062	0.008	0.016	0.002	0.868				0.868
1834	0.045	0.060	0.007	0.015	0.002	0.871				0.871
1835	0.044	0.059	0.006	0.015	0.002	0.874				0.874
1836	0.043	0.058	0.006	0.015	0.002	0.877				0.877
1837	0.043	0.057	0.005	0.014	0.002	0.880				0.880
1838	0.042	0.056	0.005	0.014	0.002	0.882				0.882
1839	0.041	0.055	0.004	0.015	0.002	0.884				0.884
1840	0.040	0.053	0.004	0.015	0.001	0.886				0.886
1841	0.039	0.053	0.003	0.016	0.001	0.887				0.887
1842	0.039	0.053	0.003	0.016	0.001	0.889				0.889
1843	0.038	0.051	0.002	0.015	0.001	0.892				0.892

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1844	0.036	0.049	0.002	0.015	0.001	0.897				0.897
1845	0.035	0.048	0.002	0.015	0.001	0.899				0.899
1846	0.034	0.046	0.001	0.014	0.001	0.903				0.903
1847	0.033	0.044	0.001	0.014	0.001	0.907				0.907
1848	0.032	0.044	0.001	0.014	0.001	0.909				0.909
1849	0.031	0.042		0.014	0.001	0.912				0.912
1850	0.030	0.041		0.014	0.001	0.914				0.914
1851	0.030	0.040		0.013	0.001	0.917				0.917
1852	0.029	0.039		0.013	0.001	0.918				0.918
1853	0.028	0.038		0.013	0.001	0.920				0.920
1854	0.027	0.037		0.014	0.001	0.921				0.921
1855	0.027	0.037		0.013	0.001	0.922				0.922
1856	0.027	0.036		0.013	0.001	0.923				0.923
1857	0.026	0.036		0.013	0.001	0.924				0.924
1858	0.026	0.035		0.013	0.001	0.926				0.926
1859	0.025	0.034		0.013	0.001	0.927				0.927
1860	0.025	0.033		0.013	0.001	0.929				0.929
1861	0.024	0.033		0.013	0.001	0.930				0.930
1862	0.024	0.032		0.012	0.001	0.930				0.931
1863	0.023	0.032		0.013	0.001	0.931				0.931
1864	0.024	0.032		0.012	0.001	0.931				0.932
1865	0.022	0.030		0.013	0.001	0.933				0.934
1866	0.022	0.030		0.012	0.001	0.935				0.935
1867	0.022	0.029		0.012	0.001	0.936				0.936
1868	0.022	0.030		0.012	0.001	0.935				0.935
1869	0.021	0.029		0.011	0.001	0.937				0.938
1870	0.021	0.029		0.011	0.001	0.939				0.939
1871	0.020	0.027		0.010	0.001	0.942				0.942
1872	0.019	0.026		0.009	0.001	0.945				0.945
1873	0.019	0.025		0.008	0.001	0.946	0.001			0.947
1874	0.020	0.026		0.009	0.001	0.944	0.001			0.945
1875	0.019	0.025		0.008	0.001	0.946	0.001			0.947
1876	0.019	0.025		0.008	0.001	0.945	0.001			0.946
1877	0.019	0.025		0.008	0.001	0.945	0.002			0.946
1878	0.020	0.026		0.008	0.001	0.944	0.001			0.945
1879	0.020	0.026		0.008		0.943	0.002			0.945
1880	0.019	0.024		0.007		0.948	0.002			0.949
1881	0.014	0.023		0.006		0.953	0.002			0.956
1882	0.014	0.023		0.006		0.953	0.002			0.956
1883	0.014	0.023		0.006		0.954	0.003			0.957
1884	0.015	0.023		0.006		0.954	0.002			0.956
1885	0.015	0.024		0.006		0.952	0.003			0.955
1886	0.015	0.024		0.006		0.951	0.003			0.954
1887	0.015	0.024		0.005		0.952	0.003			0.955
1888	0.015	0.023		0.005		0.953	0.004			0.957
1889	0.015	0.022		0.005		0.954	0.004			0.958
1890	0.015	0.022		0.005		0.955	0.004			0.959
1891	0.018	0.022		0.004		0.951	0.005			0.955
1892	0.019	0.022		0.005		0.949	0.005			0.954
1893	0.021	0.025		0.005		0.942	0.006			0.949
1894	0.019	0.022		0.004		0.949	0.006			0.955
1895	0.018	0.022		0.004		0.949	0.006			0.955
1896	0.018	0.022		0.004		0.949	0.006			0.956
1897	0.018	0.021		0.004		0.951	0.006			0.957
1898	0.018	0.021		0.003		0.950	0.007			0.957
1899	0.017	0.020		0.003		0.952	0.007			0.960
1900	0.017	0.020		0.003		0.952	0.008			0.960

