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Economic development and the demand for energy: A historical perspective on the next 20 years

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HIGHLIGHTS

► Analyses the evolution of energy intensity over two centuries of industrialisation.
► Increased specialisation of the fuel mix and convergence of economies continues to improve energy efficiency.
► Growth in per capita income over the next 20 years need not be constrained by resource availability.

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ABSTRACT

This paper draws on evidence from the last two centuries of industrialisation, analysing the evolution of energy intensity over the long- and short-run. We argue that the increased specialisation of the fuel mix, coupled with accelerating convergence of both the sectoral and technological composition of economies, will continue to improve energy intensity of economic output and to reduce the reliance on any single energy resource. This analysis suggests that even high growth in per capita income over the next 20 years need not be constrained by resource availability.

1. Introduction

When the future of global energy markets is discussed, two main concerns feature regularly. One is climate change and carbon output, an issue beyond the scope of this paper. The other is the question whether growth in energy demand will exceed the resources available to fuel continued economic growth and industrialisation, especially in the non-OECD economies. The paper contributes to this second question, with a particular focus on energy intensity and demand.

It is an attempt to draw lessons from past experiences with periods of industrialisation and structural change, and the impact they had on energy demand. The reason for this attempt originates with the need to assess future energy demand for the next 20 years in BP's *Energy Outlook 2030* (BP, 2012).

The *Energy Outlook 2030* forecasts future fuel trends for the period 2011–2030. It builds upon BP's longstanding work on the Statistical Review of World Energy, which documents trends in the production and use of energy. The results of the *2030 Outlook* are largely derived "top down": global energy demand trends are assessed and national (or regional) demand is derived using assumptions on population growth, GDP growth and changes in end-user demand. In a similar fashion, regional supply availability is assessed fuel by fuel, capacity and other constraints are taken into account, and substitutability evaluated; then, in an iterative process, demand and supply schedules and prices are determined.

The *2030 Outlook* therefore is not a "Business as Usual" exercise (i.e., it does not rely on trend extrapolation) and not constrained by any given policy scenario—rather, it is a genuine "to the best of our knowledge" forecast, warts and all.[1] The precise numbers, as with any forecasting exercise, carry a significant range of uncertainty and should always be treated with caution. The ambition is not to get the future right to the last decimal point but to delineate fault lines in today's complex global energy system, trend lines and where they may collide, points at which today's commercial and political decisions matter, or will have discernible impact on the future: in short, it is a document which should get the major trends right. The resulting projections lie broadly within the range of other publicly-available forecasts, such as the IEA World Energy Outlook (International Energy Agency, 2011) and the EIA International Energy Outlook (International Energy Agency, 2011). A more

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[1] In this respect it is different from, for example, International Energy Agency (2011) or Shell (2011).

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detailed description of the assumptions, methods and findings can be found in the 2011 and 2012 Outlooks (BP, 2011a; BP, 2012).

It was in this context that the question arose of how to have a fresh look at an old, but increasingly important issue: What constraints will the need for energy put on global growth prospects? In particular, how will the need to fuel economic growth impact the prospects of the rapidly industrializing so-called developing economies outside the OECD? This obviously is an important question, but also one where discussion is much dominated by opinion and assertion. We all have heard claims like "for the Chinese to become as rich as us, we will need four new planets" from one side of the spectrum, just as often as the "what, me worry?" from the other.

To us, this seemed to be precisely the kind of question where one can learn by having a look at the past. It is of course not the first time in history that we observe periods of rapid economic growth and structural change, coupled with pressure on the known resource base. And so the question became what, if any, lessons history may hold for economic development in regions where energy poverty is still the norm, and where high energy prices may prove an impediment to growth.

The following reports the findings of that closer look at the historical experience.

2. The data

2.1. Energy intensity

Energy intensity – defined as energy consumption per unit of GDP, and perhaps the most general measure of energy efficiency there is – lies at the heart of the following analysis. More precisely, we focus on the interplay between energy intensity and structural change—as economies develop from being dominated by agricultural production to being dominated by the industrial sector and then by services. These are periods in which both the available primary energy carriers and the composition of economic output undergo great changes.

Our analysis looks at commercially traded fuels only—primarily fossil fuels (oil, natural gas, coal) and nuclear, hydro, and modern renewables.[2] This is how energy intensity is traditionally defined, and our use of this definition is not simply for reasons of data availability: Commercially traded energy is mediated by markets, with prices playing an allocative role. Fundamentally, these fuels lie at the heart of the process of economic development we are interested in—the industrial experience.

Casting the net wider would require a different definition of energy. The International Energy Agency publishes global energy consumption estimates which include traditional and largely non-traded biomass such as firewood, peat or animal dung (it puts the share of such fuels today at about 10% of global energy consumption). Historians assemble measures using a still wider definition of energy capture, including food for human consumption and fodder for animals.

