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Long-term changes in CO₂ emissions in Austria and Czechoslovakia—Identifying the drivers of environmental pressures

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ABSTRACT

This study presents fossil-fuel related CO₂ emissions in Austria and Czechoslovakia (current Czech Republic and Slovakia) for 1830–2000. The drivers of CO₂ emissions are discussed by investigating the variables of the standard Kaya identity for 1920–2000 and conducting a comparative Index Decomposition Analysis. Proxy data on industrial production and household consumption are analysed to understand the role of the economic structure. CO₂ emissions increased in both countries in the long run. Czechoslovakia was a stronger emitter of CO₂ throughout the time period, but per-capita emissions significantly differed only after World War I, when Czechoslovakia and Austria became independent. The difference in CO₂ emissions increased until the mid-1980s (the period of communism in Czechoslovakia), explained by the energy intensity and the composition effects, and higher industrial production in Czechoslovakia. Counterbalancing factors were the income effect and household consumption. After the Velvet revolution in 1990, Czechoslovak CO₂ emissions decreased, and the energy composition effect (and industrial production) lost importance. Despite their different political and economic development, Austria and Czechoslovakia reached similar levels of per-capita CO₂ emissions in the late 20th century. Neither Austrian “eco-efficiency” nor Czechoslovak restructuring have been effective in reducing CO₂ emissions to a sustainable level.

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1. Introduction

Global climate change is one of the most severe global environmental consequences of industrialization. Since about 1750, when the use of fossil fuels took off with the onset of industrialisation in the United Kingdom, the atmospheric CO₂ concentration has risen from its long-term average of around 280 ppm to 379 ppm in the year 2005 (IPCC, 2007). This increase is the largest contributor to global climate change. Most of the atmospheric CO₂ increase (75%) can be attributed to the burning of fossil fuels and cement production, while the remainder is caused by land use change (IPCC, 2007).

In recent years, CO₂ emissions have increased at an even faster pace than expected in scenarios of the intergovernmental panel on climate change (IPCC) due to strong economic growth, an increase of carbon intensity (i.e. the amount of carbon emitted per unit of economic output) and increased population growth (Canadell et al., 2007; Raupach et al., 2007). Different nations and regions have contributed to global CO₂ emissions in very different ways. Raupach et al. (2007) assessed that the US, Europe and Japan

account for more than 60% of all CO₂ emissions that have accumulated in the atmosphere between 1751 and 2004.

In order to develop effective policy measures to combat climate change, an understanding of the underlying causes of CO₂ emissions is indispensable. Previous comparative studies have shown that the drivers for CO₂ emissions in the late 20th century differ substantially in different countries (Ang and Zhang, 1999; Sun and Malaska, 1998; Luukkanen and Kaivo-oja, 2002; Ebohon and Ikeme, 2006; Ang and Liu, 2006). One conclusion of these studies is that the level of economic development has a great impact not only on the amount of CO₂ emissions, but also on the drivers behind them (see Fan et al., 2006).

While a number of studies investigates the drivers for CO₂ emissions for specific countries (Diakoulaki et al., 2006; Friedl and Getzner, 2003; Zhang et al., 2009; Kojima and Bacon, 2009) or sectors in specific countries (Diakoulaki and Mandaraka, 2007; Liaskas et al., 2000) in recent decades, usually starting from around 1970, comparatively little work has been undertaken to understand the long-term changes of CO₂ emissions since the beginnings of industrialisation (Bartoletto and Rubio, 2008; Tol et al., 2009; Lindmark, 2002; Lindmark, 2004). Long-term analyses of CO₂ emissions shed light not only on specific industrialisation patterns of particular countries, but also generate insights regarding the industrialisation process itself, that today's industrialised countries have pursued and that developing countries

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are, to a large extent, following (Unruh and Carrillo-Hermosilla, 2006). An understanding of long-term changes in the interrelations between societies and their environment is important if we aim to find different, more sustainable pathways, not only for today's developing countries, but also – and in particular – for the industrialised world (Costanza et al., 2007).

In this study, we contribute to this understanding by providing a long-term analysis of fossil-fuel-related CO₂ emissions in two industrialised Central European regions, Austria and Czechoslovakia (current Czech Republic plus Slovakia, will be termed “Czechoslovakia” throughout the text) for the time period from 1830 to 2000, based on country-specific calculations. These two regions appear as promising case studies for comparison because of their political and economic history: Austria and Czechoslovakia belonged to the same economic entity – the Habsburg Empire – until the early 20th century. In the 20th century, their economic development followed entirely distinct trajectories. After the collapse of the Austro-Hungarian Monarchy, the interwar-period and Austria's *Anschluss* to Germany during World War II, Austria became a social market economy with an increasing degree of European integration, and joined the European Union in 1995. Czechoslovakia on the other hand, an independent state after the collapse of the Monarchy, joined the Eastern Block as a planned economy after World War II and became an important supplier of the Eastern Block's COMECON market. In 1989, with the Velvet Revolution, Czechoslovakia turned away from communism, in 1993, it separated into Czech Republic and Slovakia, and in 2004 the two countries joined the European Union. While the political and economic history of 20th century Czechoslovakia and Austria differs strongly, the two regions are similar in many other respects, such as geographic position or population density. A comparison of these two countries – while focusing on Central Europe – sheds light on the differences in the interrelation between societies and their environment which are related to political and economic disparities.

We discuss CO₂ emissions in Czechoslovakia and Austria for the time period 1830–2000. The “Kaya identity” (Kaya, 1989; Waggoner and Ausubel, 2002; Canadell et al., 2007) decomposes the drivers for a country's CO₂ emissions into contributions from population, income, energy intensity of the economy and energy composition. In this article, we analyse these variables and then perform a comparative Index Decomposition Analysis for the period from 1920 to 2000 to understand the relative contribution of the different variables to the difference in CO₂ emissions between the two countries. In order to discuss the role of economic structure (for which no comprehensive data are available for the entire period), we analyse proxy data for industrial and private energy consumption.