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1901	0.017	0.021		0.003		0.951	0.008			0.958
1902	0.017	0.021		0.002		0.951	0.008			0.960
1903	0.016	0.021		0.002		0.951	0.008			0.960
1904	0.016	0.022		0.002		0.951	0.009			0.959
1905	0.016	0.022		0.002		0.951	0.009			0.960
1906	0.015	0.022		0.002		0.952	0.008			0.961
1907	0.014	0.022		0.002		0.954	0.008			0.962
1908	0.015	0.023		0.002		0.951	0.009			0.961
1909	0.014	0.023		0.002		0.951	0.010			0.961
1910	0.014	0.024		0.001		0.952	0.009			0.961
1911	0.014	0.024		0.001		0.952	0.010			0.962
1912	0.014	0.025		0.001		0.948	0.012			0.960
1913	0.012	0.024		0.001		0.950	0.013			0.963
1914	0.012	0.025		0.001		0.945	0.017			0.962
1915	0.012	0.024		0.001		0.948	0.015			0.964
1916	0.011	0.023		0.001		0.954	0.011			0.966
1917	0.010	0.023		0.001		0.945	0.021			0.966
1918	0.011	0.025		0.001		0.928	0.036			0.964
1919	0.010	0.025		0.001		0.944	0.020			0.964
1920	0.009	0.024		0.001		0.944	0.022			0.966
1921	0.013	0.035		0.001		0.909	0.043			0.952
1922	0.009	0.027		0.001		0.931	0.032			0.964
1923	0.008	0.025		0.001		0.933	0.033			0.966
1924	0.007	0.024		0.001		0.931	0.037			0.968
1925	0.007	0.026		0.001		0.927	0.038			0.966
1926	0.012	0.044		0.001		0.861	0.081			0.943
1927	0.007	0.025		0.001		0.918	0.050			0.968
1928	0.007	0.027		0.001		0.913	0.053			0.966
1929	0.006	0.025		0.001		0.916	0.051			0.968
1930	0.006	0.026		0.001		0.907	0.060			0.967
1931	0.006	0.028		0.001		0.906	0.059			0.965
1932	0.006	0.030		0.001		0.901	0.062			0.963
1933	0.006	0.030		0.001		0.895	0.068			0.963
1934	0.005	0.028		0.001		0.895	0.071			0.966
1935		0.028				0.901	0.071			0.972
1936		0.026				0.903	0.071			0.973
1937		0.026				0.903	0.071			0.974
1938		0.027				0.895	0.078			0.973
1939		0.023				0.916	0.062			0.977
1940		0.025				0.906	0.069			0.975
1941		0.027				0.889	0.084			0.973
1942		0.027				0.904	0.069			0.973
1943		0.027				0.874	0.099			0.973
1944		0.028				0.839	0.132			0.972
1945		0.030				0.859	0.110			0.970
1946		0.030				0.870	0.100			0.970
1947		0.031				0.879	0.090			0.969
1948		0.029				0.853	0.118			0.971
1949		0.030				0.857	0.114			0.970
1950		0.029				0.855	0.116			0.971
1951		0.028				0.832	0.140			0.972
1952		0.028				0.830	0.142			0.972
1953		0.028				0.825	0.147			0.972
1954		0.029				0.815	0.156			0.971
1955		0.028				0.801	0.171			0.972
1956		0.028				0.801	0.170			0.972
1957		0.028				0.788	0.184			0.972