Morris (2010a, 2010b) surveys the evidence on pre-industrial energy capture starting with Cook's (1971) pioneering paper. Cook estimated energy capture using this broadest of definitions of energy use for a range of stylised pre-industrial and industrial societies. His estimate for "advanced agriculturalists" was energy capture of 26,000 kcal per person per day (Cook, 1971 p. 136), or about 0.95 t of oil equivalent (TOE) per person per year. Morris finds that Cook's original estimates have held up surprisingly well. Morris' own estimates are that human energy at 1 AD – the time of classical antiquity in the advanced agricultural economies of Eurasia – was about 1.1 TOE per person per year in the West (the Roman Empire) and 1.0 TOE per person per year in the East (China). A millennium and a half later, these were still advanced agricultural economies, and with levels of energy capture that had hardly changed: Morris estimates energy capture in 1500 AD was about 1.0 TOE per person per year in the West, and about 1.1 TOE per person per year in the East. On the eve of the industrial revolution, in 1800, energy capture was still about 1.3–1.4 TOE per person in both regions. These are, of course, rough estimates that average across a wide range of energy capture influenced by local technology, climate and resources (Gruebler, 2004), but the general picture of long-run stagnation in energy capture per capita still holds.

The industrial revolution changed all that. Energy consumption in England (Humphrey and Stanislaw, 1979; Fouquet and Pearson, 1998; Wrigley, 2010), and then in other industrialising economies, grew hugely. Using the historians' broad definition of energy capture, total energy use per person in the OECD today is on the order of 8 TOE per person per year, i.e., about 6 times more than in Western Europe in 1800. Essentially all of this growth is accounted for by commercial fuels, which were hardly present before industrialisation.

In the same vein, estimates of GDP per capita for individual countries and the world during the pre-industrial period suggest living standards that showed relatively little change over time. Maddison (2007, 2010), for example, estimates GDP per capita in Western Europe in 1 AD at about $576 in 1990 international dollars in 1 AD, rising to $771 in 1500 AD; his corresponding figures for the world as a whole are $467 and $566.

Maddison's estimates, though widely used, are not uncontroversial. Clark (2009), for example, points out that Maddison's estimates rely crucially on an assumed basic subsistence income ($400 per person), and suggests that direct evidence on wages in different eras and locations should be preferred. A separate problem, raised by Nordhaus (1997), is whether such estimates properly account for improvements in the quality of goods, or for entirely new goods.

But none of this changes the general picture of broadly stagnant living standards in the pre-industrial era—certainly compared to what followed. Allen (2009), for example, using evidence from Diocletian's Price Edict of 301 AD, finds that the wage of the typical Roman worker was comparable to that of most workers in Europe or Asia in the 18th century, though these wages were somewhat low compared to those that prevailed in 15th century Western Europe. And the problem of improvement in quality and range of goods is far greater for the modern era than for the period 1-1500 AD. Nordhaus (1997) used technological advances in lighting to illustrate the measurement problem, but in his original 1996 study he notes that lighting technology was essential static in the pre-industrial era.[3]

Starting with the Industrial Revolution, GDP per capita in the developed West grows hugely. Using Maddison's estimates, it grows by almost 20-fold, from about $1200 per person in 1800 to $22,000 per person in 2000 in 1990 dollars. And this is likely a significant understatement of the growth of living standards, for the reasons given by Nordhaus. Prices of modern goods in 1800, if such goods existed, would have been extremely high, and so the

[2] Modern renewables include wind, solar, geothermal and biomass in electricity production, and biofuels (ethanol and biodiesel) in transport.

[3] "Virtually all historical accounts of illumination remark on the feeble progress made in lighting technology in the millennia before the Industrial Revolution." Nordhaus (1996), p. 33.

growth of GDP per capita using 1800 relative prices would have been substantially higher than Maddison reports. DeLong (1998) suggests an additional factor of 4 for the period 1800 to 2000, turning the increase in living standards since the Industrial Revolution into a truly huge, 80-fold, advance.

Importantly, in the rest of the world, industrialisation starts later, if it starts at all. Where it does start in earnest, we see more rapid growth than we saw for the early industrialisers, because of the catching-up phenomenon. But where industrialisation does not start, living standards remained not much different from the pre-industrial world. Today, some African countries still have a GDP per capita in the vicinity of the pre-industrial level.

The picture for total energy intensity between classical antiquity and pre-Industrial Revolution is thus one of relatively slow change or stagnation. Total energy consumption per capita – "energy capture" defined most broadly – showed no strong trend during this period, and even allowing for the uncertainties and debates in incomes in the distant past, the same is roughly true of material living standards. Consequently, there is relatively little change in energy intensity before the onset of industrialisation.

