East versus West
Energy Transition and Energy Intensity in Coal-Rich Europe
1830-2000

Abstract

The paper examines energy consumption in Britain, Germany and Czechoslovakia over 130 years, including both traditional and modern energy carriers. The article is based on new series of energy consumption for Czechoslovakia that includes traditional energy sources, and, which is compared to energy use in other coal-rich countries in Europe: Germany and Britain. Changes in energy consumption are decomposed into effects from population growth, economic growth and energy intensity. There are two major findings from the long-run transitions we identify. First, by exploring the coal transition for coal-rich versus coal-poor countries in Europe, we find some remarkable similarities between both Germany and Czechoslovakia. We show that when we include Germany, England and the Czech Republic there is in an inverted U-curve in energy intensity, even when traditional energy carriers are taken into account, in contrast with results for four coal-poor countries in the Northern and Southern parts of Europe, where energy intensity was either declining or staying fairly constant in the long run. Secondly, the paper identifies a different transition path after the WII, a period in which Czechoslovakia's energy intensity diverged from the trend observed in previous decades and also in Germany and England. Through a more detailed decomposition of the Czechoslovak energy intensity after 1950, we argue that the rise in energy intensity was a consequence of multiple forces, including high industrial energy use, structural change towards metals and chemicals (the backbone of central planning) and inefficiencies in energy use in those two sectors as well as high transformation losses of the electricity production. We suggest the central-planning system to be the main driver of this development, but with effects that are particular to some sectors rather than spread across all energy use.

Keywords: energy, coal, traditional sources, transition, decomposition analysis, politics

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Introduction and motivation

Studies of past energy transitions have recently gained increased attention. This has been, to some extent, driven by the growing awareness of increased energy consumption and particularly the environmental consequences of global fossil-fuel dominance. In fact, although coal is often seen as the fuel and prime driver of the first industrial revolution, it was in fact the 20th century which could be termed the 'coal century' (Smil 2014). Even though many developed countries switched away from coal to other fossil-fuels, coal remained the clear number one energy carrier in much of the rest of the world (Smil 2003). As some newly developing countries are moving towards this trend away from coal, it has thus become of increased interest to study various patterns of energy transitions. Historical analysis of energy transitions can thus be seen as potential lesson to learn from in 'the much needed energy transition towards sustainability' (Grubler 2012).

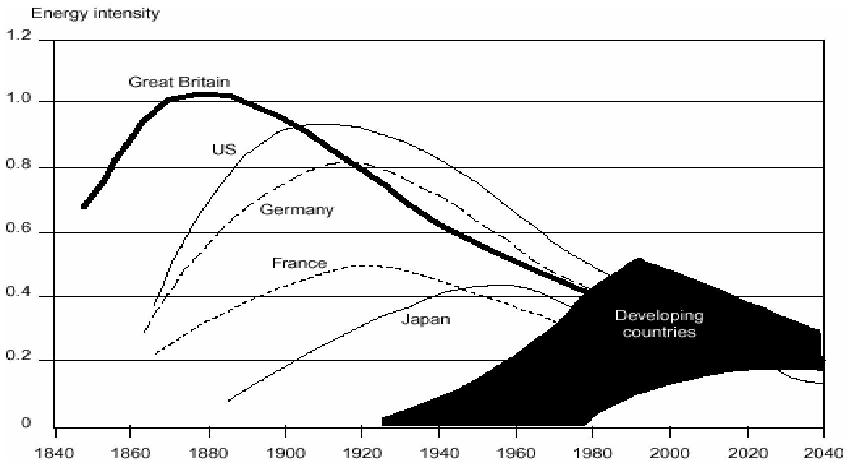
In the existing literature much of the study of national studies of past energy transitions has been confined to some of the most developed countries and within a similar institutional framework. This may have some constraining effect on our understanding of the past, as developments in final energy-use, the major agent of energy transitions, may differ substantially between various institutional/organizational settings (Grubler 2012). This paper attempts to fill in this gap and provides a quantitative account of a long-run energy transition across two systems of economic planning – the market economy and central planning. Much of the 20th century was marked by the parallel existence of two "alternative systems of organizing the production and distribution of goods and services in a nation: capitalism and state socialism" (Land et al. 1994). One would expect the energy transition to take a different turn in a planned economy and the case of Czechoslovakia gives us an opportunity to analyse this 'natural experiment' from an energy perspective. For the pruposes of the study of this experiment, we have also divided Germany into East and West Germany in search for some common trends between them and Czechoslovakia.

Background and previous research

The origins of the research on past energy transitions dates back to the decades after WWII. At this time of expanding industrial production and infrastructure building, studies of past energy use were often used for future forecasts and models. This was largely driven by the growing concern, not for the environment itself, but the supply of natural resources. Numerous papers and books solely devoted to energy history surfaced after 1960 (Schurr & Netschert 1960; Schurr 1972; Jorgenson 1984), largely produced by energy analysts. As mentioned above, the field has experienced a recent resurgence and a stronger presence within economic history (Smil 1994; Smil 2003; Gales et al. 2007; Kander et al. 2013; Kuskova et al. 2008; Malanima 2015).

Economists have puzzled over the extent to which energy consumption is simply an outcome of our growing welfare, or a necessary condition of it. If economic growth is accompanied by a proportional increases in energy consumption, our future economic opportunities may be endangered by inelastic supply or associated bads (Gales et al. 2007). Economic growth, thus becomes, in light of environmental pressures, an undesirable outcome. If, on the other hand, economic development can be decoupled from economic growth, a more optimistic picture emerges, particularly taking into account the rapid economic growth of the rest of the 'global south' (Gales et al. 2007). The most widely accepted perspective on this relationship is the concept of the Environmental Kuznets Curve (EKC), (Goldenberg and Reddy, 1990) (Figure 1). This proposed that energy intensity will increase at low levels of income per capita, as the countries industrialize, and then, after attaining a certain level of per capita income, energy intensity will start to decrease (Gales et al. 2007). One important aspect of the EKC theory is also the possibility of leapfrogging. This entails the possibility of developing countries already adopting/transferring modern technology from the developed countries at an early stage of development and thus achieving comparable levels of economic growth with a lower ratio of consumed energy to GDP after a transition across a path of increasing energy intensity (Gales et al. 2007). A quadratic logarithmic model would represent this movement.

Figure 1: Traditional portrait of the long-term evolution of energy intensities.



Source: adapted from Goldenberg, Reddy (1990).

The inclusion of traditional energy carriers changes the implied relation. The immediate consequence is to elevate the levels of energy consumption , and thus also energy intensities. The EKC is thus not found in case of several European countries without domestic coal reserves and a more drawn-out transition to fossil fuels (Gales et al. 2007). Past trends in energy intensity do not follow the same pattern for all countries. Obviously, specific industrial specialization and the degree of development will affect the country's energy intensity (Kander et al. 2013). Countries with domestic coal resources tended to locate large energy-intensive industries in proximity to mines, leading to the creation of energy-intensive clusters in certain parts of England, Germany but also Czechoslovakia, while at the same time forcing a rather energy-intensive path of industrialization in these countries (Kander et al. 2013).

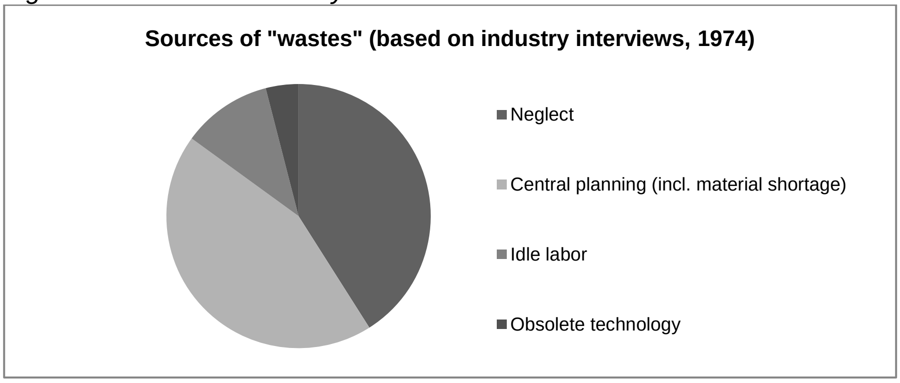
The post-war energy transition, which in Czechoslovakia is often related to the change of political regime, can be analysed from two angles. First (1), decline in energy intensity and a pattern of convergence has been identified in most developed countries (Kander et al. 2013; Henriques & Kander 2010). This development has been caused by various drivers, but efficiency changes and changes in the structures of final output have been dominant. Moreover, and this brings us to the second (2) major agent of change, changes in the fuel mix, often from inferior energy carriers to energy carriers of higher quality, translated into increased energy efficiency in energy use and thus lower energy intensity (Kander et al. 2013). Although, numerous studies have been conducted on Western European energy transitions in this period (Malanima 2015; Gales et al. 2007; Kander 2005; Kander et al. 2013), little attention has been devoted to a study of energy transition in Eastern Europe or other parts of the world with an economic system based on central-planning. On the other hand, the impact of the central-planning system on the actual productive efficiency of various communist countries has been studied quite extensively. Studies of productive efficiency of the overall economy generally highlight inefficient resource allocation as the prime driver of overall inefficiency (Land et al. 1994; Ürge-Vorsatz et al. 2006).

It is particularly in the industrial sector that the system of planning and centralized allocation of resources is believed to be detrimental to industrial efficiency, via two mechanisms (Carlin et al. 2013; Gomulka & Rostowski 1988; Brada 1974). First, planning slows down the adoption of *new processes and technologies* while at the same time it keeps inefficient plants in operation (Carlin et al. 2013). But why is central planning detrimental to the diffusion of technology? As with any other complex issue, there is a range of potential drivers. Obviously, the fact that an economic outcome is planned some time ahead – possibly years - before the plan is implemented, with performance subsequently judged by the extent to the plan ios fulfilled, could introduce delays or rigidities into the adoption of new technology. Also, this may be compounded by a reluctance at managerial level to risk uncertain technological outcomes against the fulfilment of a plan, particularly in the early stages of development. This has been evident in for example studies comparing the adoption of new steel technology in the West and the East (Nielsen 2016; Tarr 1985; Poznanski 1983; Nakamura & Ohashi 2005; Nakamura & Ohashi 2008; Poznanski 1990). This relates closely to the general theoretical framework of technology transfers. Levcik & Skolka (1984) analysed technology transfers in Czechoslovakia and concluded that overall imports of technology from OECD countries were "rather low". This could, theoretically, have led to the technological backwardness of Czechoslovak industries, although previous studies on East-West technology transfer have shown mixed results in its impact on productive efficiency. Nielsen (2016) provides a quantitative analysis specifically of the iron and steel sector, comparing it with other planned economies as well as market economies (covering countries producing over 80 percent of global steel). The author concludes that energy efficiency of the Czechoslovak iron and steel sector was one of the lowest within the sample of over 20 countries in the early 1970s (Nielsen 2016). However, a series of restructuring and energy conservation plans already implemented during the 1970s had a tremendous impact on energy consumption of the sector. Within a decade, by 1980s, the Czechoslovak iron and steel sector, in fact, reached energy efficiency levels on par with the market economies in the West.