(segue)

	Draught Livestock	Population	Firewood	Wind	Water	Coal	Oil	Gas	Primary Electricity	Modern
1958		0.029				0.762	0.209			0.971
1959		0.029				0.718	0.253			0.971
1960		0.028				0.703	0.269			0.972
1961		0.028				0.683	0.288			0.972
1962		0.027				0.663	0.309	0.001		0.973
1963		0.027				0.652	0.320	0.001		0.973
1964		0.026				0.619	0.353	0.001		0.974
1965		0.024				0.620	0.352	0.004		0.976
1966		0.024				0.594	0.378	0.003		0.976
1967		0.025				0.561	0.408	0.006		0.975
1968		0.024				0.546	0.417	0.013		0.976
1969		0.023				0.510	0.442	0.024		0.977
1970		0.023				0.470	0.461	0.046	0.001	0.977
1971		0.023				0.428	0.474	0.074	0.001	0.977
1972		0.022				0.368	0.503	0.105	0.002	0.978
1973		0.021				0.381	0.487	0.108	0.002	0.979
1974		0.021				0.355	0.481	0.138	0.004	0.979
1975		0.022				0.371	0.451	0.150	0.006	0.978
1976		0.021				0.373	0.439	0.157	0.010	0.979
1977		0.021				0.366	0.437	0.163	0.013	0.979
1978		0.021				0.353	0.442	0.168	0.017	0.979
1979		0.020				0.362	0.422	0.175	0.021	0.980
1980		0.021				0.363	0.399	0.189	0.029	0.979
1981		0.022				0.370	0.374	0.196	0.039	0.978
1982		0.022				0.350	0.380	0.198	0.051	0.978
1983		0.021				0.352	0.364	0.206	0.057	0.979
1984		0.021				0.250	0.457	0.211	0.061	0.979
1985		0.019				0.320	0.377	0.217	0.066	0.981
1986		0.019				0.338	0.364	0.217	0.061	0.981
1987		0.019				0.338	0.359	0.225	0.058	0.981
1988		0.019				0.328	0.378	0.213	0.063	0.981
1989		0.018				0.328	0.384	0.200	0.071	0.982
1990		0.018				0.323	0.389	0.205	0.065	0.982
1991		0.017				0.315	0.383	0.216	0.069	0.983
1992		0.019				0.300	0.385	0.221	0.075	0.981
1993		0.018				0.255	0.386	0.247	0.094	0.982
1994		0.017				0.174	0.467	0.252	0.090	0.983
1995		0.016				0.182	0.454	0.261	0.086	0.984
1996		0.017				0.165	0.434	0.298	0.086	0.983
1997		0.018				0.162	0.430	0.305	0.086	0.982
1998		0.018				0.136	0.439	0.316	0.091	0.982
1999		0.017				0.119	0.442	0.338	0.085	0.983
2000		0.017				0.104	0.420	0.381	0.078	0.983
2001		0.019				0.253	0.260	0.383	0.085	0.981

Note: data has not been collected or estimated for livestock after 1935. firewood after 1850. wind power (from windmills and sailing ships) after 1938. and water power after 1907. when their contribution to the aggregate total was negligible. Some columns show that these energy carriers did not even provide 0.1 percent of the aggregate total before these dates.