The picture following the Industrial Revolution is quite different. Because the subsequent growth in material living standards in industrialising countries was considerably greater than the growth in total energy use, total energy intensity will actually have fallen by the end of industrialisation. For example, using the estimates above for the developed West of an increase in energy capture per person of 6 times and an increase in GDP per capita of 20 times implies a decline of a factor of 3–4 in total energy intensity over two centuries of industrialisation, from about 1200 TOE per $million GDP in 1990 dollars in 1800 (for comparability with the 2030 analysis below, about 750 TOE per $million in 2010 dollars), to about 400 TOE per $million in 1990 dollars (about 250 in 2010 dollars). Adjustments to account for advances in technology would imply still larger declines in energy intensity, as they decrease the valuation of GDP at the start of industrialisation; e.g., using DeLong's adjustment, energy intensity on the eve of the Industrial Revolution would have been 4 times higher, and the decline in total energy intensity in the West in the next two hundred years would have been in excess of a factor of 10.

This pattern of an overall decline in total energy intensity is also apparent in detailed country studies, though with noticeable variations across countries: see, e.g., Gales et al. (2007), for a study of long-run energy intensity in Sweden, the Netherlands, Italy and Spain,[4] and where energy use includes not only commercial and traditional energy sources but also food and fodder, i.e., the same broad definition of total energy capture employed above.[5]

The focus in this paper, however, is on commercially-traded fuels. And because pre-industrial countries used little in the way of commercially-traded fuels, energy intensity measured as the share of commercially-traded fuels in GDP follows a different pattern in the course of industrialisation: starting from a near-zero level, it increases markedly over a period of decades before starting to decline. We explore this pattern in detail below.

2.2. Data sources

Turning to GDP first, the key measurement problems here are familiar from the theory of index numbers. The usual procedure is to use a set basket of goods and to aggregate these using a set of prices or weights. The same weights are used for all countries, all years. We replicate this in our analysis, using GDP in 2005 PPP (purchasing-power-parity) weights from the Penn World Tables for 1970 (Penn World Tables, 2011) onwards, and chain-linking these to the long-run (Maddison, 2010) series using 1990 PPP weights for earlier years and then rescaled into 2010 prices for expositional purposes only.[6] The goal is to measure all activity at the same prices, so that differences in levels and growth rates etc. are all driven by differences in the volume of production or consumption of goods. However, the basket of goods defining the weights is, by its very nature, somewhat arbitrary, and we make no attempt to adjust the GDP series for new goods etc. *à la* Nordhaus/DeLong.

Data on energy production, prior to 1965, is used as reported in Etemad and Luciani (1991). This extensive data source, compiled from statistical yearbooks and other specialised sources, reports production data for coal, black and brown separately, natural gas and crude oil as well as non-hydrocarbon sources of primary energy such as nuclear, hydro, geothermal and peat. For the earliest industrialising countries data is available from 1800 onwards, with more countries being tracked as industry and commercial energy production grow. Although there is variation by energy carrier, data on energy production for approximately 60 countries is available by 1964.

In order to construct country-level series for energy consumption we then link this with trade data taken from various volumes of Mitchell's (2007) *International Historical Statistics*. These sources, also collated from statistical yearbooks and other specialised sources, report, at the country level, series for the import and export of coal, natural gas and crude oil. From these we construct series for net exports, which combined with the information on energy production from Etemad and Luciani, permit the construction of the series for domestic energy consumption by country.

Mitchell also reports data on production by fuel, but the number of individual countries is lower than that of Etemad and Luciani. It is important to note that these two sources are consistent with each other where they overlap; indeed Etemad and Luciani use data from Mitchell where considered to be the authoritative source, and at other times both use the same source. Therefore, in order to maximise the information by country and the associated analysis, we use the combination of these two sources without loss of data robustness.

All energy data, both on production and consumption, after 1965 is as published in the BP *Statistical Review of* World *Energy 2011* (BP, 2011b). This dataset is constructed from a range of governmental and other publicly available sources and made available on an annual basis.

The data on population by country for 1950 to 2030 are provided by United Nations Population Division (2009). For years prior to 1950 we have estimated population levels by applying growth rates estimated by Maddison (2010) to the UN reported level in 1950.

[4] Gales et al. (2007) find that total energy intensity is generally declining during industrialisation in the countries they examine. The UK followed a different pattern: as one of the referees pointed out, the UK's industrialisation exploited large coal reserves, and because it was the first to industrialise, the technologies employed were inefficient and energy intensive. This generated an energy intensity path that initially increased and then decreased, even when traditional energy sources are included. See Fouquet and Pearson (1998) and Wrigley (2010) for detailed discussion of the long-run UK/England experience.

[5] We note here that some studies of long-run energy intensity have used an intermediate definition of energy, including and distinguishing between commercial and traditional fuels (e.g., firewood) but excluding food and fodder. Schurr et al. (1960) is an early example; Gruebler (2004) provides a recent treatment and overview.