A second mechanism is *inefficient resource allocation* under which the supply of raw materials and other factors of production, including energy carriers, was largely determined by administrative decisions rather than prices (Montias 1959). In order to estimate the material balances, which were used both for short-term as well as long-term planning, latest production figures were simply matched with future output targets and same ratio of material (energy) intensity was applied. This was practised particularly during the 1950s, however certain adjustments to the rigid system of material allotment were introduced during 1960s (Brada 1974). It was in this decade that planners realized some of the deficiencies of the detailed centralized planning adopted from the Soviet Union and a series of reforms were implemented across the region, the most radical ones being in Czechoslovakia and Hungary (Brada 1974).

Other studies confirm the view of central planning and particularly the wasteful and polluting effects of the centralized allocation of resources, for example a study on workers' attitudes conducted across various Eastern-European countries in 1974. According to this only 30 percent of respondents indicated that materials used within the production process were used optimally and in an efficient matter, while the rest of respondents identified some degree of waste (44 percent respondents referred to some waste and 11 percent pointed to serious material waste). In respect to energy use, 36 percent of respondents found the use of energy in production to be efficient, while 40 percent found it somewhat wasteful and 8 percent largely wasteful. When inquiring in to the drivers of these wastes in production processes (be it materials, energy or even working hours), 41 percent of respondents referred to human neglect, 32 percent highlighted the drawbacks of central planning in allocating resources and only 4 percent pointed out the technological incapacity of production and obsolete technology (Figure 2).

Figure 2: Sources of industry wastes



Source: Fall & Winter (1992)

Obviously, neglect or generally poor morals and irresponsibility are some of the aspects impossible to measure or capture with most available econometric tools. On the other hand, in respect to energy (particularly electricity and fossil fuel use), the explanations of waste (inefficiencies) of the central planning can be identified in following areas:

- Technologically obsolete production processes.
- Low-technology products which in turn used high amounts of energy in their operation or had shorter life cycles.
- Sub-optimal production processes (machines not operating at full/optimal output), which to some degree can be linked to neglect. Fall & Winter (1992) refer to interviews with Romanian enterprises which reported producing at 50 per cent of full capacity while consuming 80 to 90 per cent of energy at full production.
- Energy embodied in final products which had to be scrapped due to their low quality (scrap rate of up to 30 percent of total production) or later modified to meet certain quality standards (again up to 30 percent of total production).
- Energy embodied in the components used for production of these scrapped products.
- Negligence, or generally poor morals and irresponsibility.

A brief Czechoslovak economic history

Before moving further to the analysis of various path of energy transition and particularly the post-WWII divergence, it is important to remind the reader of some peculiarities in Czechoslovak economic history. This is especially important for a full understanding of rising industrial energy consumption after 1950.

Historically, Czechoslovakia, or the Czech lands when referring to the pre-WWI period, was one of the most developed parts of Eastern Europe, despite still being on the periphery and catching–up to its Western counterparts. Although delayed, the relatively rapid industrialization especially after 1870, laid the ground for the industrial structures of the country. By 1913, Czechoslovakia had become the most industrialized part of the Austria-Hungarian Empire supplying much of the material needs of the Monarchy. It has been estimated, that only some 30% of the final Czechoslovak production in this period was consumed domestically. (Cisar & Pokorny 1922). In fact, it is believed that before WWII "most of the products known on the world's market as Austrian, came from the territory comprising the new Republic" (Cisar & Pokorny 1922). Following WWI and the disintegration of the Austria-Hungarian Empire, Czechoslovakia lost virtually all of its export markets which were so fundamental to the development of its industries. At the same, it was also in the interwar period that the country started to fall behind the technological advances of Western Europe, especially moves towards electrical engineering or transportation equipment (Berend 2001). But although the share of domestic exports, particularly those of consumer goods (textiles, leather goods, glass and porcelain) declined after WWII, the Czechoslovak economy attracted foreign investment and increased its gross domestic product by 40% between 1913 and 1929 (Berend 2001). In fact, in terms of economic growth, Czechoslovakia performed best among all central and eastern European countries.

Immediately after WWII over 60 percent of exports (Table 2) went to Western markets (Germany, USA and Sweden in particular). When the Communist party won the country's first democratic elections in 1946, Czechoslovakia was the second country (after the USSR) to introduce a model of central planning. But the two-year plan of the Czechoslovak government was to a significant extent based on the country's trading balance and its primary focus was to reconstruct the country's economy and increase the living standards of the population while at the same time keeping some elements of market mechanisms. The Czechoslovak economy recovered in these 2 years and was set on a socialist path of growth with some market mechanisms. It was the full seizure of power by the Communists in 1948 which radically shifted the direction of development. The first 5-year plan was heavily influenced by Soviet officials and Czechoslovakia as the most industrialized country of the newly established COMECON, became the machine shop of Eastern Europe, while at the same time subordinating its own needs in order to meet "the demands of industrialization of the other Comecon states" (Teichova 2013). Trade changed significantly: while in 1947 the Soviet Union accounted for 5 percent of trade (with the rest of Eastern Europe accounting for further 7 percent), by 1953 the share of exports to the Soviet Union increased to over 32 percent. The year 1948 is therefore often seen as the turning point in Czechoslovak development and the beginning of the industrial intensification which was more or less sustained for the next 40 years (Table 1). As a result of the 5-year plan of 1948 production became re-aligned, for example armament and ammunition production quadrupling 1950-1952 (with majority for exports).

Table 1. Commodity structures of Czechoslovak exports 1949-1953 (% total)

	1949	1953
Total	100.0	100.0
Machines, equipment and tools	27.2	42.4
Fuels, raw materials and minerals	37.0	36.8
Breeding stock and other animal	0.1	0.0
Foods including raw materials	7.8	8.6
Consumer goods excluding foods	27.9	12.2

Sources: Teichova (1988:144)

Table 2. Geographical distribution of Czechoslovak foreign trade 1948-1953 (% total)

	1948	1953
Imports total	100.0	100.0
- from socialist countries	39.7	78.9
- from non-socialist countries	60.3	21.1

Exports total	100.0	100.0
- to socialist countries	39.6	78.1
- to non-socialist countries	60.4	21.9

Sources: Teichova (1988:146)

The structure of the paper

The paper thus addresses two major issues – coal-transition (1) and post-WWII transition (2):

(1) *Coal transitions:* In section 1 we account for the different energy systems of our three countries. Fossil fuel transition in Germany and Czechoslovakia will be analysed in more detail. In section 2 we compare the aggregate and per capita energy consumption for the whole period of study. In section 3 we analyse the changes in aggregate energy consumption. To this purpose we use a decomposition analysis. On the basis of this, we are able to distinguish the relative importance of population, per capita product and a residual representing the role of technical change in a broad sense including changes in industrial structures.[1]

(2) *Post-WWII transitions:* Section 4 decomposes the energy intensity further into within-sectoral change and between-sectoral change, to explore the role of the industrial sector and a possible service transition. Section 5 contains a concluding discussion, which sums up the main results of the study and makes some overall comments on further studies that may be worth pursuing on basis of the results of the present study.

1. The long-run energy transition. Comparisons of the national energy systems in coal-rich countries

The common feature of all three countries is that traditional energy carriers were relatively quickly replaced by modern energy sources, or in the case of England, had become only a small share of consumption at an early date (Figures 3-5). If we classify food for men and working animals, firewood, wind and water and peat as traditional energy carriers, we find that their contribution to the total energy input may have become less than 50 percent as early as 1700 in England (Warde, 2006), and in 1863 and 1873 in Germany and the Czech Republic respectively. This is a rather early transition to modern energy carriers, particularly when compared to other Western countries without immediate coal supplies. In Sweden, for example, traditional energy carriers accounted for more than 50 percent of domestic energy consumption until late 1920s, while in Italy of Spain this transition occurred first only just before World War II.

[1] Commoner (1971a), (1971b), Ehrlich et al. (1977), Ehrlich and Ehrlich (1990).