3. Per Capita Energy Consumption and Energy Intensity

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1560	20.0	19.4
1561	20.0	19.3
1562	19.9	19.2
1563	19.8	19.1
1564	19.8	19.0
1565	19.6	18.9
1566	19.5	18.8
1567	19.4	18.7
1568	19.2	18.6
1569	19.1	18.5
1570	19.1	18.4
1571	19.0	18.3
1572	18.9	18.3
1573	18.9	18.2
1574	18.8	18.1
1575	18.7	18.0
1576	18.6	17.9
1577	18.5	17.9
1578	18.4	17.8
1579	18.3	17.8
1580	18.2	17.7
1581	18.1	17.7
1582	18.0	17.6
1583	17.9	17.6
1584	17.8	17.5
1585	17.7	17.5
1586	17.6	17.4
1587	17.6	17.4
1588	17.7	17.3
1589	17.6	17.2
1590	17.5	17.2
1591	17.5	17.1
1592	17.5	17.1
1593	17.6	17.0
1594	17.5	16.9
1595	17.4	16.9
1596	17.4	16.9
1597	17.5	16.8
1598	17.6	16.7
1599	17.5	16.7
1600	17.4	16.6
1601	17.2	16.5
1602	17.2	16.5
1603	17.3	16.5
1604	17.4	16.5
1605	17.4	16.6
1606	17.4	16.6
1607	17.3	16.7
1608	17.4	16.8
1609	17.4	16.8
1610	17.5	16.9
1611	17.6	16.9
1612	17.6	17.0
1613	17.7	17.0
1614	17.9	17.1
1615	17.9	17.1
1616	18.0	17.2

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1617	18.2	17.3
1618	18.3	17.3
1619	18.3	17.4
1620	18.3	17.5
1621	18.3	17.6
1622	18.3	17.8
1623	18.5	17.8
1624	18.7	17.9
1625	18.9	18.0
1626	19.1	17.9
1627	19.1	17.9
1628	19.1	18.0
1629	19.0	18.0
1630	19.0	18.0
1631	19.0	18.0
1632	19.1	18.0
1633	19.2	18.0
1634	19.2	18.0
1635	19.1	18.0
1636	19.1	18.1
1637	19.1	18.1
1638	19.2	18.1
1639	19.2	18.0
1640	19.4	18.0
1641	19.4	18.1
1642	19.5	18.1
1643	19.6	18.2
1644	19.7	18.2
1645	19.8	18.2
1646	19.8	18.3
1647	19.9	18.3
1648	20.0	18.4
1649	20.1	18.4
1650	20.2	18.4
1651	20.4	18.5
1652	20.5	18.5
1653	20.7	18.5
1654	20.8	18.6
1655	20.9	18.6
1656	20.9	18.7
1657	21.1	18.7
1658	21.5	18.7
1659	21.9	18.7
1660	22.1	18.8
1661	22.3	18.9
1662	22.6	18.9
1663	22.8	19.0
1664	23.0	19.1
1665	23.2	19.2
1666	23.6	19.3
1667	23.9	19.4
1668	24.1	19.4
1669	24.4	19.5
1670	24.7	19.6
1671	25.1	19.7
1672	25.4	19.8
1673	25.6	19.9
1674	25.8	20.0

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1675	26.0	20.1
1676	26.3	20.2
1677	26.5	20.4
1678	26.6	20.5
1679	27.1	20.6
1680	27.5	20.7
1681	27.9	20.7
1682	28.2	20.7
1683	28.5	20.7
1684	28.6	20.7
1685	28.9	20.8
1686	29.1	20.8
1687	29.2	20.8
1688	29.2	20.9
1689	29.3	20.9
1690	29.5	20.9
1691	29.6	21.0
1692	29.7	21.0
1693	29.9	21.0
1694	30.0	21.1
1695	30.1	21.1
1696	30.2	21.1
1697	30.3	21.2
1698	30.2	21.1
1699	30.3	21.2
1700	30.5	21.3
1701	30.5	21.2
1702	30.6	21.2
1703	30.6	21.2
1704	30.6	21.2
1705	30.9	21.3
1706	30.8	21.1
1707	30.8	21.1
1708	30.9	21.0
1709	30.9	21.0
1710	31.1	21.0
1711	31.3	20.9
1712	31.8	21.1
1713	31.5	20.8
1714	31.5	20.7
1715	31.7	20.7
1716	31.7	20.7
1717	31.8	20.7
1718	31.7	20.7
1719	31.7	20.7
1720	31.9	20.7
1721	32.2	20.6
1722	32.4	20.6
1723	32.5	20.6
1724	32.3	20.4
1725	32.7	20.6
1726	32.5	20.5
1727	32.5	20.5
1728	33.1	20.5
1729	33.7	20.4
1730	34.4	20.5
1731	34.5	20.4
1732	31.8	20.6