[6] The last pre-forecast year in the 2030 *Outlook* is 2010. The rescaling from 2005 to 2010 prices computes as a simple across-the-board increase of 12%.

3. Energy intensity and economic development

3.1. A general pattern

Measuring energy intensity – again, the energy necessary to produce one unit of economic output, and hereafter confined to commercial energy – since the Industrial Revolution generates a very consistent pattern over time, across countries, and across economic systems; it was first identified by Schurr et al. (1960) for long-run commercial energy intensity in the US in a pioneering early work.[7] This pattern has the shape of a bell curve, with energy intensity in every country or region first rising (i.e., economies use more energy per unit of GDP), then peaking, and eventually declining. Typically, the decline is gentler than the initial increase.

This pattern, stable across countries and time, at first sight reflects the well-known, stylised pattern of economic development: commercial energy intensity rises sharply as people and production activities are shifting from low energy intensive activities in agriculture to high energy intensive activities in industrial production; it then declines, more gently, as economic activity is transferred to the less energy intensive service sector. And indeed, the rise and fall of the industrial sector's share in GDP develops generally in lockstep with this pattern, and so the structural transformation of developing economies appears to be its main driver.

The explanation links back to what has been discussed already. As long as the primary sector-and here mostly subsistence agriculture-dominates economic activity, most commercial energy is consumed in the residential sector and for basic needs, such as cooking or heating. The level of energy consumption per capita stays roughly constant at these early stages of economic development; and so does per capita income.

The accumulation of capital and then industrialisation changes the picture. As labour and capital shift to more productive use in industrial activity, the rapid productivity advancements of the secondary sector will increase both the share of industry in GDP and the rate of economic growth.

The case for rising energy intensity during industrialisation is clear if these productivity improvements are driven by extensive growth (more energy-consuming equipment per worker). However, periods of industrialisation have been and still are also periods during which, in a complicated interaction with technological change, primary fuel supplies are diversifying rapidly. This would, ceteris paribus, translate into specialisation that enhances energy efficiency; however, historically it also translated into heavy conversion losses as a rising share of primary fuels are converted into electric power without which industrialisation (and urbanisation) is not feasible. At this stage, even intensive growth may increase energy intensity. Finally, rising income levels themselves lead to higher residential demand for energy. Overall, the onset of industrialisation sees commercial energy consumption rising, measured in per capita terms or relative to GDP.

In the final, post-industrial stage, the composition of economic activity tends toward the tertiary or service sector, driven by the changing structure of demand and higher income elasticity for services.[8] A diminishing industrial sector – the shift toward less energy intensive economic activity – by itself reduces the amount of energy required per unit of GDP for the economy as a whole. In addition, technological progress will play a subtle role to the same effect: the effects of efficiency improvements in the industrial sector counterbalance to some extent the effects of a growing share of this (most energy-intensive) sector; as the industrial sector share in GDP finally becomes large and its expansion first slows and then starts to decline, these efficiency improvements within the industrial sector will outweigh the negative effect from the expansion of the industrial sector, and hence start to contribute to an improvement of energy efficiency for society as a whole. Finally, the composition of the industrial sector also is not static but will shift from heavy and energy intensive sub-sectors toward light manufacturing as the need for energy-intensive infrastructure and urbanisation projects declines, thus again contributing to lowered industrial energy consumption per unit of output.[9]

But we can do more than just rationalise the bell shaped pattern of energy intensity during economic development. A few simple and sturdy economic factors go a long way in explaining the level at which the curve peaks.

- Technology: Everything else equal, peaks tend to be lower for countries that industrialise later, reflecting the development of more efficient technologies over time (Reddy and Goldemberg, 1990). Countries which industrialise late do not replicate the technology of earlier periods; moreover, the advantages of leapfrogging and catching up hold on both sides of the equation, with improvements in both conversion and end-use efficiency. (For example, modern coal-fired turbines achieve an energy efficiency on the order of 20 times greater than that of Watt's steam engine; while the average fuel economy of the US passenger cars has roughly doubled since the 1970s, even though the typical car today is faster, more comfortable and safer.)
- Resource endowments: Everything else equal, greater domestic resource availability will lift the peak because of lower prices, fewer incentives to maximise energy efficiency, and less fear of import dependency (see, e.g., Soile and Balogun, 2011 for a recent analysis). Again, the argument has two sides—it holds for comparable industrial sectors across countries (if tradable goods are manufactured, this will give a competitive advantage to the resource poorer producer); but it may also bias the industrial structure itself toward more or less energy intensive production sectors and consumer behaviour, as unequal fuel prices across countries (or politics) play their role. (For example, although it industrialised later, US energy intensity in our data peaked at a level higher than in the UK because resource availability in the US was higher.).
- Economic system: Countries which industrialised under central planning tend to exhibit very high energy intensity, first because resource allocation is not governed by price signals, but also because there is an ideological bias toward heavy industry, and administrative enforcement of this bias is unchecked by market mechanisms such as prices or competition (Leslie et al., 1994; Ürge-Vorsatz et al., 2006). The former Soviet Union (FSU) and Russia are a case in point, but the Chinese path is impressive as well. Importantly, the improvement in energy intensity once central planning has been abolished and markets start to function, is swift and dramatic.