2. Materials and methods

2.1. Energy and CO₂ emissions datasets

The analysis is based on time series data on fossil-fuel-related CO₂ emissions for the two regions Austria and Czechoslovakia with yearly data from 1830 to 2000. These datasets were established based on previously published data on the energetic metabolism of the two regions (Krausmann and Haberl, 2007; Kuskova et al., 2008). The methodology to assess fossil-fuel-related CO₂ emissions was largely adopted from a previous study on Austria's carbon metabolism (Erb et al., 2008).

The datasets on socio-economic energy metabolism are based on yearly national (or regional) statistical publications, as well as some modelling assumptions (for detailed descriptions of sources and methods, see Krausmann and Haberl, 2007; Kuskova et al., 2008). Both of these studies face the problem of changing political boundaries and rely on national and regional data for different time periods. This has particular impact on the quality of data on foreign trade (which was not considered “foreign” trade in the 19th and early 20th centuries when the regions both were part of the Habsburg Empire). For the case of Austria, it is however possible to keep the same (or a quite similar) area of reference throughout the entire time period. For the case of Czechoslovakia, this is not the case: from 1830 to 1915, all data refer to Bohemia plus Moravia (similar to today's Czech Republic), while all later data refer to Czechoslovakia, i.e. today's Czech Republic plus Slovakia. Distortions due to this shift in the area of reference will be discussed with the results. We consider the same area of reference (Czech Republic plus Slovakia) after the separation of the two countries in 1993 in order to be consistent with the earlier data. This enables us to depict the medium-term effects of the end of communism. However, with the different economic developments in the Czech Republic and Slovakia, we end our analysis in the year 2000. The further addition of data of two increasingly different countries would have yielded results which are very difficult to interpret.

The datasets on the energetic metabolism (Krausmann and Haberl, 2007; Kuskova et al., 2008) include data on primary energy consumption of all socio-economically processed energy carriers (including biomass used as technical energy, but also as food and feed). This study is confined to CO₂ emissions from fossil fuels and cement production. We use the data on primary energy consumption of fossil fuels (i.e. hard coal, brown coal, crude oil and natural gas) to calculate the amount of net-CO₂ emitted to the atmosphere every year: we convert the primary energy from gross to net calorific values and apply CO₂ contents for all fossil energy carriers to obtain the amount of CO₂ (see Table 1). Since the quality

Table 1

Factors used to convert units of energy (TJ, Terajoule) to units of CO₂ (metric tons). Sources: Haberl (1995); CHMI (2009); BMWA (1990).

	Unit	Both countries	Austria	Czechoslovakia
Brown coal				
Gross calorific value/heating value	J/J	1.19		
t CO ₂ per TJ heating value	t/TJ		97	100
Hard coal				
Gross calorific value/heating value	J/J	1.04		
t CO ₂ per TJ heating value	t/TJ		97	93
Crude oil				
Gross calorific value/heating value	J/J	1.06		
t CO ₂ per TJ heating value	t/TJ		70	73
Natural gas				
Gross calorific value/heating value	J/J	1.1		
t CO ₂ per TJ heating value	t/TJ		52	56

of the energy carriers and the type of use differs in the two countries, country-specific values of CO₂ emissions per unit of energy are applied (BMWA, 1990; CHMI, 2009). CO₂ emissions from cement production, which are not included in the datasets on the energetic metabolism of the two countries, are obtained from the CDIAC database (Marland et al., 2000). The totals of CO₂ emissions are consistent with the time series of Marland et al. (2000), though they differ slightly in the period before World War I (when Marland et al. have higher estimates of CO₂ emissions) and in the mid-1980s, when our estimate is 10–20% higher.

CO₂ emissions or uptake of carbon related to land use change or the combustion of biomass were not included in this analysis. Studies for Austria have shown that carbon stocks in vegetation did increase in the period under investigation (Gingrich et al., 2007), but these were overwhelmed by the total CO₂ emissions, dominated by emissions from fossil fuels (Erb et al., 2008).

The CO₂ datasets are complemented by data on population available in Krausmann and Haberl (2007) and Kuskova et al. (2008), as well as data on GDP (Maddison, 2003, GDP in 1990 Geary-Khamis-US-Dollars). Unfortunately, the area of reference for Czechoslovak GDP differs from all the other indicators in the period 1830–1920. Therefore we can only investigate the explanatory variables in detail for the time period 1920–2000.

Identifying and quantifying the drivers of emissions trends is the goal of a great variety of methods. We employ two formal methods in this study: simple factorization and Index Decomposition Analysis. The former method generates an understanding for trends in the explanatory variables, while the latter formally assesses the absolute and relative importance of the different variables in explaining the differences in CO₂ emissions between the two countries. In addition to this, selective proxy data on the economic structure of the two countries are presented to discuss the role of the industrial sector and private consumption for explaining the different CO₂-emission pathways in Austria and Czechoslovakia.

2.2. Factorization through the Kaya identity

In order to compare the differences in drivers of CO₂ emissions between Austria and Czechoslovakia, we use the standard Kaya identity (Kaya, 1989; Waggoner and Ausubel, 2002; Canadell et al., 2007). It factorizes total fossil-fuel related CO₂ emissions (C) as a product of the driving forces population (P), per-capita Gross Domestic Product ($G = \text{GDP}/P$), energy intensity of the economy (in our case: Domestic Energy Consumption per GDP, $I = \text{DEC}/\text{GDP}$), and carbon intensity of energy consumption ($F = \text{CO}_2/\text{DEC}$), as follows:

$$C_k = P_k G_k I_k F_k \quad (1)$$

The subscript k denotes the country. This simple factorization can be done for both countries in parallel, thereby allowing a comparison of the evolution of the different factors over time.

2.3. Index Decomposition Analysis

In order to take full advantage of the data relating not only to the aggregate factors used in the Kaya factorization, but their composition, we then conduct a cross-country Index Decomposition Analysis on the difference in CO₂ emissions between Austria and Czechoslovakia.