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1733	34.6	20.4
1734	34.5	20.4
1735	34.4	20.4
1736	34.3	20.4
1737	34.4	20.4
1738	34.5	20.4
1739	34.4	20.4
1740	34.4	20.3
1741	34.7	20.5
1742	35.3	20.5
1743	35.4	20.4
1744	35.5	20.5
1745	35.4	20.5
1746	35.4	20.5
1747	35.6	20.6
1748	35.7	20.5
1749	35.6	20.5
1750	35.3	20.3
1751	35.3	20.4
1752	35.7	20.6
1753	35.9	20.8
1754	36.8	21.0
1755	36.6	21.3
1756	36.8	21.5
1757	37.3	21.7
1758	37.7	21.9
1759	38.1	22.1
1760	38.5	22.3
1761	38.6	22.3
1762	39.0	22.3
1763	39.5	22.4
1764	39.9	22.4
1765	39.8	22.3
1766	39.7	22.0
1767	40.3	22.2
1768	41.2	22.5
1769	41.7	22.6
1770	42.3	22.9
1771	42.1	22.7
1772	42.5	22.8
1773	43.0	23.0
1774	43.2	23.0
1775	42.6	22.7
1776	42.8	22.8
1777	43.1	23.0
1778	43.6	23.2
1779	44.0	23.5
1780	44.5	23.6
1781	45.1	23.9
1782	45.7	24.0
1783	45.6	24.0
1784	46.3	24.1
1785	46.2	24.1
1786	46.7	24.4
1787	47.2	24.7
1788	47.0	24.6
1789	47.4	24.9
1790	47.6	25.1

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1791	47.8	25.2
1792	47.9	25.4
1793	48.1	25.6
1794	48.7	26.0
1795	49.3	26.3
1796	49.4	26.4
1797	50.0	26.8
1798	50.3	27.1
1799	50.6	27.3
1800	50.8	27.6
1801	52.8	27.3
1802	53.4	27.0
1803	53.9	26.7
1804	54.4	26.6
1805	54.8	26.4
1806	55.1	26.2
1807	55.8	26.2
1808	56.2	26.0
1809	56.8	26.0
1810	57.4	25.9
1811	57.9	25.8
1812	58.4	25.8
1813	58.8	25.8
1814	59.0	25.7
1815	58.8	25.5
1816	59.0	25.5
1817	59.2	25.4
1818	59.5	25.4
1819	59.9	25.4
1820	60.1	25.4
1821	60.2	25.3
1822	60.2	25.3
1823	60.4	25.4
1824	60.6	25.4
1825	60.7	25.3
1826	60.9	25.3
1827	61.0	25.2
1828	61.2	25.2
1829	62.7	25.7
1830	62.7	25.6
1831	62.9	25.6
1832	63.0	25.6
1833	63.2	25.5
1834	64.4	26.0
1835	65.4	26.3
1836	66.2	26.6
1837	67.1	26.9
1838	67.9	27.1
1839	69.1	27.6
1840	72.0	27.9
1841	73.0	27.5
1842	74.0	27.1
1843	75.6	26.8
1844	78.4	27.1
1845	79.8	26.9
1846	82.4	27.1
1847	85.4	27.4
1848	86.8	27.2