[7] Humphrey and Stanislaw (1979) and, more recently, Fouquet and Pearson (1998) document this pattern for the UK; Reddy and Goldemberg (1990), in an influential paper, extended this to several other developed industrialised economies; and see Gales et al. (2007) and Gruebler (2004)for more recent treatments.

[8] Though part of this increase in the relative size of the service sector will be due to the increase of the relative prices of services, a point due originally to Baumol and analysed in the context of energy use by Kander (2005).

[9] The interplay of energy intensity, economic structure and industrialisation can be analysed more formally using decomposition techniques. See, e.g., Sun (1998) for a study covering developing and developed countries over the period 1973–1990.

Economies which industrialised under central planning indeed play an important role in our explanation of the convergence in energy intensity which we observe since the late 1980s. But before moving on to this discussion, a peculiarity in the non-OECD data deserves closer scrutiny.

3.2. Transition and energy intensity

The problem is that more recent non-OECD data on the link between energy intensity and the share of the industrial sector seem to call into question the explanation just advanced: the share of manufacturing in non-OECD output *rose* by 9% (from 15% to 24%) from 1970 to 2010, while energy intensity *declined* over that same period (by a total of 14%). Does this mean the historical experience from earlier periods of industrialisation is no longer applicable? What drove this decline in energy intensity?

Several possible general explanations can be drawn from what has been said already, but the key to a satisfactory answer lies in one-off adjustments of the manufacturing sector caused by the breakdown of central planning in the Soviet Union and its more gradual abandonment in China.

Part of the explanation is that efficiency gains from technological progress (in industrial production, but also on the consumption side) can outpace the increase in energy intensity associated with a rising share of manufacturing in GDP. As discussed already, this will happen in the long term because of two offsetting effects: as long as the share of industry is small but growing rapidly, energy intensity increases because industrialisation outweighs the effect of technical progress within the industrial sector. The technical progress effect dominates once the share of industry is large and growing slowly (or even shrinking), and energy intensity falls.

If this were to be the case within the non-OECD since the 1970s, the very issue we came to study would evaporate—if rapid industrialisation in the non-OECD had such different features from the past, what would be the point of deploying historical evidence to learn about its future? The answer to this question lies in the fact that during this period, part of the non-OECD experienced rapid industrialisation, while at the same time another part – Eastern Europe and the former Soviet Union – experienced rapid *deindustrialisation*, though perhaps "reversal of overindustrialisation" is a more accurate description.

In fact, the non-FSU non-OECD industrialisation experience in this period did indeed follow the established historical pattern: when the FSU is excluded, the share of manufacturing in the non-OECD increased (from 15% to 25% 1970–2010), and energy intensity also increased by 13%. But the FSU experience was very different: the depression caused by the transition from central planning in the FSU gave rise to huge non-OECD energy efficiency improvements as the composition of the industrial sector changed and large segments of inefficient and uncompetitive industries shut down permanently. As evident from Fig. 1, in the first years of transition, energy consumption in these countries fell by less than GDP (energy was available almost for free to begin with). However, the FSU's share in non-OECD energy consumption was so large[10], and its GDP share so much smaller, that it reduced total non-OECD energy intensity even during the first years of its severe depression.[11] As Russia and other successor states of the Soviet Union recovered, the effect of huge efficiency improvements in their industrial sector and the improvements in domestic energy intensity impacted the non-OECD as a whole Figs. 2–4.

[10] This is an example of the "resource endowment" effect on peak energy intensity as discussed earlier.

[11] The share of energy consumption of the FSU in the non-OECD economies was 40%, but its share of GDP only 23%. Therefore even as GDP fell faster than energy consumption (and energy intensity in the FSU increased), this contributed to a decrease in energy intensity in the non-OECD countries as a whole.

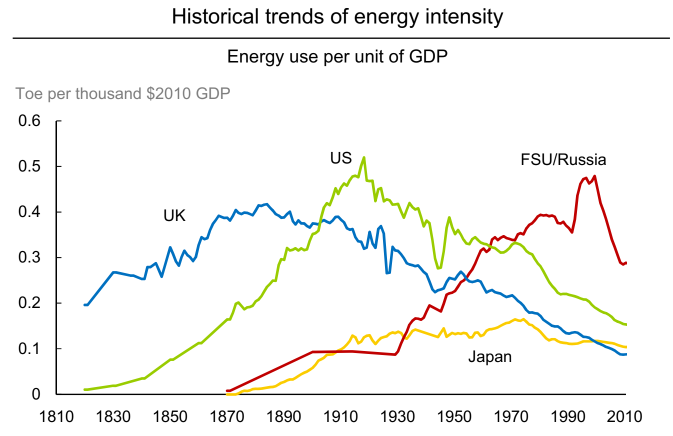

Fig. 1. Energy intensity in UK, US, Japan, Russia/FSU.