Figure 3: The English energy transition 1800-2000

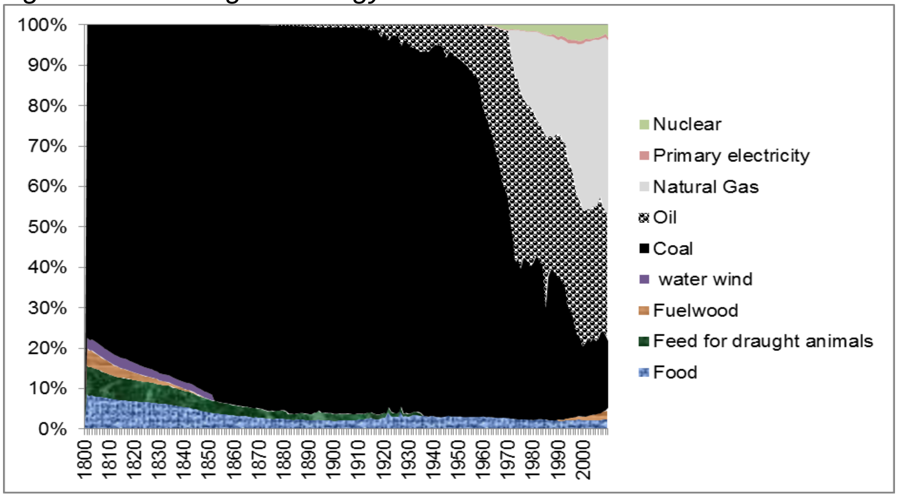


Figure 4: The German energy transition 1800-2000

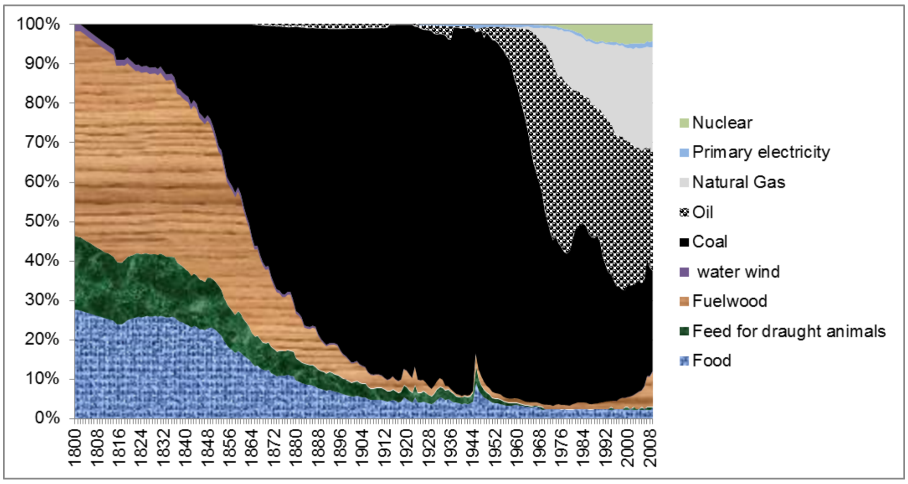
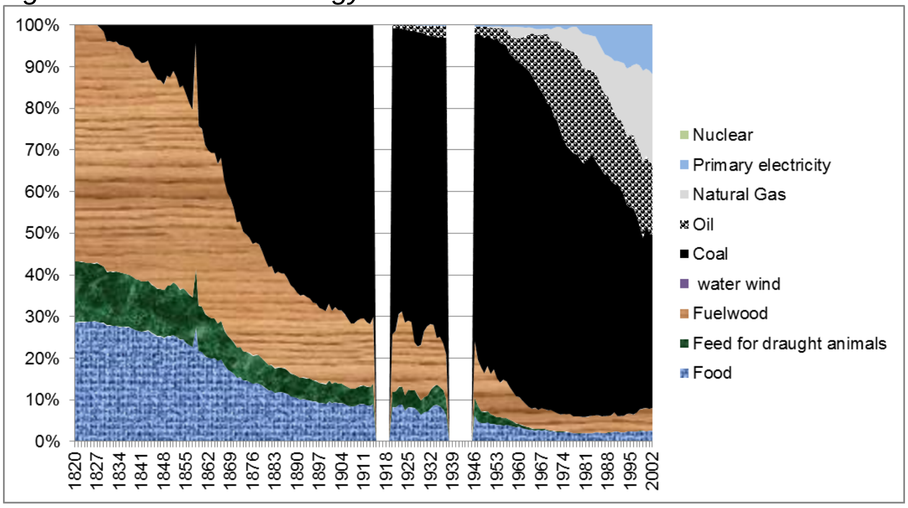


Figure 5: The Czech energy transition 1820-2000



The relative importance of specific traditional energy carriers differed among our countries.

Table 3. Composition of energy consumption in England, Germany and the Czech Republic in 1850 (%)

	England	Germany	Czech Republic
Food (men, animals)	7,1	35,2	32
Firewood	0	37,5	54
Wind, Water	1,5	1,5	<1
Fossil fuels	91,4	25,8	14

Clearly, England as the first country to go over to coal, had high shares of fossil fuels in its domestic energy consumption mix. The role of traditional sources such as food for men and animal fodder was of far less importance already around 1800, while in less industrialized parts of Europe food, feed and importantly firewood remained the major energy source.

Table 4. Composition of energy consumption in England, Germany and the Czech Republic in 1900 (%).

	England	Germany	Czech Republic
Food (men, animals)	3,7	9	14
Firewood	0	5	19
Wind, Water	0	0,3	0
Fossil fuels	96,3	85,7	68

The dominance of coal varied considerably. At its peak its share was 82 percent in the Czech Republic (shortly after World War II), 93 percent in Germany a decade earlier (1940s) and staggering 96 percent in England (1883). (Table 5).

Table 5. Composition of energy consumption in England, Germany and the Czech Republic in 1950 (%).

	England	Germany	Czech Republic
Food (men, animals)	3,1	6	8
Firewood	0	1,7	11
Wind, Water	0	0	0
Fossil fuels	96,9	91,7	82
Primary electricity	0	0,6	0

Note: primary electricity is an abridged expression used for hydro- and nuclear electricity. Primary electricity does not actually exist, electricity being in any case a secondary form of energy. Electricity is here calculated by its heat content, and not by the energy content of the water or uranium used for its production.

Over 200 years, a long energy transition had been accomplished with the almost total disappearance of traditional carriers such as wind, water and draft animals (Table 6). Interestingly, all three countries showed similarities in the dominance of coal. At the same time, it is important to highlight the actual length of coal transition which was far more prolonged in England comparing to Germany and Czechoslovakia. In fact, while England slowly progressed to a maximum utilization of coal over two centuries, it took Germany and Czechoslovakia decades. This is a common trend of any technology diffusion in the core countries with a lengthy early stages of technology testing, followed by rapid increases in deployment (Grubler 1990). Germany and Czechoslovakia, in this respect, were only followers moving towards the use of coal once the steam technology reached certain degree of development.

Table 6. Composition of energy consumption in 2000 in England, Germany and the Czech Republic (%).

	England	Germany	Czech Republic
Food (men, animals)	2,2	2,8	2
Firewood	0,9	2,6	6
Fossil fuels	92,8	88,6	81
Primary electricity	4,1	6	10

Note: Primary electricity is of different importance in our three countries.

1.1. Fossil fuel transitions – an overview

Comparing the transition patterns to all three major fossil fuels – coal, oil and natural gas, some similarities across the countries within our sample can be observed. First the transition to coal in Germany and the Czech Republic shows a similar pattern development (Figure 6). During the second fossil fuel transition, the move towards oil, both Germany and England were relatively quick (Figure 7). However the Czech Republic's adoption was much more limited, with oil reaching a maximum share of 25 percent. All three countries lacked, at this time, domestic oil resources, and the heavy expansion of the Czechoslovak coal mining and high costs of obtaining foreign currency for importation may have blocked the increased penetration of oil. A more detailed analysis of the actual end-use of various liquid fuels also explains this relatively low penetration of oil compared to England and Germany. The transport sector, and in particular the personal transport sector was supressed under the planned economy. It is estimated that only some 5 percent of final oil consumption (a figure which even might be overestimated) was consumed by private cars, a share which doubled just between 1989 and 1990 as restraints were released. The whole transport sector accounted for an average share of 12 percent, while the bulk of all liquid fuels (50-60 percent) were used for electricity generation and the rest in industrial production. The origins of the third fossil fuel transition with a shift towards natural gas can be traced back to 1970s in all three (Figure 8). Here, England again took a pioneering role drawing in North Sea reserves discovered in 1965, becoming the first country where natural gas nowadays accounts for more than 50 percent of domestic energy consumption.

Figure 6. Coal transitions in Czechoslovakia and Germany (years to reach 50 percent share of coal in domestic energy consumption)

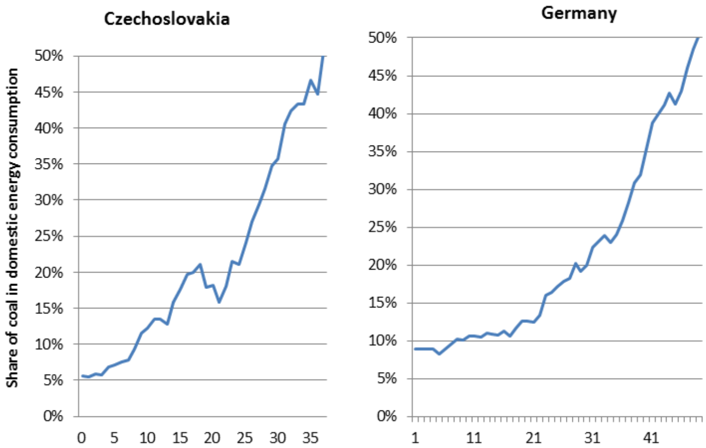


Figure 7. Oil transitions in Czechoslovakia, Germany and England (years to reach 50 percent share of coal in domestic energy consumption)

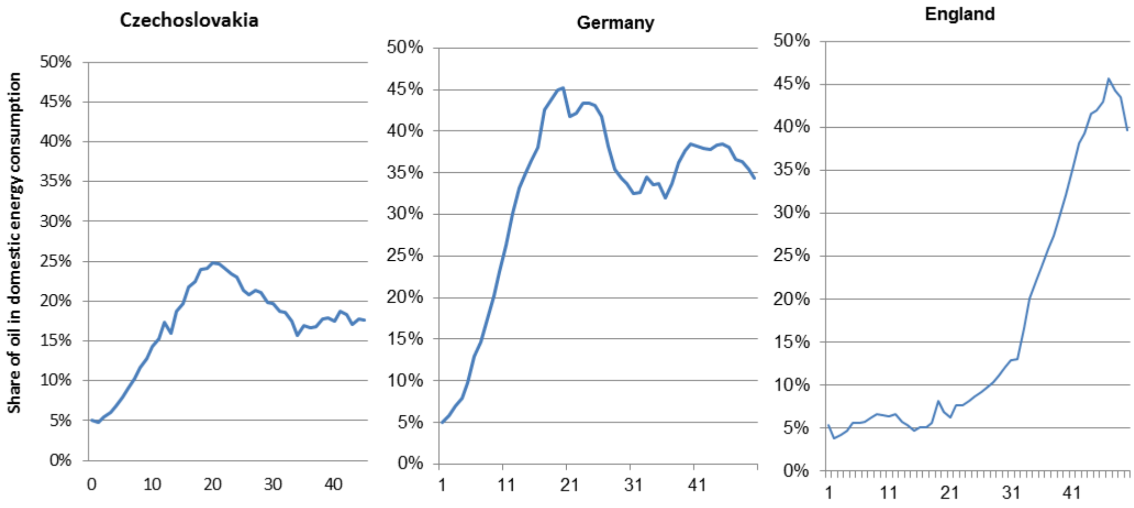
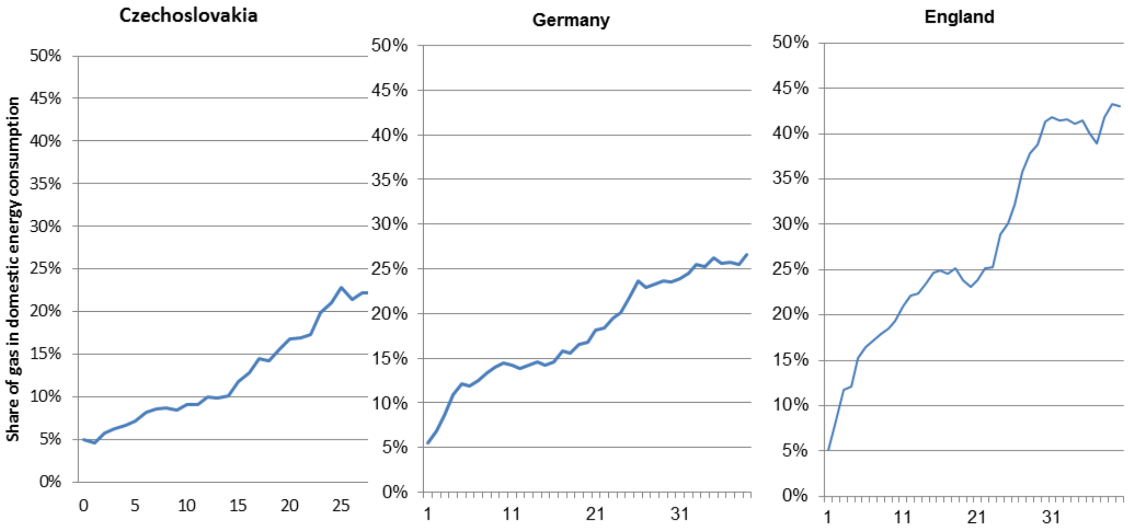