We use the Log Mean Divisia Index (LMDI) method. This method is preferred because it is symmetrical and provides perfect decomposition (does not leave a residual term). The LMDI method is often applied to quantify change over time within a single country (Ang et al., 1998; Ang, 2004, 2005), but can also be applied

to cross-country studies (Zhang and Ang, 2001; Bartoletto and Rubio, 2008). In this way, we compare the contribution of the effects of population, income, energy intensity and energy composition to the differences in CO₂ emissions between the two countries every year, to identify similarities and differences between the two countries over time.

The emissions of each country can be written as

$$C_k = P_k G_k I_k \sum_i S_{k,i} F_{k,i} \quad (2)$$

where C_k , P_k , G_k and I_k are as in Eq. (1), and $S_{k,i}$ is the share of energy source i (E_i/E) and $F_{k,i}$ is the carbon content of energy source i (C_i/E_i). According to the LMDI, the difference between the emissions of both countries is thus

$$\begin{aligned} \Delta C &= C_c - C_a = P_c G_c I_c \sum_i S_{c,i} F_{c,i} - P_a G_a I_a \sum_i S_{a,i} F_{a,i} \\ &= \Delta C_P + \Delta C_G + \Delta C_I + \Delta C_F + \Delta C_S \end{aligned} \quad (3)$$

The subscripts c and a denote Czechoslovak and Austrian quantities, respectively. The factor ΔC_P quantifies the difference in emissions due to population, or population effect, ΔC_G is the income effect (due to G), ΔC_I is the energy intensity effect (due to I), ΔC_F is the emission coefficient effect (due to F) and ΔC_S is the fuel share effect (due to S). The reason to measure $C_c - C_a$ rather than $C_a - C_c$ is that the first is always positive.

The formulae for the cross-country decomposition factors are:

$$\begin{aligned} \Delta C_P &= \ln\left(\frac{P_c}{P_a}\right) \sum_i \frac{C_{c,i} - C_{a,i}}{\ln(C_{c,i}/C_{a,i})} \\ \Delta C_G &= \ln\left(\frac{G_c}{G_a}\right) \sum_i \frac{C_{c,i} - C_{a,i}}{\ln(C_{c,i}/C_{a,i})} \\ \Delta C_I &= \ln\left(\frac{I_c}{I_a}\right) \sum_i \frac{C_{c,i} - C_{a,i}}{\ln(C_{c,i}/C_{a,i})} \\ \Delta C_F &= \sum_i \ln\left(\frac{F_{c,i}}{F_{a,i}}\right) \frac{C_{c,i} - C_{a,i}}{\ln(C_{c,i}/C_{a,i})} \\ \Delta C_S &= \sum_i \ln\left(\frac{S_{c,i}}{S_{a,i}}\right) \frac{C_{c,i} - C_{a,i}}{\ln(C_{c,i}/C_{a,i})} \end{aligned} \quad (4)$$

The LMDI method thus provides five factors for each year of comparison, adding up exactly to the difference in Czechoslovak and Austrian CO₂ emissions.

2.4. The role of economic structure

Since no comprehensive data on the economic structure of the two countries is available for the entire time period, we use proxy data on the economic structure to complement the results from the index decomposition analysis and challenge the hypotheses derived from them. The output of iron (Mitchell, 2003; Hwaletz, 2001; the online-database of the United States Geological Survey at <http://minerals.usgs.gov/minerals/pubs>; the online-database of the World Steel Association at www.worldsteel.org; and data provided by the Czech Statistical Office) serves as proxy for the importance of the industrial sector, and car ownership (provided by Mitchell, 2003; Statistik Austria; the Ministry of Transport of the Czech Republic and the online-database of Eurostat at <http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes>) relates to private consumption. Data on final energy consumption for industry and transport was obtained from the International Energy Agency, from 1960 onwards for Austria, from 1971 onwards for Czechoslovakia (IEA, 2007). These data refer to final energy consumption, i.e. energy use after transformation losses, as

opposed to primary energy consumption which is used for all other analyses in this article. In contrast to the formal analysis performed to investigate the Kaya identity, the effect of economic structure on the differences in CO₂ emissions between Austria and Czechoslovakia will be more descriptive. Temporal trends in the differences of our economic structure data will be compared to those of CO₂ emissions.

3. Results and discussion

3.1. CO₂ emissions in Austria and Czechoslovakia 1830–2000: similarities and differences

As is the case for every industrialised country, in Austria and Czechoslovakia, CO₂ emissions have increased since 1830. However, this increase has taken extremely different forms. Fig. 1a and b present per-capita emissions of CO₂ in both economies for the different energy carriers. It may seem obvious to use population as a scaling factor for emissions, but it is theoretically conceivable for a country's emissions to be linked more closely to other factors. Multivariate cross-country STIRPAT analyses (Dietz and Rosa, 1997; York et al., 2003) have shown that population is usually found to be proportional to CO₂ emissions.

Until the early 20th century – i.e. in the period when Austria and Czechoslovakia belonged to the same political entity – per-capita CO₂ emissions in Czechoslovakia and Austria developed in quite a similar pattern. Though the use of coal took off earlier in

Czechoslovakia and caused higher CO₂ emissions in the mid-19th century, per-capita-values stabilised around a similar level as in Austria (3.5 t CO₂/cap/yr) before the beginning of World War I. The unity under the Habsburg Monarchy led to similar consumption patterns, but masked a fundamental difference in the situations of the two countries: Czechoslovakia is home to significant coal deposits, and was a major coal extractor since the 19th century, whereas Austria has but few fossil fuel deposits.