China plays a different role. It accounts for most of the increase in the share of the industrial sector in non-OECD GDP over the period 1970–2010. However, China contributed to lower non-OECD energy intensity through rapid economic growth, supported in particular by the high value added of its export industry. The starting point was different, with a much smaller share of the workforce in industry, and a better option of building up a new industrial sector from scratch and abandoning old energy-intensive industrial behemoths gradually. But the inverse relationship between a rising share of manufacturing in total output and falling energy efficiency also started after central planning lost its role in 1978.

In this way both China and Russia are examples of the more general principle that changes in the composition of the industrial sector itself may lead to gains in energy efficiency for the economy as a whole, if they are strong enough to outperform the rise in energy intensity associated with a rising share of industry.

The combination of improved efficiency in China and Russia resulted in declining energy intensity in the non-OECD as a whole over the 1990s, despite the growing share of manufacturing in GDP. The general lesson is how much the composition of industry, in addition to its efficiency and relative size, can affect the energy outcome.

3.3. Changes in the fuel mix

So far we have concentrated on primary energy as a whole, but the historical view also offers a closer look at changes in the composition of fuels over time. The most striking feature here is how fuels were not merely substituted one by one (as in coal replacing wood, oil replacing coal, and gas replacing oil), but the extent to which the diversification of fuel supplies increases, in close correspondence with technological diversification e.g., Nakićenović and Jefferson (1995). Industrialisation in the nineteenth century was dominated by coal (Freese, 2006; Wrigley, 2010), fuelling the steam engine, railway systems and, later, the electricity grid. The first half of the twentieth century saw the gradual emergence of crude oil as an energy source, initially for kerosene lighting, but then rapidly gaining share with the rise of the internal combustion engine (Yergin, 1991; Dahl, 2007).

Although coal remained the main provider of energy services through the first half of the twentieth century (and the principal feedstock for power generation much longer), this century, and especially the "age of oil" after the second world war, ought rightly

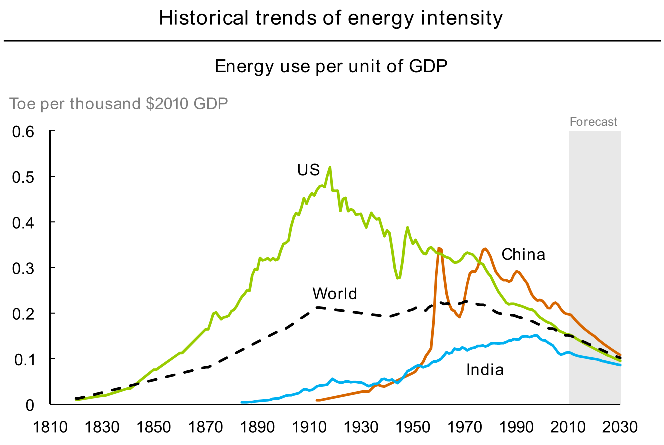

Fig. 2. Energy intensity for World, China, India, US.

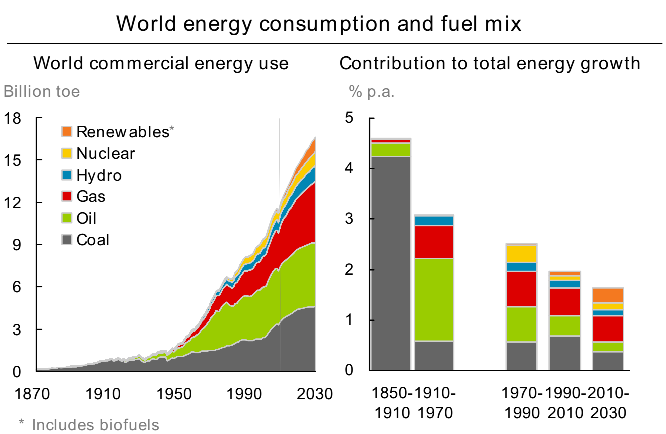

Fig. 3. Long term fuel trends.