Figure 8. Natural gas transitions in Czechoslovakia, Germany and England (years to reach 50 percent share of coal in domestic energy consumption)



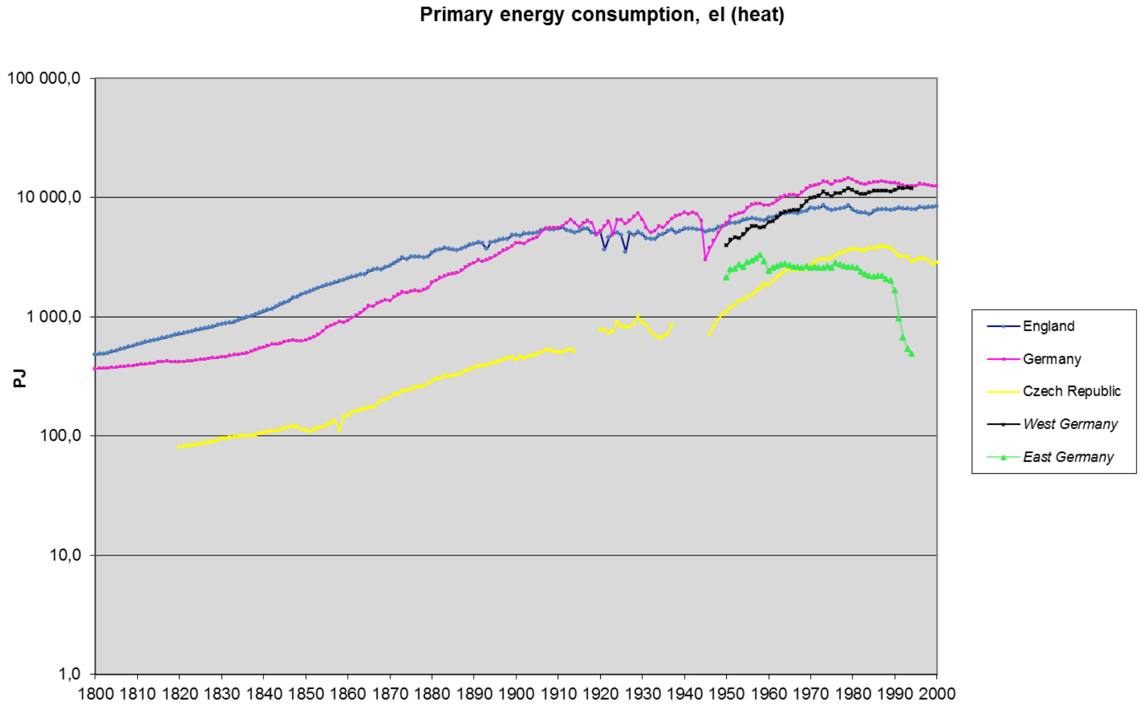
2. Aggregate energy consumption

There are clear similarities in the long-term patterns of absolute energy consumption in the three coal-rich countries (Figure 8). There were modest rates of increase until the WW II, a period of faster growth rates in 1950-73 and declining growth rates between 1973 and 2000. These facts integrate well the overall economic growth patterns and lend some credibility to the idea that more growth requires more energy and more energy allows for further growth. However some differences are obvious:

1. The interwar period was marked by fluctuations in total energy consumption in all countries studied, related to economic crisis and industrial unrest.
2. Although the overall energy consumption in 1950-1973 was increasing in all countries, the rate of growth was significantly higher in Czechoslovakia

3. In East Germany, the overall energy consumption recorded the lowest rate of growth after WWII with a decline after late 1980s.
4. The Czech lands show a flattening and decline in energy consumption after 1990 while in Germany and England energy consumption continued to increase, albeit slowly. This reflects industrial restructuring which followed after the revolution. Driven by the newly established workings of market economy, inefficient, obsolete and unnecessary plants or even whole industrial branches, ceased to exist in the first decade of market reforms.

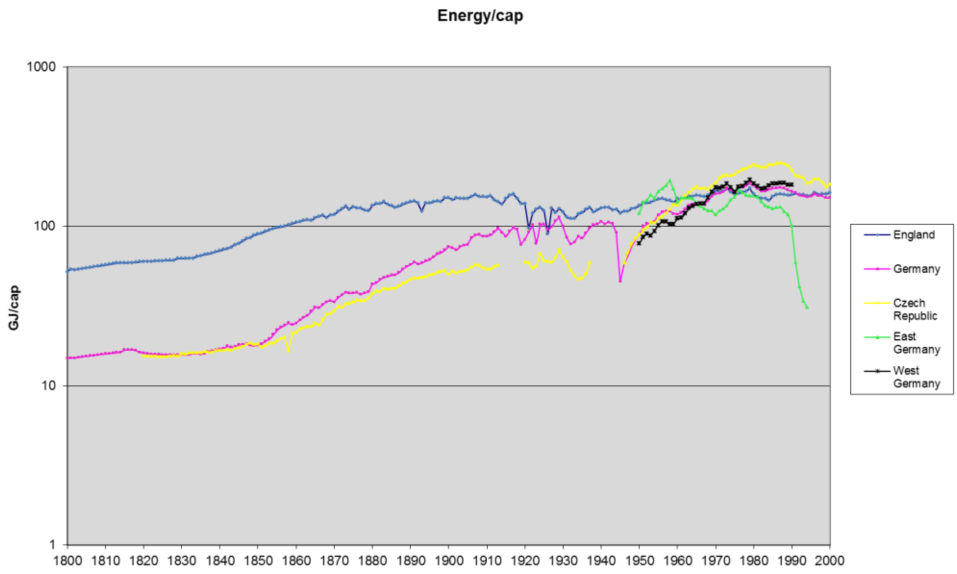
Figure 9: Primary energy consumption in Germany, Britain and the Czech lands, (Petajoules, PJ).



To some degree the different levels of energy consumption are naturally connected to the size and population of the country. When examining the energy consumption per capita (Figure 10), we see more distinct developments. In the early stages of industrialization the Czech Republic and Germany have similar levels of per capita energy use. At the same time, England as the industrial leader of 19th century Europe clearly stands out. Since 1850s, a certain pattern of convergence in energy per capita can be visible, though it is also at this time that Germany significantly increased its domestic energy consumption. By the end of WWI, both Germany and England have comparable levels of energy per capita, while the Czech Republic lagged behind. Following WWII, the Czech Republic and Germany had a comparable level[2] of energy per capita, however the trend diverged after 1950s. Since 1970, in fact, it is the Czech Republic which has the highest levels of energy per capita.

[2] It is here important to highlight the role of changing total population on the calculation of energy per capita. Following World War II, many countries recorded casualties. In case of the Czech Republic, there were further 3 million inhabitants of German origin which were forcibly displaced in 1945 and 1946, only to appear in the Germany population statistics. This is likely to explain the similar levels in energy per capita in those countries.

Figure 10: Energy consumption per capita in Germany, Britain, the Czech lands (Gigajoules, GJ).



3. Decomposing energy consumption

A frequently used formula for decomposing the environmental impact into its main components is the Commoner-Ehrlich formula:[3]

$$I = P \cdot A \cdot T \qquad (1)$$

where:

I environmental impact of a group or nation;
P population size;
A per capita affluence (measured by proxies such as income per capita);
T a residual and an indicator of the relative environmental impact

Translated into an energy context, the Commoner-Ehrlich formula becomes the following identity, where *E* stands for total energy consumption, *Y* for GDP (*A* in (1)*,* while the *T*-factor is the energy intensity (*E/Y*):

$$E = P \cdot \frac{Y}{P} \cdot \frac{E}{Y} \qquad (2)$$

Written as growth rates instead this is the same as:

$$e = p + y + e_y \qquad (3)$$

where *e, p, y* and e_y are the annual rates of increase of total energy consumption, population, per capita GDP and energy intensity (Table 5). In our identity (3), whenever *p*+y exceeds e_y, the consequence is an increase of total energy consumption *e*.

Overall, results in Table 7 summarize the yearly growth rates of each component of the Commoner-Ehrlich formula. While individual components will be further discussed in

[3] For an overview, see Ekins (2000), pp. 154-81. The formula has often been used in the environmental research. Well known examples are Gowdy, Miller (1987), and Casler, Hannon (1989). On the decomposition analysis see also Ang-Zhang (2000).

more detail in chapters 3.1.-3.3., one specific period will be highlighted here: 1950-1973, which also further lays motivation of an LMDI decomposition (Logarithmic Mean decomposition) of specifically Czechoslovak energy intensity. The period after 1950 is the most striking in case of Czechoslovakia. In England and Germany, the forces of improved productivity and efficiency had a stronger impact on the overall trend of energy consumption. They have been able to reduce greatly the growth of energy consumption and finally, at the very end of the century, to neutralize it. Contrary to this, Czechoslovakia is the only country which shows a pattern of growth in all three factors (population, per capita GDP and energy intensity) resulting in the largest increase in total energy consumption, primarily 1950-1973. This will be further discussed in section 4. Even splitting Germany into West and East Germany for the after WWII years, we cannot observe similar trend in East Germany despite the fact that which together with Czechoslovakia it became a planned economy.

Table 7. Yearly growth rates in Energy (total), Population, per capita GDP, Energy intensity in 4 periods (1870-2000)(%).