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1849	89.4	27.5
1850	91.3	27.5
1851	93.8	27.5
1852	96.2	27.9
1853	98.4	28.9
1854	100.1	27.7
1855	101.4	27.9
1856	102.4	28.4
1857	103.4	28.2
1858	105.7	28.5
1859	107.3	28.5
1860	109.1	29.0
1861	110.6	29.5
1862	112.2	29.4
1863	114.3	29.4
1864	112.5	28.9
1865	117.6	30.9
1866	119.5	30.7
1867	121.1	31.3
1868	117.5	28.9
1869	121.4	28.7
1870	122.4	29.2
1871	127.7	30.2
1872	132.5	31.2
1873	137.5	32.0
1874	132.1	30.8
1875	135.5	32.1
1876	132.9	31.8
1877	132.2	32.1
1878	128.8	30.3
1879	127.6	29.4
1880	135.5	31.1
1881	139.6	32.2
1882	139.3	32.4
1883	143.1	33.8
1884	138.2	32.5
1885	135.2	30.9
1886	132.6	29.3
1887	134.4	28.5
1888	138.1	29.5
1889	141.3	30.5
1890	143.0	31.9
1891	145.0	32.7
1892	140.6	30.1
1893	125.2	26.3
1894	140.9	28.7
1895	140.6	28.6
1896	142.8	28.0
1897	144.8	27.6
1898	143.5	27.8
1899	151.6	29.7
1900	151.7	29.4
1901	147.0	29.1
1902	151.1	30.0
1903	150.8	29.3
1904	150.0	28.5
1905	150.5	28.4
1906	154.2	30.6

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1907	159.3	31.2
1908	154.1	29.5
1909	154.1	29.0
1910	153.8	28.8
1911	156.1	28.4
1912	147.4	26.7
1913	159.8	26.9
1914	154.6	25.6
1915	155.5	25.6
1916	159.9	26.3
1917	157.4	29.2
1918	146.5	29.0
1919	142.3	30.8
1920	148.9	30.8
1921	104.3	21.0
1922	135.6	26.4
1923	142.7	26.6
1924	148.8	28.9
1925	139.3	25.2
1926	82.0	14.7
1927	144.9	25.4
1928	136.0	24.1
1929	142.2	26.7
1930	136.7	25.6
1931	127.5	23.3
1932	122.5	21.1
1933	121.5	20.2
1934	130.3	20.8
1935	130.7	20.3
1936	137.3	21.1
1937	140.9	21.6
1938	135.2	18.9
1939	159.3	20.5
1940	155.4	19.6
1941	145.0	18.0
1942	141.0	18.3
1943	141.0	19.2
1944	141.6	20.2
1945	130.7	19.0
1946	129.1	18.3
1947	126.2	17.3
1948	135.8	18.8
1949	135.9	18.4
1950	140.4	19.1
1951	148.5	19.5
1952	147.4	18.7
1953	148.1	18.2
1954	152.6	18.6
1955	155.6	18.8
1956	156.4	19.0
1957	154.9	18.2
1958	151.5	16.9
1959	149.8	16.3
1960	158.0	17.1
1961	157.8	16.5
1962	161.1	16.1
1963	165.3	16.2
1964	164.5	15.9

(segue)

	Per capita consumption (GJ)	Energy Intensity (MJ/ 10 000 1990$)
1965	178.6	17.0
1966	176.1	16.2
1967	173.9	15.8
1968	176.9	15.8
1969	183.3	16.1
1970	186.5	15.9
1971	182.8	14.7
1972	184.2	15.0
1973	192.6	15.8
1974	180.9	14.5
1975	174.4	13.7
1976	176.4	13.4
1977	180.2	13.3
1978	181.7	13.6
1979	190.0	14.5
1980	176.2	13.2
1981	171.9	12.5
1982	169.1	12.0
1983	169.1	11.6
1984	168.6	11.1
1985	175.3	11.0
1986	178.4	10.7
1987	175.9	10.4
1988	177.2	10.4
1989	177.5	10.6
1990	179.0	10.7
1991	181.7	10.6
1992	179.6	10.1
1993	183.0	10.1
1994	191.0	10.3
1995	201.2	10.5
1996	209.2	10.6
1997	208.1	10.3
1998	209.9	10.1
1999	215.2	10.2
2000	208.0	10.1

Note: Energy Intensity figures use GDP data from Maddison (2003). This produces higher earlier intensity figures than other GDP series.

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