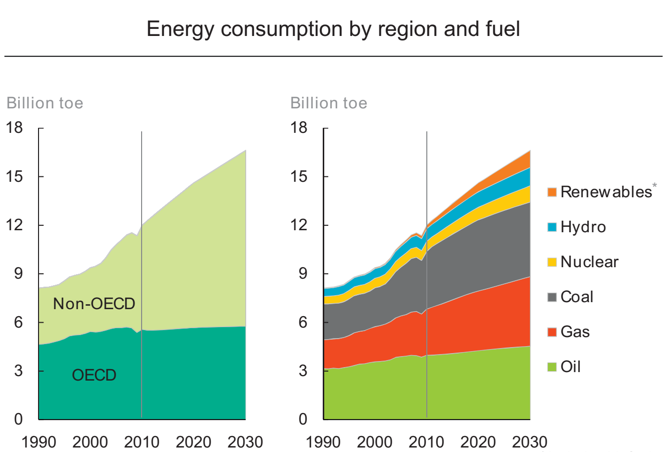

Fig. 4. OECD/Non-OECD chart of energy consumption.

already be termed an age of diversification. Different fuels emerged at scale-not only specialising to meet alternative needs (chemical feedstock, heating, industrial use, or transport) but also in competition with each other; and finally even challenging the stranglehold coal had maintained over power generation—the single largest source of global fuel demand in the twentieth century.

When the position of crude oil as the dominant source of commercial energy growth was challenged by supply disruptions in the 1970s (Yergin, 1991; Hartshorn, 1993), diversification of fuel supplies accelerated, with nuclear power and natural gas substituting for crude oil in electricity generation, and oil becoming more focussed in transport services. In the *2030 Outlook* we assume that fuel diversification will continue apace, driven by the power sector, where growth will be fuelled in almost equal parts by renewables, gas, coal, and nuclear, with more than half of generation growth accounted for by non-fossil fuels, and more than half of the growth of fossil feedstock accounted for by gas (oil will continue to be squeezed out).[12]

In global energy, renewables (in power and transport) will be the fastest growing category and natural gas the fastest growing fossil fuel. The period 2010–2030 should be the first 20 year interval during which the combined contribution of non-fossil fuels (hydro, nuclear and renewables) to global energy consumption growth outpaces the contribution of every individual fossil fuel (of which natural gas has the single biggest contribution to energy consumption growth). Total energy consumption will remain about 80% based on fossil energy carriers, but we expect the shares of the three major fuels (oil, gas and coal) to converge at about 27% of total fuel consumption each. If this happens, energy consumption would, for the first time in history, not be dominated by a single fuel.

Why does this matter? The driver of this gradual specialisation is the markets tendency to adopt more efficient technologies to provide services more cheaply and the comparative efficiency of each of the commercial fuels, in terms of production and conversion to usable energy (see for example Fouquet, 2011). The average fuel efficiency of the capital stock, in the form of motor vehicles, electricity generating plants and industrial equipment, will continue to increase as a result, and so will the efficiency of production and conversion of the fuel mix itself.

4. Convergence

A journey into the past is interesting in its own right, but this is not why we undertook it. We started out with a particular question—whether the provision of energy resources during past periods of rapid industrialisation and economic development can help us to understand today's situation. Will the pressure on known fuel supplies render today's wave of industrialisation and development unsustainable?

The data vindicate a hopeful perspective. They show massive and accelerating convergence since about 1990, toward lower and lower levels of global energy intensity. In fact, not since the early years of British industrialisation have the differences in energy intensity across major economies been as small as they are today Table 1.

What drives this process? Ultimately, it is the forces of "globalisation" that accelerate long term trends which have been seen before: the gentle slope which demarcates the transition from industrial to service economies has become steeper. This is because all tradeable fuels can now be traded across nearly all international borders, including countries which had been closed to international trade before the 1990s, and this greatly accelerates the allocation of fuels to their most efficient use. Similarly, technologies are becoming shared internationally to an extent not known before, and even consumption baskets (determining the end-use of energy) are becoming standardised and similar across formerly very different countries and cultures.

It is possible to date the beginnings of this process. At a global level, energy intensity peaked in 1970 and has been declining ever since. However, it is really since the late 1980s or early 1990s

[12] This and other forward looking statements are based on Energy Outlook 2030 (BP, 2012).

Table 1
Energy consumption and energy intensity 1990–2030.

Energy consumption (MTOE)							Energy intensity (TOE/million $2010 PPP)						
Year	**US**	**Brazil**	**Russia**	**China**	**India**	**World**	**Year**	**US**	**Brazil**	**Russia**	**China**	**India**	**World**
1990	1968	124	862	681	181	8109	**1990**	222	103	374	298	142	197
1995	2122	153	664	913	236	8578	**1995**	213	111	485	248	151	187
2000	2314	185	620	1038	296	9382	**2000**	191	123	439	229	147	174
2005	2351	207	657	1691	364	10801	**2005**	170	119	339	227	119	165
2010	2286	254	691	2432	524	12002	**2010**	158	116	298	204	117	155
2015	2258	290	731	3118	676	13360	**2015**	139	109	260	175	107	142
2020	2270	333	766	3688	871	14627	**2020**	124	104	228	151	102	129
2025	2263	371	801	4091	1048	15635	**2025**	109	97	204	128	94	115
2030	2241	407	838	4431	1262	16632	**2030**	97	92	185	109	88	103

that the process of rapid convergence from non-OECD economies gathers pace. Note that this is roughly the same period which saw economic growth and industrialisation in the developing world take off. The root cause for both appears to be the break-down of central planning.[13]