			E	*p*	*y*	e_y
England	***1800-1869***		2,50%	1,29%	0,85%	0,44%
	1870-1913		1,65%	1,14%	0,92%	-0,35%
	1920-1937		1,78%	0,83%	1,62%	-0,22%
	1950-1989		0,85%	0,35%	2,22%	-1,66%
		1950-1972	1,58%	0,52%	2,46%	-1,34%
		1973-1989	-0,14%	0,13%	1,90%	-2,10%
	1990-2000		0,72%	0,31%	2,15%	-1,67%
Czech Republic	***1870-1913***		2,28%	0,64%	1,15%	0,41%
	1920-1937		0,99%	0,63%	2,58%	-2,13%
	1950-1989		3,33%	0,59%	2,45%	0,22%
		1950-1972	4,78%	0,71%	3,22%	0,80%
		1973-1989	1,35%	0,43%	1,45%	-0,52%
	1990-2000		-2,38%	-0,03%	0,37%	-2,59%
Germany	***1870-1913***		3,63%	1,15%	1,59%	0,89%
	1920-1937		2,46%	0,36%	3,98%	-2,00%
	1950-1989		2,22%	0,38%	4,16%	-2,22%
		1950-1972	3,73%	0,65%	5,64%	-2,39%
		1973-1989	0,17%	0,02%	2,16%	-1,99%
	1990-2000		-0,53%	0,36%	1,30%	-2,11%
West Germany	***1950-1989***		2,79%	0,53%	4,04%	-1,74%
		1950-1972	4,54%	0,88%	5,39%	-1,66%
		1973-1989	0,52%	0,08%	2,29%	-1,83%
East Germany	***1950-1989***		0,01%	-0,29%	2,57%	-2,16%
		1950-1972	1,10%	-0,35%	3,71%	-2,08%
		1973-1989	-1,41%	-0,20%	1,10%	-2,26%

A disaggregated analysis per country and per factor provides a clearer picture of the overall trend. If we contrast the relative importance of any factor (p, y and e_y) in the determination of overall energy consumption in the whole period 1870-2000, with the average of the three countries studied in 1950-1973, we can see that the importance of energy intensity (the technology factor) has been remarkable in England and Germany but less so in Czechoslovakia.

Table 6. The importance of any factor in determining the overall energy consumption in 1973-2000 in comparison with the average for the three countries in 1870-2000 (%)

		p	*y*	e_y
All 3 countries	***1870-2000***	19.9	65.8	14.3
England	***1950-1973***	12.0	56.9	31.1
Germany	***1950-1973***	7.4	65.1	27.5
Czech Republic	***1950-1973***	14.8	68.2	17.0

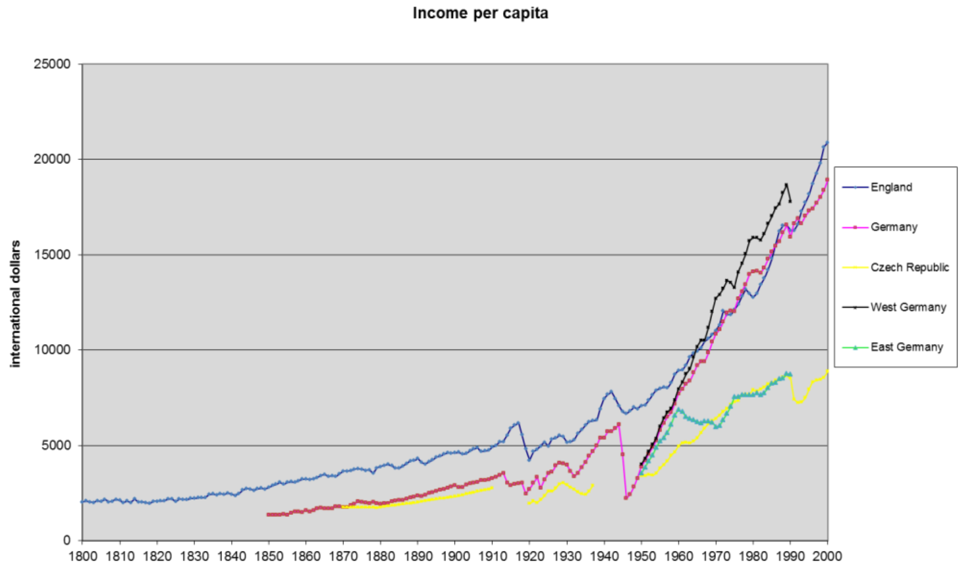
3.1. The P-factor

On the whole, the *P*-factor shows small variations in growth rates over time (less than 1 percent per year in 1950-2000), and is thus incapable of explaining a factor that shows large fluctuations, such as energy. Globally, in our three countries, population grew by a factor of 2.1 between 1870 and 2000, while total energy consumption increased by a factor of 5.6. We need then to look at the income per capita variable, the *Y/P*-factor.

3.2. The Y/P-factor

The *Y/P*-factor (in eq. 3) or the income per capita (Figure 11) is a more volatile variable than the *P*-factor and as such is more able to "explain" development of the *E*-factor over time. Energy consumption, however, is not merely a function of income, as the differences between countries show.

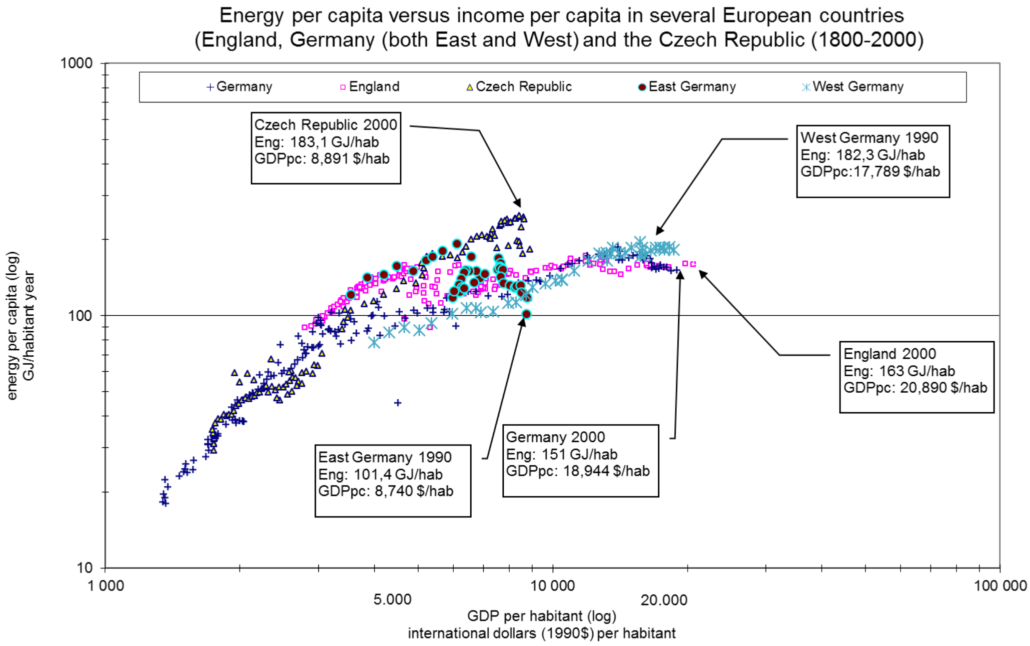
Figure 11: *Income per capita (constant international 1990 PPP dollars).*



Naturally this is not the place to discuss the long-term economic development of these three countries, but the differences across them appear as much in levels as in trends.

The rise in per capita GDP was the strongest variable in determining an unprecedented growth in energy consumption (Figure 12), even though energy intensity decline contributed to partially neutralize this upward trend. Generally, post-war increases in per capita incomes (or the affluence of the population) reached the highest annual growth rates and were the most important factor for overall energy consumption (Table 6).

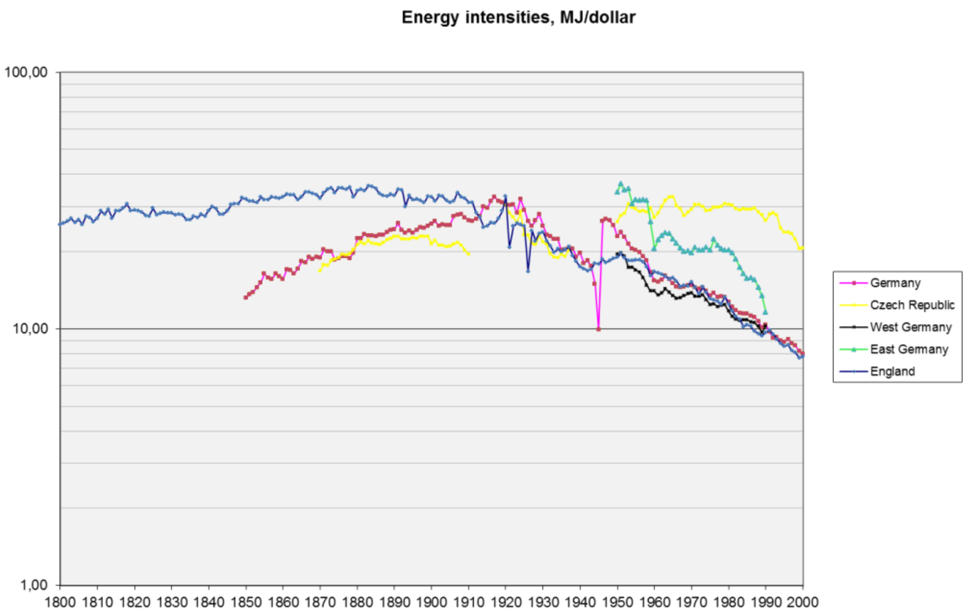
Figure 12: *Energy* per capita *versus income* per capita*.*



3.3. The E/Y-factor

E/Y (in eq. 3) is a factor, or a residual, that catches everything that has not been taken in by the *P*-factor and *Y/P*-factor together. Despite the wide increases in energy consumption over the last 100 years, production has slowly become more efficient in energy terms. Towards the end of the 20th century, both Germany and England dropped to less than 10MJ/$, a level which is well below those of the previous 100 years.

Figure 13: Energy intensity (Mj/int. PPP1990 dollar).



How does our approach change the perception of the relationship between energy intensity and economic growth? The standard presentation of the EKC has the levels of income per capita, rather than time, on the x-axis. In Figures 14 and 15 energy intensity includes all types of energies put into use by the economic system and it is represented in the y-axis. Income per capita, measured by the GDP per inhabitant of each of our four countries, is represented in the x-axis. In a comparative study of coal-poor 'North-South' Europe (see Gales et al., 2007), the result does not have the expected inverted-U shape implied by past literature on the subject (Figure 14). For the most part, the figure looks more like a wave, moving towards higher levels of income with a long-term trend of lower levels of energy intensity. In fact, the only inverted-U shape that can be identified is the one peaking around the first oil crisis for three of the four countries (Spain being the exception).