This inequality in resource endowment becomes visible in CO₂ emissions of the interwar-period, when the two regions split into separate countries. In coal-rich Czechoslovakia, CO₂ emissions grew continuously in the 1920s and decreased for a few years during the world economic crisis of the early 1930s. In coal-deprived Austria, on the other hand, fossil CO₂ emissions slumped directly after the collapse of the Habsburg Monarchy. Here too, the economic crisis had a severe effect on emissions. After World War II, CO₂ emissions grew extremely steeply in Czechoslovakia, reaching almost 18 t CO₂/cap/yr in the 1980s. With the collapse of the Eastern Block and the restructuring of the Czechoslovak economy, emissions dropped to about 12 t/cap/yr in 2000. While emissions also grew in Austria during this period, they never attained even half of the Czechoslovak peak value. Interestingly, CO₂ emissions in Austria reached their current level of around 8 t/cap/yr already in the late 1970s and stabilised from then on.

Coal was by far the most important energy carrier until the beginning of World War II, making up for more than 90% of all fossil-fuel-related CO₂ emissions. From the 1930s, there are increasing differences in the composition of CO₂ emissions: In Czechoslovakia, coal continued to be the most important source of CO₂ emissions throughout the 20th century. Even though its share in total CO₂ emissions declined steadily, coal still contributed more than 70% to all CO₂ emissions in 1990, with crude oil being the second most important CO₂ source, and to around 60% in 2000 when natural gas became roughly as important as crude oil. In Austria, coal lost importance much more quickly and was overtaken by crude oil as most important source of CO₂ emissions already in the mid-1960s. Crude oil kept its importance throughout the 20th century, while CO₂ emissions from coal reached similar levels as those from natural gas around 1980 and stayed at similar levels until the year 2000 (between 1 and 2 t CO₂/cap/yr).

The similarities in the two countries are, firstly, that CO₂ emissions increased during the process of industrialisation, and, secondly, that there is a certain sequence in the increasing importance of energy carriers in terms of CO₂ emissions, even though the point in time and the extent of their contribution varies: coal was the first important source, then crude oil gained importance, and later natural gas. These two observations are closely related to changes in the energetic metabolism during industrialisation, which have been described for Austria (Erb et al., 2008, Krausmann and Haberl, 2007), Czechoslovakia (Kuskova et al., 2008), and for a number of other European countries (Schandl and Schulz, 2002, Bartoletto and Rubio, 2008, Gales et al., 2007, Kunnas and Myllyntaus 2009) and compared with developing countries (Marcotullio and Schulz, 2007). These observations on the fuel shift or energy transition thus seem to hold true for industrialisation processes in general (Grübler, 2004)—however the extent and duration of the “coal stage” differ strongly among countries.

The differences in CO₂ emissions between Austria and Czechoslovakia became important only after World War I, when they became separate countries. Particularly in the period between 1945 and the mid-1980s, the two countries followed very different pathways in terms of extent and composition of their CO₂ emissions. These differences owed largely to the much higher emissions from coal in Czechoslovakia. From the late 1980s however, and in particular after the Velvet Revolution in 1989, CO₂ emissions declined in Czechoslovakia and somewhat converged with the

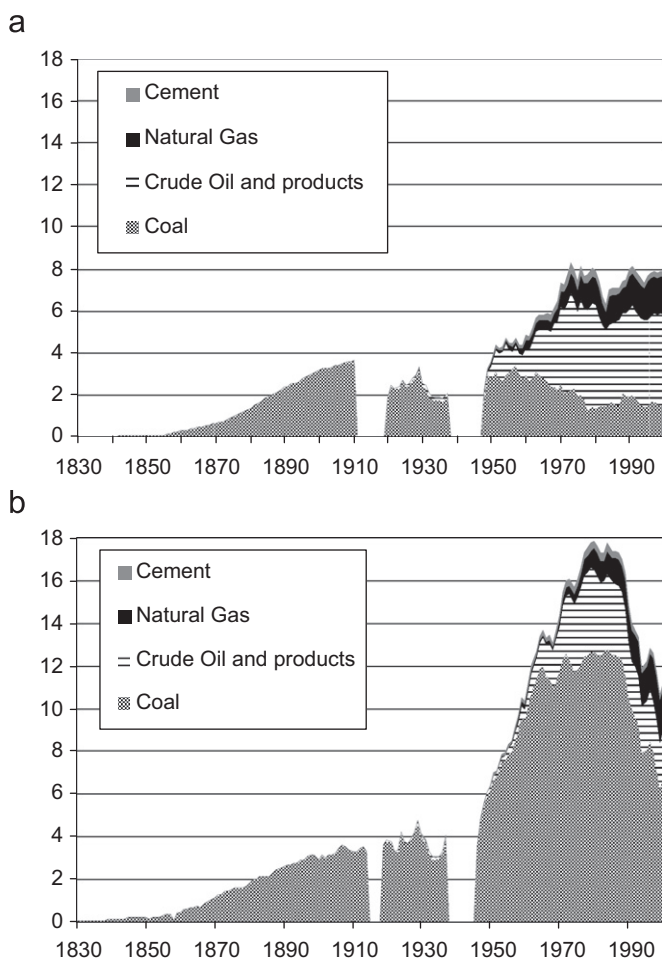


Fig. 1. Fossil CO₂ emissions in Austria (a) and Czechoslovakia (b) in metric tonnes CO₂ per capita and year, total and per energy carrier.

Austrian level. This insight encourages us to focus the analysis of the socio-economic drivers of CO₂ emissions on the period after World War I, as we will do in the next section.

3.2. Drivers of CO₂ emissions—the Kaya identity and its factors

The drivers of CO₂ emissions can be assessed using the factors expressed in the Kaya identity (Eq. (1)): population (P), income (G), energy intensity of the economy (I) and carbon intensity of energy consumption (F). Data availability permits this analysis only for the time period 1920–2000. The data are presented in Fig. 2.

