

Long term changes in social metabolism and land use in Czechoslovakia, 1830-2000: An energy transition under changing political regimes

Petra Kuskova¹, Simone Gingrich^{2*}, Fridolin Krausmann²

¹ Department of Social Geography and Regional Development, Faculty of Science, Charles University in Prague, Czech Republic

² Institute of Social Ecology, Faculty for Interdisciplinary Studies Vienna, Klagenfurt University, Austria

***Email of corresponding author:**

simone.gingrich@uni-klu.ac.at,

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Abstract

Industrialisation goes along with sweeping changes in society's interrelations with its environment. The transition from an agrarian to an industrial society leads to fundamentally new patterns in social metabolism, a process which has been described as socio-metabolic transition. This paper investigates this transition for the case of the current Czech and Slovak republics and presents a dataset on the development of key variables related to social metabolism during the last 170 years. The dataset includes time series data on the extraction of biomass and fossil fuels, energy consumption and land use. Combining data on Bohemia and Moravia (1830-1915) with data on Czechoslovakia (1918-1992) and the Czech and Slovak Republics (1993-2002), the study covers a period of consecutive political and institutional changes. It includes the feudal regime of the late period of the Habsburg Empire and its disintegration with WWI, the short period of the Czechoslovak Republic in the interwar period, the era of a planned economy under a communist regime, the collapse of this regime and the subsequent turn towards a market economy and European integration in the 1990s. The period was characterized by economic and physical growth. It saw a doubling of population and a growth in GDP by a factor 20. Domestic energy consumption (DEC) increased by a factor 10 and the share of biomass in DEC declined from more than 98% to less than 20%. All in all the observed changes closely resemble the characteristic path of the socio-metabolic transition as observed in other Western European economies. Major political and economic changes did not result in fundamental alterations of the socio-metabolic transition until the mid-20th century. The communist era (1945-1989) was characterized by rapid physical growth and changes in the energy and land use system very similar to those of other Western European economies in the same period, however leading to DEC values substantially higher than those of other European countries at around 300 GJ/cap in the mid-1980s. The disturbances caused by the Velvet Revolution resulted in short term turbulences in social metabolism and structural adaptations, and around the year 2000, the Czech and Slovak Republics show biophysical features very similar to those of other Western European countries.

Introduction

The concept of social or industrial metabolism (Fischer-Kowalski, 1998; Fischer-Kowalski and Hüttler, 1998, Ayres and Simonis, 1994) captures biophysical aspects of the economy and allows to investigate interactions between societies and their natural environment. It has proven useful to study sustainability problems related to the use of natural resources (emerging both on the input and the output side) and social metabolism has been established as a key concept in sustainability science. During the last decades the investigation of patterns, structure and dynamics of the socio-economic use of materials and energy in relation to economic development has made significant progress and an increasing body of literature dealing with different aspects of social metabolism is published (see for example Weisz et al., 2006; Bringezu et al., 2004; Behrens et al., 2007). It has been argued repeatedly that a historical perspective on society-nature interactions supports the understanding of current patterns and dynamics (Martinez-Alier and Schandl, 2002; Hornborg et al., 2007; Costanza et

al., 2007) and a few studies have so far focussed on the long term historic development of social metabolism, contributing case studies on the social metabolism of pre-industrial societies and the impact of industrialization on the use of energy, materials and land (cf. Hornborg, 2006; Kander, 2002; Lindmark, 2002; Iriarte-Goñi and Ayuda, 2007; Schandl and Schulz, 2002; Krausmann and Haberl, 2002; Malanima, 2002; Gales et al., 2007; Cusso et al., 2006).