Figure 14: Energy intensity versus income per capita North-South.

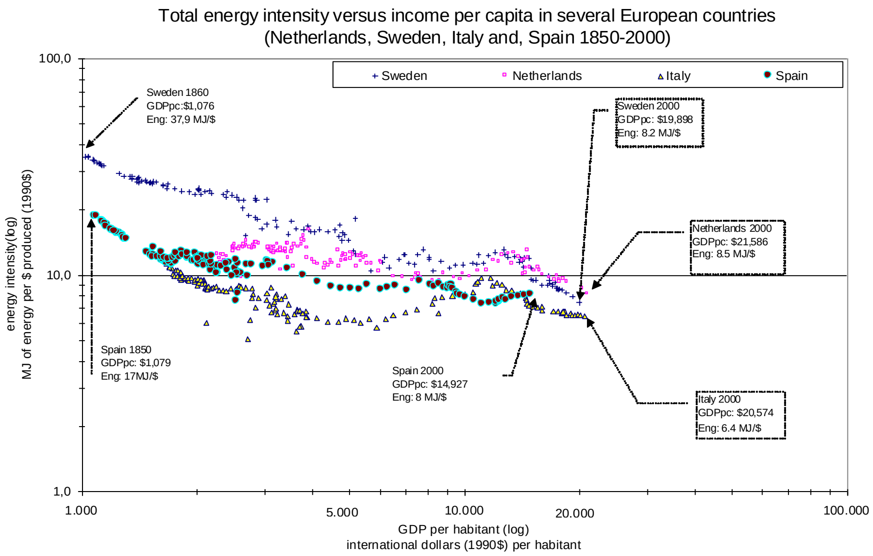
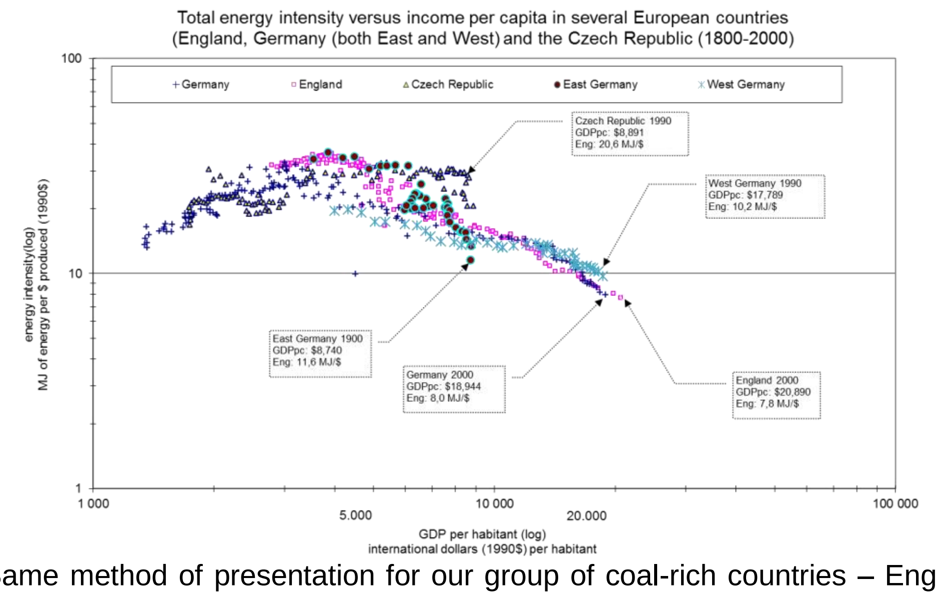


Figure 15: Energy intensity versus income per capita East-West.



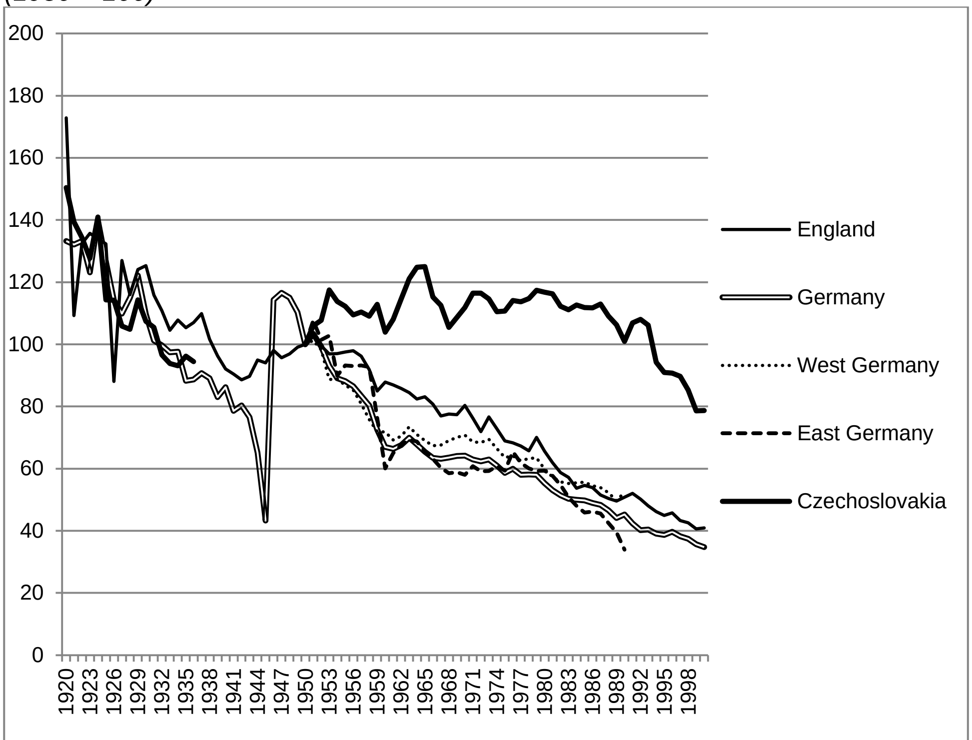
Same method of presentation for our group of coal-rich countries – England, Germany and Czechoslovakia – shows a distinctly different pattern of energy intensity. As can be seen in

Figure 15, the combined curve of energy intensities for three countries resembles in fact the inverted U-curve as proposed by Goldenberg and Reddy (1990), even when traditional energy carriers are included. This highlights the differences associated with the various path of industrialization as discussed in section 2. In case of our three countries, all of which possessed significant coal reserves, the path of industrialization took a similar turn with generally more energy-intensive industrial development. Since the technology of the first industrialization could be deployed with the largest savings in regions with reliable coal supplies, energy intensive industries took over the economic structures of those countries.

4. Decomposing energy intensity 1950 - 1973

As already concluded in previous sections energy transition in Czechoslovakia largely followed similar patterns as identified in Germany and England, both in terms of energy mix as well as absolute levels of energy intensity, although with a certain temporal lag. The period which, however, shows a particularly distinct and specific development is the period of central-planning in 1950-1973. Not only did the levels of energy intensity increase in this period to peak during 1970s, the dominance of coal was far more long-lasting than was the case of Germany and England. Figure 16 shows a clear trend of declining energy intensity in the after-WWII period, with Czechoslovakia was the only exception. Even East Germany country subject to centralised planning, followed similar trends of energy intensity as West Germany. While in the other countries energy intensity was set on a path of a long-term decline, Czechoslovakia increased its energy intensity by some 19 percent between 1950 and 1973, a pattern unseen in most of the developed world.

Figure 16. Development in energy intensity in England, Germany and Czechoslovakia after WWII (1950 = 100)



To further shed more light on this anomalous rise in energy intensity, a decomposition analysis of the sectoral energy use was conducted. The method employed for the calculations corresponds with the multiplicative version of the Log Mean Divisia Index method (Ang 2005;

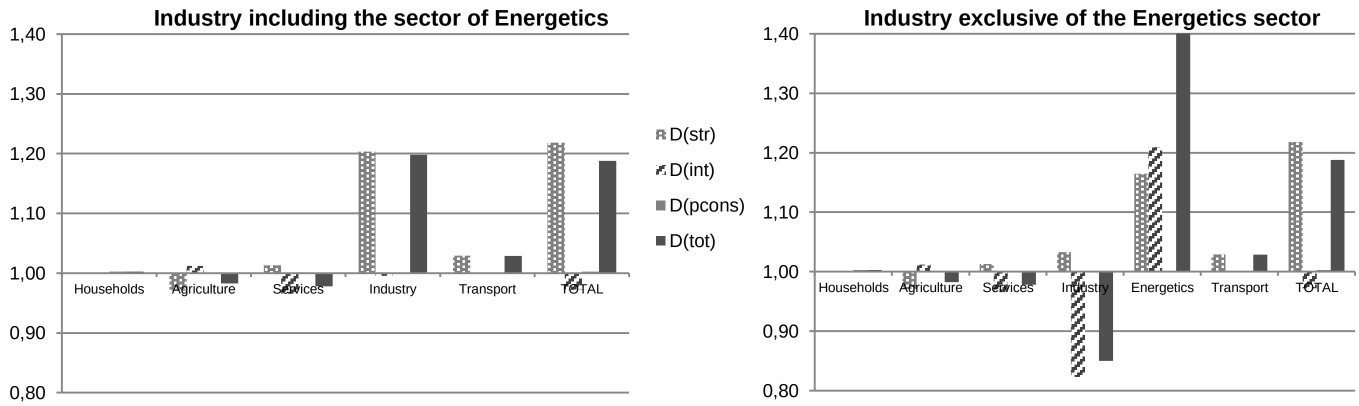
Ang & Zhang 2000; Henriques & Kander 2010). This method allows the calculation of the role of structural changes (increasing shares of certain sectors) and intensity changes (sometimes referred to as technical changes and implying changes in the sectoral energy intensities). The major hypothesis here is that the shift to heavy industries in Czechoslovakia was the major driver of increased energy intensity as well as overall energy consumption in the early stages of the central planning system. At the same time, and as discussed in section 2, the system of central-planning has often been described as inefficient and wasteful. Employing the LMDI method enables us to distinguish between structural and intensity changes at the level of individual productive sectors.

Three various decomposition calculations have been employed First, decomposition of the energy intensity of the whole economy by taking into account the total productive sectors as well as households (Figure 17). Following the results of the first decomposition, the remaining focus will be targeted on the individual industrial sectors and the energy intensity of primary energy (Figure 19) plus their respective electricity intensities (Figure 20-21).