CO₂ emissions in absolute terms were higher in Czechoslovakia than in Austria throughout the entire time period. The pattern of their development is similar to that of the per-capita values which have been described in the previous section. It is interesting to note that Austria's absolute CO₂ emissions increased continuously with one break in the 1930s and roughly stabilised since the early 1970s, while Czechoslovakia's growth of CO₂ emissions experienced two periods of distinct absolute decrease: one during the world economic crisis in the early 1930s, and a second, longer and stronger one in the late 1980s and 1990s.

Population in Czechoslovakia was almost twice that of Austria since the 1920s. While it grew fairly continuously during the time period in Austria, Czechoslovak population strongly decreased after World War II, related to the transfer of German-speaking minorities out of the country.

Income was similar in the two countries during the interwar-period at 2000–3000 \$/cap/yr, but increased much more steeply in Austria after World War II, reaching 20,000 \$/cap/yr in 2000. In Czechoslovakia, the breakdown of communism went along with a brief, but strong decline of GDP in the early 1990s, and the 1989 value of roughly 9000 \$/cap/yr was reached again only in 2000.

The energy intensity of the economy was consistently and significantly higher in Czechoslovakia than in Austria during the entire time period. In both countries it declined over time. The interwar-period was characterised by fairly high energy intensities in both countries (45 MJ/\$ in Czechoslovakia and 25 MJ/\$ in Austria). In Czechoslovakia, energy intensity decreased rapidly after the late 1920s. From after World War II to the late 1980s, energy intensity was relatively stable in Czechoslovakia around 35 MJ/\$, while it decreased steadily in Austria from the mid-1950s to only 10 MJ/\$ in 2000. From the early 1990s, Czechoslovak energy intensity sunk, and in 2000 the value was below 25 MJ/\$—in the pre-1950s Austrian range.

The composition of Domestic Energy Consumption (DEC) in the two countries differed remarkably, particularly after World War II. In the interwar-period, biomass dominated in both countries; however, the share of coal was higher in coal-producing Czechoslovakia than in coal-importing Austria. After World War II, both countries shifted to higher shares of fossil fuels, but in Czechoslovakia, coal was the most important fossil energy carrier (dominated by brown coal), while in Austria, coal was soon replaced by crude oil as the most important fossil fuel, and both hydropower electricity and natural gas gained importance. Since the 1980s, and particularly after 1990, also in Czechoslovakia the share of natural gas and primary electricity, mainly from nuclear power, went up, while coal lost importance.

The combination of these factors can be summarized as follows: population was larger in Czechoslovakia, whereas Austria's income was much greater in the second half of the 20th century. The larger energy intensity plus the more carbon intensive energy supply of Czechoslovakia, counterbalanced by the higher Austrian income, resulted in much larger carbon emissions in Czechoslovakia. The comparative Index Decomposition Analysis presented in the next section assesses the absolute and relative importance of the different variables over time.

3.3. Comparative Index Decomposition Analysis of CO₂ emissions

We use the variables discussed above (population, income, energy intensity and energy composition), along with the carbon contents of the energy carriers, to perform a comparative Index Decomposition Analysis, in order to quantify their importance in explaining the difference in CO₂ emissions between Czechoslovakia and Austria in the period from 1920 to 2000.

Fig. 3 depicts the results of the Index Decomposition Analysis, (a) as totals, and (b) as shares of the total. By adding the positive contributions (above the horizontal axis) and the negative (below), one obtains the total difference in CO₂ emissions (100% in Fig. 3b), indicated by the black line. Variables explaining the higher CO₂ emissions in Czechoslovakia throughout the entire time period are population, energy intensity, and energy composition. Except for a few years after World War II, income was a counterbalancing factor against these in the entire period. The difference in CO₂ emissions, as well as the importance of the different factors varied over time. The carbon contents of energy carriers accounted for no more than 3% of the difference between the two countries and will thus not be further discussed.

The difference in total CO₂ emissions was fairly small in absolute terms in the interwar-period (below 50 million tonnes CO₂/yr), and increased in the 1950s–1970s to over 200 million tonnes CO₂/yr in the 1980s. After 1990 the difference decreased quickly to just over 100 million tonnes CO₂/yr in 2000.

The population effect was a constant and important explanatory factor throughout the time period. Its relative importance was greatest in the interwar-period, but declined in the early afterwar period. From 1990 the relative importance of the population effect increased again slightly.

Energy intensity was the most dynamic of the positive explanatory variables. Its relative importance declined in the interwar-period. However, energy intensity became increasingly important quickly after World War II and, from the mid-1960s onwards, it was the strongest explanatory factor for the difference in CO₂ emissions between Austria and Czechoslovakia. This is consistent with the observation that energy intensity in Central and Eastern European countries in the 1980s was one of the highest in the world (Ürge-Vorsatz et al., 2006). Interestingly however, the energy intensity effect even gained relative importance after the collapse of the communist regime. This indicates that the Czechoslovak decline in income was stronger than the decline in energy consumption in the 1990s, as compared to the developments in Austria.

Another astonishing feature of the differences between Austrian and Czechoslovak CO₂ emissions is the development of the composition effect, which describes the effect of the composition of energy supply. Its absolute and relative importance grew from the mid-1920s. After World War II, the composition effect grew at the same pace as total differences in CO₂ emissions and remained a constant explanatory factor. Quite surprisingly, the relative importance of the composition effect remained constant after the Velvet Revolution.

Both the increasing relative importance of the intensity effect and the constant relevance of the composition effect can be understood only fully when we consider the counterbalancing effect of income (negative sign in Fig. 3a and b). Throughout the entire period (with only one exception in the early post-war years), the income effect alone would have made Austria a bigger emitter than Czechoslovakia. In absolute terms, the income effect increased after World War II and stabilised around 1990. However, the relative importance of the income effect became particularly important after 1990—all other explanatory variables lost importance in absolute terms, while the income effect stayed stable.