From such a biophysical perspective, the historical process of industrialization appears as a transition from an agrarian socio-metabolic regime with a land based controlled solar energy system towards an industrial regime with a fossil fuel based energy system (Sieferle, 2001; Krausmann et al., 2008b). During this socio-metabolic transition, the strong linkage between land, energy and labour is abolished and important biophysical limits for growth are relieved and new patterns of socio-economic material and energy use (metabolic profiles) prevail (Fischer-Kowalski and Haberl, 2007; Krausmann et al., 2008b). So far, most long term historical studies have focussed on Western European countries. Knowledge about the dynamics of social metabolism in communist countries and in particular the relation between industrialization, economic growth and social metabolism in the centrally planned economies of Eastern Europe is still very limited. This paper presents a new case study on biophysical aspects of industrialization in the former Czechoslovakia and Bohemia and Moravia, respectively, an Eastern European region with a distinct economic and political history. In a comprehensive view, it discusses changes in the social metabolism in the region of today's Czech and Slovak Republics from 1830 to 2000 by combining information on Bohemia and Moravia (1830-1915) with Czechoslovakia (1918-1992) and later the Czech and Slovak Republics (1993-2000). With this 170 year time span the study covers the social and economic changes related to the transition from a feudal state, when Bohemia and Moravia were lands of the Austro-Hungarian Empire, to a centrally planned economy and the post-communist stage. These transitions were related to periods of severe economic and political crises and economic disruption. The Czechoslovak case allows to investigate how different political and economic regimes are reflected in socio-metabolic patterns. By complementing the set of existing case studies on long term changes in social metabolism with a new one with very specific socioeconomic characteristics, this paper contributes to the advancement of a biophysical reading of industrialization and the understanding of socio-metabolic transition processes.

The paper presents annual time series data for a number of key variables related to the socio-metabolic transition (including extraction, trade and consumption of biomass, coal, oil, natural gas, electricity; land use, agricultural yields and livestock) in Bohemia and Moravia/Czechoslovakia for the period 1830 to 2000. The complete dataset can be downloaded from our web page (<http://www.uni-klu.ac.at/socec/inhalt/1088.htm>). We present empirical results on changes in land use, biomass production and energy consumption and a discussion of these results in the context of the socio-metabolic transition. We investigate the changes in energy and land use in relation with economic development and population growth and in comparison with other European case studies. With this analysis we a) provide insights into the long term dynamics of social metabolism and the metabolic regime transition in Bohemia and Moravia/Czechoslovakia and b) we highlight how abrupt changes in economic and institutional settings and economic political crises are reflected in biophysical parameters.

Materials and methods

This study empirically assesses long term changes in social metabolism and land use for the territory of today's Czechia and Slovakia in the time period from 1830 to 2000. Based on the

methodological framework of material and energy flow accounting (MEFA, see e.g. Haberl, 2002), we compiled data for (used) domestic extraction, imports and exports of biomass and fossil fuels, hydropower and nuclear heat and calculated aggregate MEFA indicators including domestic extraction (DE), physical trade balance (PTB) and domestic energy consumption (DEC). In order to fully capture the transition from a biomass based, controlled solar energy system towards an area independent fossil fuel based energy system in the course of industrialisation (Sieferle et al., 2006), a dataset comprising a number of key variables related to the land use system was compiled. This includes detailed information on changes in land use, biomass production and livestock. Outputs of the socio-economic system (dissipated energy) and related substance flows, such as Carbon emissions, were not empirically assessed in this study.

The compilation of time series data is based on official statistical records, national and regional data compilations and international data sets. Annually published statistical records and data from special surveys are available from the early 19th century for the lands of the Austrian part of the Austro-Hungarian Empire, including Bohemia and Moravia which basically form the territory of the current Czech Republic. For current Slovakia, which was then part of the Hungarian Kingdom, no aggregate data are available. For most of the 20th century we refer to national statistical yearbooks of the respective political-administrative entities, data compilations edited by the Statistical Office of the Czechoslovak Socialist Republic and also international data sources, above all the statistical database of the Food and Agricultural Organisation (FAO, 2004), the energy statistics database of the International Energy Agency (IEA, 2004) and the energy statistics yearbooks and COMTRADE database of the United Nations (UN, 2004; United Nations Statistical Division, 2004).

Table 1 presents an overview of all sources which were used for the compilation of time series data.