4.1. The book-keeping effects of electricity generation

The first results for Czechoslovakia show, that in the early period of central planning it was in fact structural change towards industry which had the largest effect on the overall energy intensity of the Czechoslovak economy (the left-hand graph in Figure 17). Within the first two decades of central planning, the energy intensity increased by almost 19 percent, an increase which was mainly driven by the industrial sector. The role of the other productive sectors (agriculture, services and transport) was, indeed, marginal. Also energy intensity of the household sector did not change significantly, on par with England. In fact, these results for the period of 1950-1973 seemingly support the initial hypothesis of heavy industrialization of Czechoslovakia, move away from consumer goods to industrial production and generally wasteful and polluting energy policy in the absence of market prices for fuels and energy services.

Figure 17: Differences in the level of aggregation: Decomposition of energy intensity by sector (1950-1973), energy sector extracted from the industrial sector (right-hand graph)



Source: Own calculations
Note: Decomposition of changes in energy intensity into structural drivers and technological drivers. Values about the threshold 1 indicate increasing effect of change. So for example in the left-hand graph structural changes (here increased move towards industry in the overall Czechoslovak economy) raised the energy intensity by almost 20%.

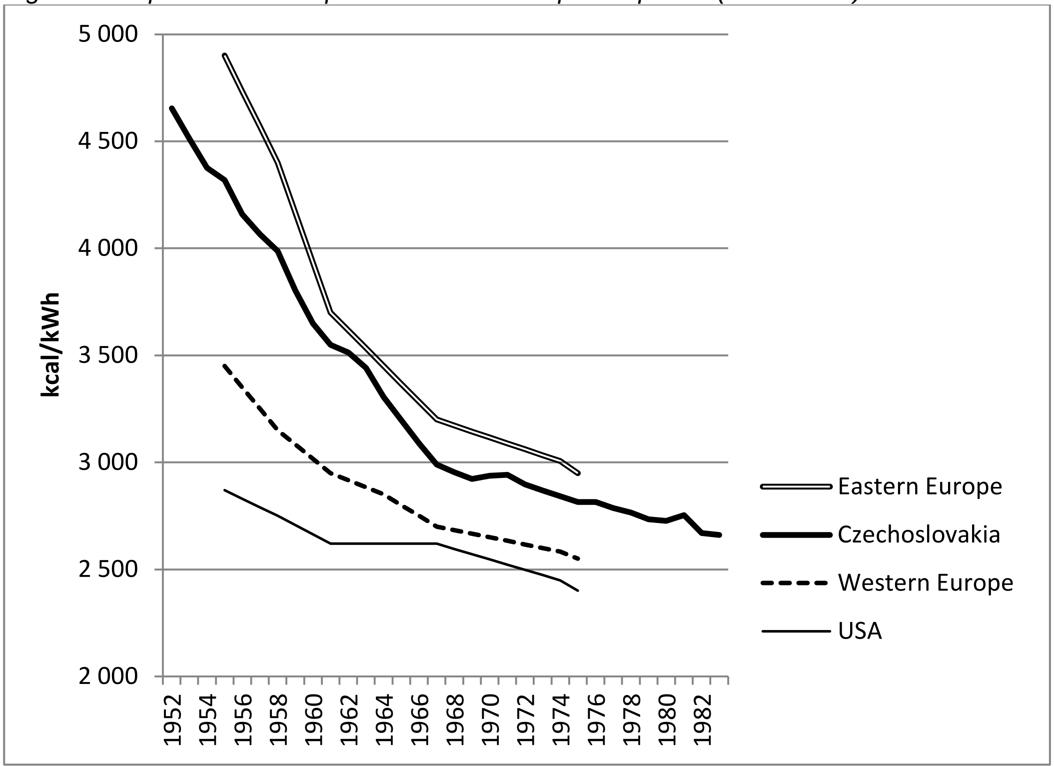
However, a more careful investigation of the individual industrial sectors reveals a rather different story. In fact, as Figure 17 (right-hand graph) shows it was the energy sector, and the production of electricity in particular, which was the sole driver of growing energy intensity, increasing its share of domestic energy consumption from just 7 percent in early 1950s to some 45 per cent by 1973. Figure 17 is an example of how different levels of aggregation can give different levels of interpretation. In traditional energy accounting, the energy sector (mainly electricity production) is included as one productive sector. The energy consumed within the electricity sector, even though the end-use occurs outside of this sector, is only accounted for by the electricity sector. This in turn results in somehow blurred picture of industrial energy intensity. In Czechoslovakia. Although the electricity sector grew rapidly to account for the largest share of primary energy consumption (from 7 to 45% between 1950 and 1973), it barely doubled its share in value added to just over 2 per cent of GDP. This may not come as such a surprise. In a centrally-planned economy, the absence of the market price of energy has often been seen as a barrier to efficient energy policy. In Czechoslovakia, a country with an energy system largely dominated by the domestic coal supplies, wholesale prices of coal did not even cover the costs associated with the actual coal mining which in turn has further driven the demand for coal as well as electricity production (Vyzkumny Ustav Palivoenergetickeho Komplexu 1988). The suppression of the actual value added in the denominator of the energy intensity formula, is likely to have resulted in high sectoral energy intensity. On the other hand, although this may have an impact on the energy intensity of the electricity sector in particular, the opposite effect may have been seen in all industrial branches which benefited from the low electricity prices and it is possible that the effect could have been redistributed across those sectors.

4.2. The electricity production and distribution systems in Eastern Europe

Moreover, the electricity production system in Czechoslovakia, which expanded so extensively after the WWII, differed from the West in various aspects. First, the actual efficiency of the fuel conversion to electricity was far lower compared to Western Europe and the USA. On average, the coal consumption (per kWh produced) in Czechoslovakia was 16 percent higher than the West European average between 1950 and 1973, with up to 30 percent lower efficiency in the early 1950s (Europe 1976; Federalni Statisticky Urad 1984). Second, the Czechoslovak electricity network also suffered from higher transmission and distribution losses. In Western Europe, those losses amounted to some 7 percent of the electricity produced, while the losses in Czechoslovakia peaked around 12-13 percent in the early 1950, roughly on par with transmission losses in West Europe before WWII (Europe 1976)[4]. This has in turn resulted in comparatively higher consumption of primary energy in the electricity generation sector.

[4] Though, a steady slow trend of transmission efficiency improvement was recorded throughout the whole period of study.

Figure 18: Specific consumption of coal-based power plants (1955-1973)



Note: Annual time-series for Czechoslovakia, 3-year benchmarks for Eastern Europe, Western Europe and the USA
Source: (Federalni Statisticky Urad 1984; Europe 1976)

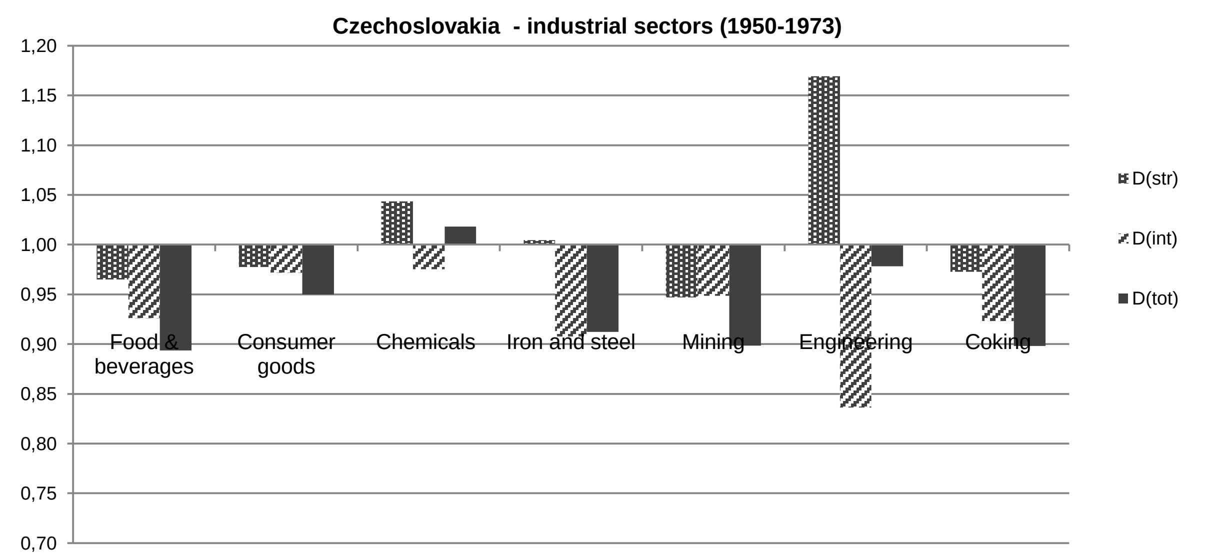
Lastly, the pattern of final electricity consumption in Czechoslovakia, and generally in Eastern Europe, differed from the West. While the share of households in the final consumption of electricity fluctuated between 15 and 35 percent in West Germany and the UK in the early 1960s, the share of households in final consumption of electricity in Czechoslovakia was only about 7 percent (Federalni Statisticky Urad 1979). In fact, it was the industrial sector which was by far the largest consumer of final electricity maintaining high levels until mid-1970. Consequently, in order to address this issue decomposition of industrial energy intensity (section 4.3.) and electricity intensity (section 4.4.) was analyzed below.

4.3. Decomposition of industrial energy intensity – primary energy

In order to fully understand the drivers of industrial energy intensity, it is necessary not only to decompose the consumption of primary energy but also the redistribution of secondary energy, in this case electricity. For the first task, a multiplicative decomposition of primary energy intensity was conducted for seven major industrial sectors (Figure 19). Consumer goods, within this study, refer to textiles, glass, porcelain and other industry, an aggregation due the limited data availability on sectoral energy consumption. In the next step, electricity was redistributed between individual sectors in order to observe changing intensity of electricity consumption and again a multiplicative decomposition was conducted, this time using annual data to observe also a change over time (Figure 20-21).

The decomposition of industrial primary energy intensity (Figure 20) shows an overall declining energy intensity of all industrial sectors, though partly offset by the structural shifts, mainly towards engineering, chemicals, and iron and steel. Those were the only three productive sectors in Czechoslovakia which drove the industrial energy intensity up in the first years of central-planning due to their greater weight in the overall structure of production. This largely relates to the focus of the 5-year plans implemented in Czechoslovakia, with an increased focus on the production of heavy industrial goods. In absolute terms, industrial energy intensity declined, largely driven by intensity falls within all industrial sectors. In fact, all industrial sectors managed to lower their relative energy intensity, though it is likely that this was to some extent offset by increased electricity consumption.