From this analysis we can distinguish three principal stages: (1) the interwar-period with little dynamics when the population effect was the strongest, with decreasing importance of energy

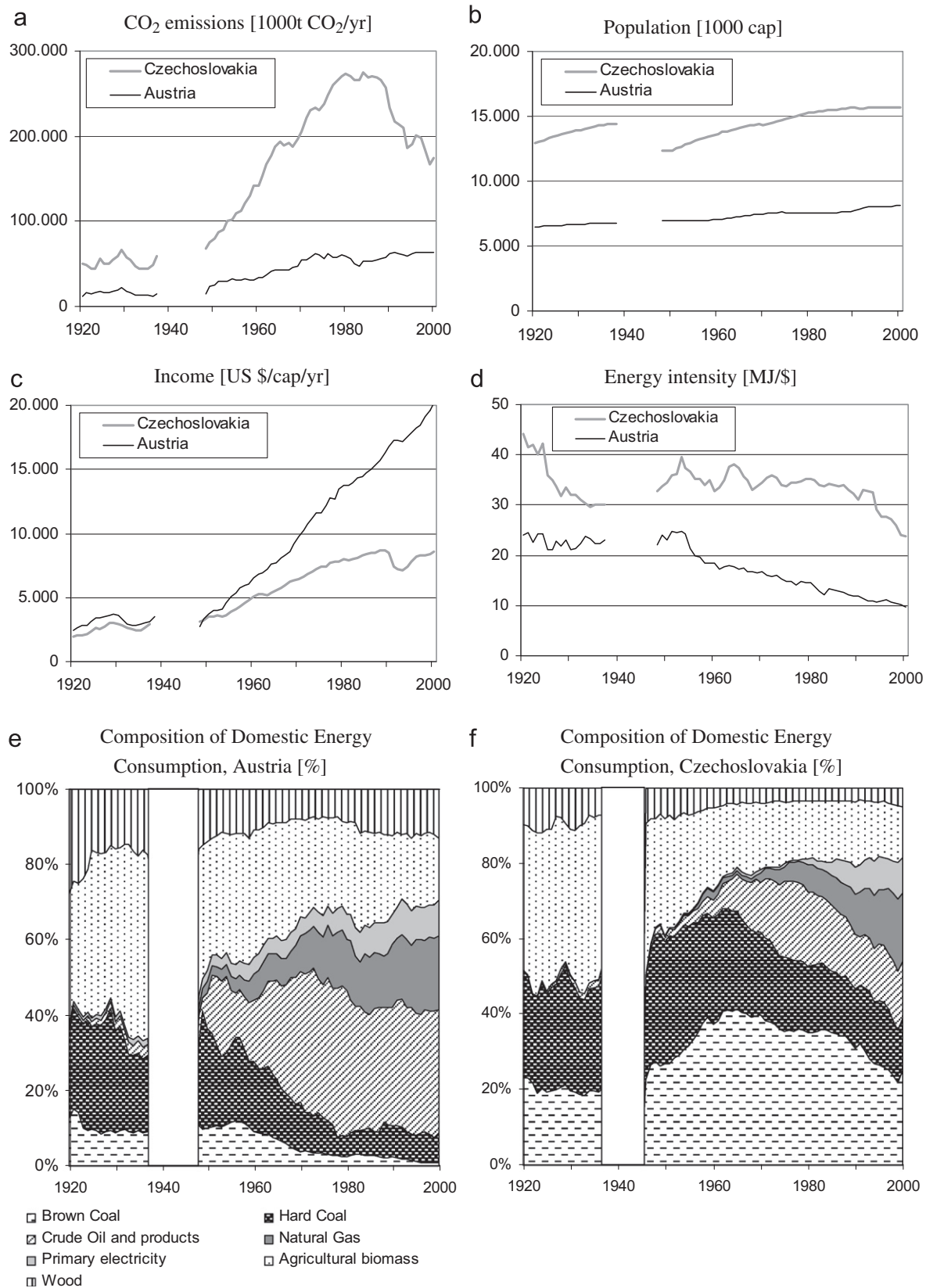


Fig. 2. Factors in the Kaya identity used in the Index Decomposition Analysis: CO₂ emissions (a), population (b), income (c), energy intensity (d), energy composition in Austria (e) and Czechoslovakia (f), 1920–2000.

intensity and increasing importance of energy composition; (2) the post-war period until the mid-1980s with increasing differences in CO₂ emissions between Czechoslovakia and Austria, explained by

astonishingly even increases in all effects analysed; and (3) the period from 1990 to 2000, when the difference in CO₂ emissions went down, and the role of income gained relative importance.

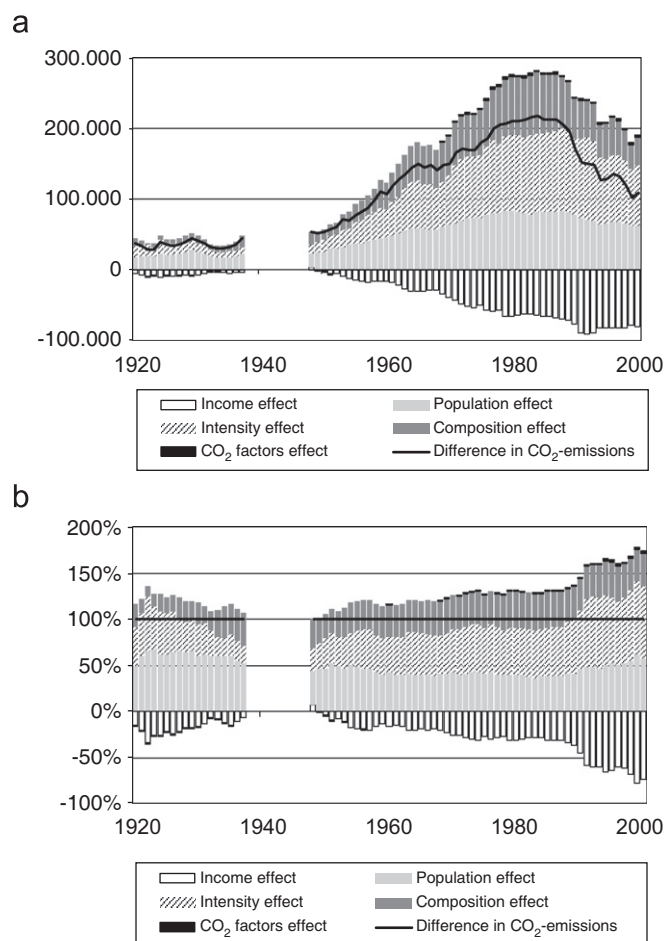


Fig. 3. Results from index decomposition analysis of the differences in CO₂ emissions between Czechoslovakia and Austria (a) in 1000 t CO₂/yr, (b) as shares of total