It is often forgotten today that until a little more than 20 years ago about one third of humankind lived in economies strictly organised by the principles of central planning (and this is without even counting the highly regulated derivative models in India and a plethora of smaller countries, mostly in the Southern Hemisphere); and we all lived in a world where global trade and the exchange of technologies and products was severely restricted. The deregulation of these economies and the liberalisation of trade since the late 1980s (in China, since Tiananmen Square) ushered in the unprecedented pace of industrialisation in the so-called developing world we have witnessed since, as well as the convergence to lower levels of energy intensity that have become so prevalent.

The famous "end of history" in fact was the beginning of an unprecedented pace of catching-up in economic growth. The corollary in energy markets was accelerating convergence in energy intensity toward the most advanced OECD levels: global energy intensity declined by 0.8% per annum between 1970 and 1990 and by 1.2% in the past 20 years; in the non-OECD, intensity rose initially by 0.8% per annum, but since 1990 it declined at an average rate of 1.5%.

In the *Energy Outlook 2030,* we assume this process of convergence to continue and economic growth, especially in non-OECD economies, to become significantly less energy intensive. To pick the biggest example, we expect China's energy intensity over the next 20 years to decline by 3.1% per annum. In part, this reflects the stylised path of economic development, as China passes through a peak in its share of industry in GDP as income rises and the legacy of central planning disappears. In part, it reflects an unabated trend toward convergence to lower global levels of energy intensity.[14]

For the world as a whole, putting numbers on these trends for major economies and regions, a comparison of the next 20 years with the previous 20 year period translates into higher GDP growth (3.7% vs. 3.2%), lower population growth (0.9% vs. 1.3%), and therefore a significant improvement in per capita GDP of about 70% over the next 20 years. The improvements in global energy intensity will continue to accelerate, with the energy required for each unit of GDP falling by 2.0% per annum over the period 2010–2030. To put this in context: significant improvements in per capita income will be accomplished with energy consumption per capita growing at about the same rate as in 1970–1990 (0.7% p.a.)—a period not known for rapid income growth.

There is an additional source of uncertainty, however. We pointed out earlier that living standards and energy consumption in countries bypassed by industrialisation are often no higher than they were in the pre-industrial world. Once Africa rises and industrialises, this is likely to have an impact on global aggregates: Even if it manages to follow the pattern established elsewhere and to avoid old technologies and production methods, we would expect its energy intensity to rise and Africa is too big not to have an impact on the global energy intensity profile. In similar fashion, India currently looks like an attempt to leapfrog full-scale industrialisation altogether. If it doesn't succeed, we would expect India's energy intensity profile to tick upward as a result—but double peaks in energy intensity have happened before (e.g., in Japan); they may impact but will not alter the global trend. When industrialisation in Africa and possibly India will start in earnest we will see more rapid growth of income and energy demand—exactly like we saw in countries which industrialised before them.

5. Conclusion

For all we know today, and for all we can learn from history, the convergence of national energy intensity levels at lower and lower global values should continue—as long as economic openness allows global fuel trade, the exchange of technical knowledge and the standardisation of products to continue.

Likewise, fuel supplies under these conditions should continue to specialise, a process encouraged by the same factors of trade, universal adaptation of energy technologies, and standardisation of end-use. Continued specialisation means continued enhancements of the efficiency of energy production as well as energy use.

Putting numbers on these trends leads us to believe that per capita growth in energy consumption from 2010–2030 should not be materially different from the period 1970–1990, which was characterised by higher population and lower economic growth.

The resulting projections for energy demand fuel by fuel in the *Energy Outlook 2030* provide one half of the story. The other half is the availability of resources to meet that demand, which is beyond the scope of this paper.[15] The resource analysis behind the *Energy Outlook 2030* indicates that no resource constraint will cause energy poverty, shortages or prices so high as to inhibit continued economic growth, at least over the forecast period to

[13] See for example Babecky and Campos (2011) for a meta-analysis of growth and reform in transition economies.

[14] By comparison, Chinese energy consumption per capita over the next 20 years in the 2030 Outlook is forecast to develop roughly on par with Japan's historical per capita consumption levels (at comparable income levels), but significantly lower than the historical levels of the US.

[15] See Sorrel et al. (2010) for a comprehensive discussion of oil resource availability.

2030. One of the key conclusions of the *Energy Outlook 2030*, that energy markets can accommodate the continued economic development and industrialisation of today's non-OECD economies, rests therefore in part on the historical analysis of long run energy demand trends presented in this paper. This, of course, is not to say everything will happen as predicted, where considerable "above ground" risks should be attached to any such forecast: Protectionism, regulation and a plethora of other interventions may yet mar the actual outcome.

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