Figure 19: Decomposition of industrial energy intensity by sector (1950-1973), energy sector excluded

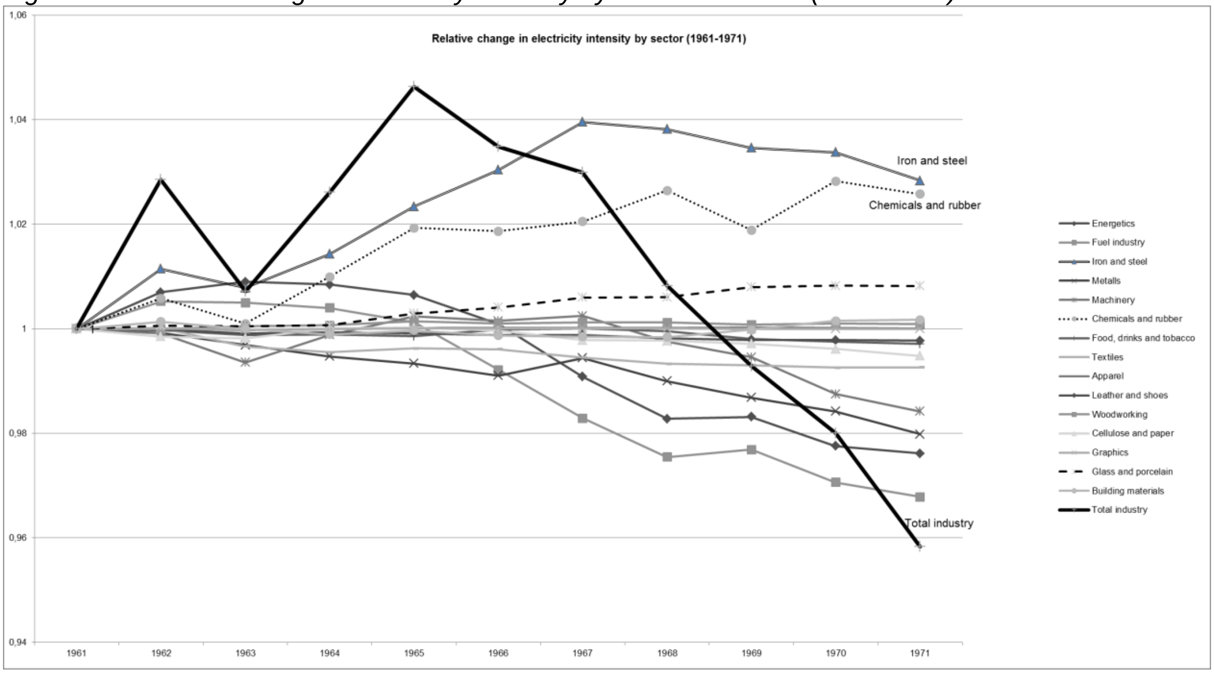


Note: Includes only consumption of primary energy, as is common in other decomposition studies.

4.4. Decomposition of industrial energy intensity – electricity consumption

To further assess the potential inefficiencies associated with the expanding electrification, it is necessary to look at the final consumers of the electricity produced. Indeed, the electricity network expanded dramatically in the early stages of central planning, reaching per capita consumption levels above those observed in many Western European countries such Belgium and France. As discussed above, Czechoslovak industries were the major consumer of final electricity (77 percent). Thus while as we have seen from the perspective of primary energy, Czechoslovak industries managed to lower their energy intensity, Figure 19, illustrates how this decline was to some extent related to the increased utilization of electricity in material processing. Historically, the introduction of electrical processes 'provided the fundamental technological basis for producing particular metals and chemicals' or even fully took over in the production of already-established processes such as steel and glassmaking (Schurr 1990). In fact, these were industries that had already been a trademark of Czechoslovak production and exports before WWII. The growing intensity of electricity utilization is highlighted in Figure 20. while the actual drivers (structural or technological) are analysed in Figure 21. It must be noted, though, that the earliest available electricity consumption data reach back to 1961, 10 years after the other decomposition calculations begin. It can be seen that the electricity intensity of iron and steel sector increased significantly between 1961 and 1971, while for the chemical industry it was mainly structural change that had effects, that is, the overall expansion of the sector. Although there is no detailed data on final electricity consumption by individual sectors for the period 1950-1961, it is believed that the utilization of centralized electricity in the manufacturing processes took off first after WWII, somewhat later than in the USA and Western Europe. Preliminary data from the 1935 industrial census show that electricity was mainly used in coal mining (50 percent share), textiles (19 percent), paper and pulp production (7 percent) and glassmaking (4 percent) and the overall levels were relatively low.

Figure 20: Relative change in electricity intensity by industrial sector (1961-1971)



What overall can thus be concluded from the decomposition of industrial energy intensity? The results shown in this paper identify the industrial sector to be the prime, and sole, driver of growing energy intensity during the period 1950-1973. Inefficiency in this sense was not, thus, a property of the Czechoslovak economy as a whole, and indeed neither was this the case in East Germany. Structural change in the Czechoslovak economy towards a larger shares of heavy industries, as well as the export orientation in industrial goods, drove the overall trend upwards. At the same, and also in combination with the decomposition of electricity intensity, we can clearly see that some of the efficiency improvements in the primary energy intensity were consumed by the increasing utilization of electricity. In particular two sectors were identified to have a significant effect, those that also increased their structural shares: iron and steel and chemicals, driving the absolute electricity intensity up by 3,1% and 2,7% just within one decade (1961-1971) – iron and steel through upward changes in sectoral intensity, while chemicals driven by the growing shares of the sector. It is not so surprising to have identified exactly those two sectors as having some increasing effect in both decomposition of primary energy as well as electricity. In combination with the inefficient and energy intensive production of electricity, this had a large impact on the overall energy intensity of the Czechoslovak industrial sector.

Figure 21: Drivers of electricity intensity by industrial sector, 1961-1971, 1971-1980 and 1980-1987

	1961-1971			1971-1980			1980-1987		
SECTOR	D_{tot}	D_{str}	D_{int}	D_{tot}	D_{str}	D_{int}	D_{tot}	D_{str}	D_{int}
Energetics	0,975	1,014	0,962	0,999	1,000	0,999	1,005	1,001	1,005
Fuel industry	0,967	0,987	0,980	1,007	0,968	1,040	0,997	0,977	1,020
Iron and steel	1,031	0,985	1,047	0,968	0,979	0,989	0,985	0,984	1,001
Metalls	0,980	0,994	0,986	0,985	0,994	0,991	0,993	0,996	0,998
Machinery	0,984	1,028	0,958	0,988	1,022	0,966	0,997	1,019	0,978
Chemicals and rubber	1,027	1,072	0,958	0,961	1,031	0,933	0,981	1,002	0,979
Food, drinks and tobacco	0,997	0,992	1,005	0,996	0,995	1,001	1,000	0,997	1,003
Textiles	0,992	0,994	0,999	0,994	0,998	0,997	0,998	0,998	1,000
Apparel	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Leather and shoes	0,998	0,999	0,998	0,998	0,999	0,999	0,999	0,999	1,000
Woodworking	1,001	0,999	1,002	1,001	1,001	0,999	1,000	1,000	1,000
Cellulose and paper	0,995	0,997	0,997	0,997	1,004	0,993	1,003	1,000	1,003
Graphics	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Glass and porcelain	1,009	1,001	1,007	1,000	1,001	1,000	0,998	0,999	0,998
Building materials	1,002	0,998	1,004	0,998	1,000	0,998	0,992	0,995	0,997
Total industry	**0,96**	**1,06**	**0,90**	**0,90**	**0,99**	**0,91**	**0,95**	**0,97**	**0,98**

Note: D_{tot} denotes the change in total electricity intensity, with D_{str} ascribes the impact from the structural change and D_{int} the impact from the technology/intensity change. In the decade 1961-1971, for example, impact from technology change in sectors of glass, building materials and iron increased the sectoral electricity intensity. Analogically, the impact from structural change (growing shares of the sector in the economy) in the sectors of energetics or chemicals drove up the sectoral energy intensity.

5. Conclusions

The aim of this paper was to analyse energy transition of Czechoslovakia and compare its pattern of development with two other coal-rich countries – Germany and England, but also relate our results to existing research on coal-poor countries. Although each country was characterized by different timing of industrialization, this paper has identified some similiarities among all three coal-rich countries. First, the existence of domestic coal reserves had an impact on the formation of energy-intensive economic structures, which in turn destined the countries for a rather energy-intensive path of industrialization. In both Germany and Czechoslovakia, the transition in terms of energy mix – towards coal – was relatively fast and reached high levels. England, the frontrunner of coal transition, was at the core of technological development with prolonged initial stages of experiments and testing. The coal transition has thus been far slower in England than in any other parts of the world, which could benefit from England's technological advances. Moreover, by the beginning of WWII all three countries did not only reach similar energy mix dominated by coal, but also convergent energy intensities levels. Comparing the energy intensity levels of our three countries – England, Germany and Czechoslovakia, the paper has found a very clear trend of inverted U-curve. This is interesting development which shows that for this period of study, coal, energy intensity and economic structures were closely interrelated.

Even though the paper identified certain similarities among England, Germany and Czechoslovakia, divergences appeared after the WII, specifically in the trend in energy intensity in Czechoslovakia compared to the other two countries (even when Germany was split between East and West). In the first two decades of central planning in Czechoslovakia (1950-1973), the energy intensity of the whole economy increased by 19% compared to the constantly declining trend in England and both Germanies. This increase was caused by a combination of three specific factors, all of which drove the overall energy intensity of the Czechoslovak industries: structural change towards heavy industry (pig iron, steel and chemicals), growing electricity intensity of those expanding heavy industries and an inefficient and energy-intensive electricity production sector. This finding correlates with the efficiency study of Czechoslovak iron and steel sector which found low efficiency levels compared to the rest of the world before 1973 (Nielsen 2016) even when measured in physical output rather than prices. It has not been able, though, within the scope of this study to distinguish the actual drivers on inefficiencies within the industrial sectors but problems with the material planning and general neglect are likely to have been responsible. Yet this trends towards the inefficient use of energy were not found across the whole economy but in specific sectors, and do not seem to have characterized East German development, possibly because of the specific role assigned to Czechoslovakia in developing heavy industry within the COMECON system. Equally, the Czech experience differs from the Western European countries analyzed although the British system of electricity supply, nationalized after 1948, was also subject to strongly co-ordinated planning and political influence. It can be concluded, that there was some negative impact of the central-planning system on the Czechoslovak energy system and its efficiency, but the precise reasons for international differences in particular sectors requires further research. Certainly, however, the consequences of developments in Czechoslovakia became apparent during 1970s and 1980s as it became near the top of the list of the world's most environmentally damaged regions (Turnock 2001).

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