3.4. Economic structure in Austria and Czechoslovakia

Data on iron production in Austria and Czechoslovakia serve as proxy data for the industrial sector. Iron production is a particularly energy intensive industrial process, but the amount and type of energy used to produce a unit of output varies considerably between countries (Worrell et al., 1997). Iron and steel production were important parts of the industrial sector in both countries throughout the investigated time period, and subject to heavy political interventions. After World War II, the Austrian iron and steel industries (“VOEST”), which had been expanded during the War, were nationalised and formed an important part of the European Recovery Programme. Czechoslovakia on the other hand produced large amounts of iron and steel for the COMECON market.

Fig. 4 depicts iron¹ production per capita and year in Austria and Czechoslovakia for the period 1920–2000, as well as data on final energy consumption in the industrial sector and the share of coal in industrial final energy consumption. After World War II, the development of iron production in the two countries was somewhat similar to that of CO₂ emissions: the greatest differences occurred in the 1970s and 1980s, when Austria produced between

¹ The data we use here refer to iron production only and do not include steel, because consistent data were available for long time periods for iron only. Cross-checks with steel production show that steel production in both countries seems to follow similar trends as iron production, though in total the values for steel production are higher in both countries.

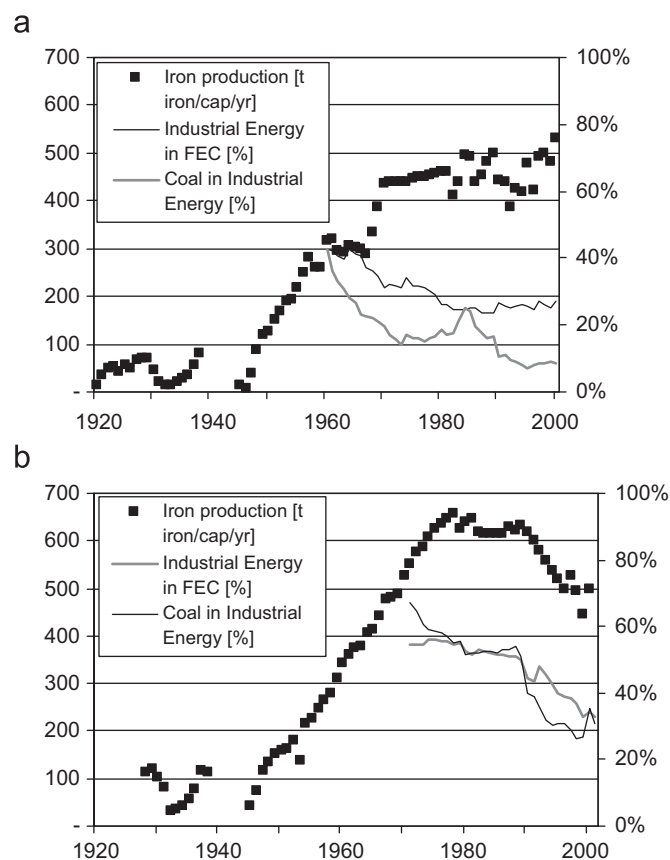


Fig. 4. Industrial proxy data: iron production in tons per capita and year (left y-axis), industrial final energy consumption as share of total final energy consumption (right y-axis), and share of coal in industrial final energy consumption (right y-axis). Note that industrial energy consumption refers to final energy consumption as opposed to primary energy consumption discussed earlier in the text.

450 and 500 tons per capita and year, and Czechoslovakia more than 600 t/cap/yr. It is thus plausible to assume a certain correlation between industrial production and the difference of CO₂ emissions between Czechoslovakia and Austria.

Other factors such as energy efficiency and CO₂ intensity in industrial production also seem to have played relevant roles, since in the 1950s and 1960, as well as in the 1990s, iron production levels were very similar in the two countries, while CO₂ emissions were higher in Czechoslovakia. This is supported by the fact that Czechoslovakia used more final energy (with a much higher share of coal) in industry than Austria.

The proxy data for the relevance of the industrial sector seem to follow similar trends as the differences in CO₂ emissions between Czechoslovakia and Austria—the development of the industrial sector thus seems to correlate with the differences in CO₂ emissions between the two countries in the observed time period.

In order to understand the role of private consumption in CO₂ emissions we analyse data on car ownership. Other activities than driving have high impacts on CO₂ emissions of households. One important factor which we cannot consider in this study due to a lack of data is residential energy use. However, the number of cars is a relevant figure because it stands for a new kind of consumer culture which developed after World War II in most of Europe (see e.g. Pfister, 1995).

Fig. 5 displays the number of cars per 1000 inhabitants, and compares it to values of domestic energy consumption of crude oil (which is not exclusive to transportation uses, since it is also used in

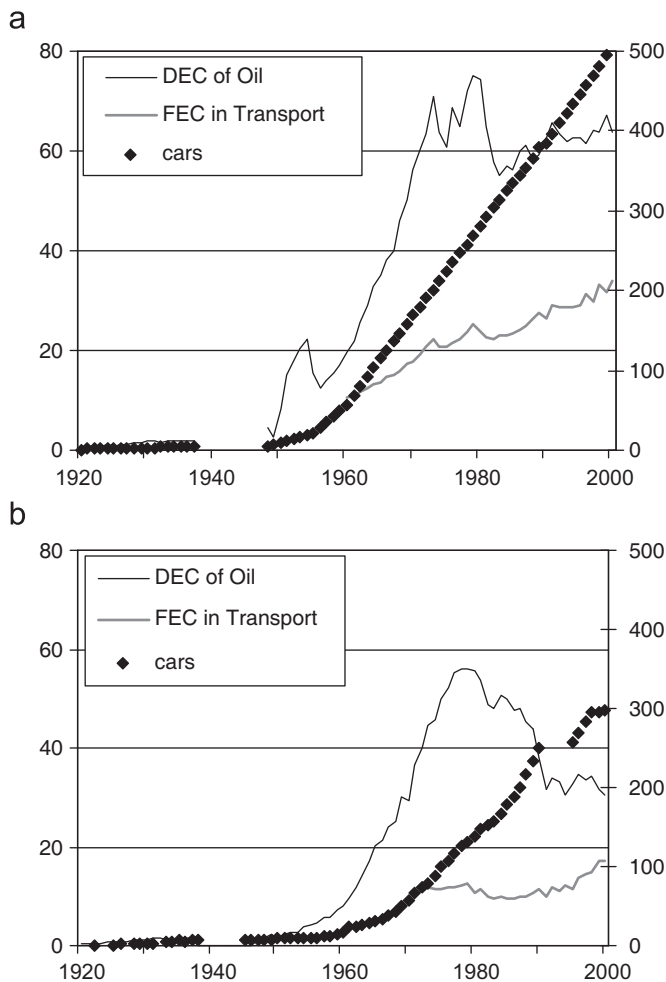


Fig. 5. Proxy data for private consumption: domestic energy consumption (DEC) of crude oil and products in GJ/cap/yr (left y-axis), final energy consumption (FEC) in transport in GJ/cap/yr (left y-axis) and cars in numbers per 1000 capita (right y-axis).

industry, heating and electricity production) as well as to final energy consumption in transport. Car ownership increased much sooner in Austria than in Czechoslovakia, and remained larger until 2000. In 2000, every other Austrian owned a car, while in Czechoslovakia, there was less than one car per three inhabitants.

In Austria, the higher car ownership went along with more final energy used for transport. In Czechoslovakia, transport energy per capita and year increased from the early 1980s onwards (and more strongly from the early 1990s) and reached half the Austrian value at around 100 GJ/cap/yr in 2000. The per-capita consumption of crude oil peaked in the mid-1970s in both countries, and then stabilized or decreased. Effectively, when oil became precious, it was substituted by other carriers for the other applications, but remained dominant in transportation.

The differences in private consumption thus did not follow similar trends to CO₂ emissions. Austria's CO₂ emissions were lower in the early afterwar-period, while car ownership was higher. However, between 1990 and 2000 with the stabilisation of oil consumption and the increase of transport energy in both countries, the difference between the two countries stabilised.

4. Conclusion

In this last section, we will briefly sum up the differences and similarities between Austria and Czechoslovakia in terms of their

long-term changes in CO₂ emissions, and draw some conclusions. We can distinguish four stages with respect to the extent of the differences in CO₂ emissions between Austria and Czechoslovakia and the socio-economic drivers behind them in the period from 1830 to 2000:

The first stage is the period when Czechoslovakia and Austria were part of the industrialising Habsburg Empire, i.e. from the beginning of our period until World War I. In this period, CO₂ emissions developed very similarly in the two countries, as coal slowly replaced wood as the most important technical energy carrier.

The second period is the interwar-period, i.e. around 1920–1938. During this period, the difference in CO₂ emissions was larger than before, because Austria – now no longer part of a large economic unit endowed with coal – used less coal than before World War I. In this period, the most important explanatory variable for the difference is population.

The third stage, from after World War II to the mid-1980s, is characterised by increasing differences in CO₂ emissions. These differences are explained by relatively evenly rising importance of all effects investigated: energy intensity, energy composition and population—counterbalanced by the income effect. Interestingly, energy intensity was not the single most important factor during this period, as has been previously suggested (Ürge-Vorsatz et al., 2006). In terms of economic structure, the importance of the industrial sector contributed to these differences, while private consumption acted as counterbalance.

The differences between the two countries in terms of CO₂ emissions ceased to increase already before the fall of the iron curtain. And from 1990 to 2000, we observe a convergence in CO₂ emissions. This was related to a strong decrease of coal consumption in Czechoslovakia associated with a restructuring of industry, which lowered the importance of the energy composition effect. Also, the effect of energy intensity declined, while the importance of income as counterbalance became relatively more important.

The differences in CO₂ emissions between Austria and Czechoslovakia are in our view overshadowed by some very general similarities. Firstly, CO₂ emissions from fossil fuel use increased during the industrialisation process. Secondly, a fuel shift from biomass to coal and later to crude oil, natural gas and electricity can be observed. Along with this shift went a stabilisation or even decline of CO₂ emissions in the late 20th century. These features have also been observed in other European countries (Kunnas and Myllyntaus, 2009; Bartoletto and Rubio, 2008; Krausmann et al., 2008; Tol et al., 2009) and seem inherent to industrialisation in general.

The examples studied here underline the fact that there does seem to be a common pattern of CO₂ emissions development during industrialisation. Despite the fact that the two economies followed very different economic and political paths for several decades in the 20th century (during which CO₂ emissions differed substantially), current CO₂ emissions are at a strikingly similar level. The comparison of the two countries shows that two extremes, an “eco-efficient” country, as Austria could be viewed, and previously communist, restructuring countries like the current Czech Republic and Slovakia end up with CO₂ emissions which are more than double the global average (which, as it is, is not sustainable). One could say that neither Austrian efforts towards eco-efficiency nor Czech and Slovak restructuring resulted in anything close to sustainability. Thus, a fundamentally new economic structure with different ways of production and consumption is needed for a future shift towards sustainability. This will also require radically new policy measures.

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