For items not covered in statistics, data estimation procedures were performed. The most important estimates concern grazed biomass and used crop residues throughout the entire time series, and foreign trade in those periods when no trade was reported for the reference system. For the estimate of grazed biomass, we use a “grazing gap” approach (Krausmann et al., 2008a), calculating the amount of grazed biomass by subtracting known amounts of feed supply from estimated feed demand. Feed supply measured in tons dry matter includes fodder crops, hay, crop residues used as feed, and market feed. Used crop residues, i.e. straw and beet leaves, are estimated by applying species-specific harvest indices and recovery rates. Feed demand is estimated using species specific feed demand factors which are adjusted over time to reflect gains in animal production and live weight (Sandgruber, 1978). No trade data was reported for the Austro-Hungarian lands Bohemia and Moravia. Based on literature (e.g. Lorenz von Liburnau, 1878; Mrazek, 1964) we estimated net trade for the period 1830 to 1915 assuming that in the mid-19th century Bohemia and Moravia began to export a significant share of their production of coal, sugar and cereals. For the period from 1992 to 2000, net trade of the Slovak and Czech Republics is calculated as the difference between the sum of Czech and Slovak imports and exports that is, not considering trade between the two countries.

Period	Data	Sources
1830-1915	Land Use	1822/1856: Summary tables of the Franciscan Cadastre (k.k.Finanz-Ministerium (Editor), 1858)
	Harvest	1830: Sandgruber, 1978
	Live Stock	1868-69: Landwirtschaftliches Wochenblatt des k.k. Ackerbau-Ministeriums, Volume I, Nr.1, 1869, and Volume II, Nr.13, 1870
		1831-1865: Tafeln zur Statistik der österreichischen Monarchie
		1874-1913: Statistisches Jahrbuch des k.k. Ackerbauministeriums
		1870-1881: Statistisches Jahrbuch der österreichischen Monarchie
		1881-1913: Österreichisches Statistisches Handbuch für die im Reichsrathe vertretenen Königreiche und Länder
	Population	1828-1871: Tafeln zur Statistik der österreichischen Monarchie
	Fossil Fuel Production	1866-1874: Statistisches Jahrbuch der österreichischen Monarchie
		1875-1917: Hwaletz, 2001
1920-1992	Land Use	1920-1932: Státní úrad statistický v Praze (Editor), 1920-1932
	Harvest	1932-1938: Státní úrad statistický v Praze (Editor), 1934-1938
	Live Stock	1920-1983: Federální statistický úrad (Editor), 1985
	Population	1950-1990: Federální statistický úrad (Editor), 1958-1989
		1990-1992: Federální statistický úrad (Editor), 1990-1992
	Fossil Fuels Production	1920-1932: Státní úrad statistický v Praze (Editor), 1920-1932
		1932-1938: Státní úrad statistický v Praze (Editor), 1934-1938
Foreign Trade	1920-1983: Federální statistický úrad (Editor), 1985	
		1950-1990: Federální statistický úrad (Editor), 1958-1989
		1990-1992: Federální statistický úrad (Editor), 1990-1992
		1961-1992: Data from International Energy Agency and Food and Agricultural Organization.
1993-2000	Land Use	1994-2002: Statistical Yearbooks of the Czech and Slovak Republics
	Harvest	1993-2002: Statistický úrad Slovenskej republiky (Editor), 2003
	Live Stock	1993-2002: Ministry of the Environment of the Czech Republic (Editor), 2000
	Population	1993-2002: Data from International Energy Agency and Food and Agricultural Organization and UN Energy statistics
	Fossil Fuel Production	
	Foreign Trade	

Table 1. Data sources

For the calculation of energy flows, all material categories were aggregated to consistent categories (seven categories for agricultural biomass, one for wood, and five for fossil fuels: brown coal, hard coal, crude oil and natural gas). Material given in mass was converted into energy units applying the specific energy contents (gross calorific value) of the respective

material (Haberl, 1995). Electricity generated from nuclear power was converted into nuclear heat (that is the respective type of primary energy) by assuming an efficiency of 30%; for electricity from hydropower the assumed efficiency was 95% (Krausmann and Haberl, 2002). Data on GDP in purchasing power parities were taken from the Groningen data base (Maddison, 2003). Data on population for the respective reference system were compiled from the above mentioned national statistical sources.

A major difficulty in compiling consistent time series data appeared to be the change of administrative boundaries of the case study region.

Table 2 gives an overview of the political and administrative changes which occurred in the region from 1830 to 2002. From 1830 to 1918 the territory of Czechia and Slovakia was part of the Austro-Hungarian Empire. After the collapse of the Empire the Czechoslovak Republic was established, consisting of Bohemia, Moravia, Slovakia and a small part of current Ukraine (Ruthenia). In 1938, Bohemia and Moravia were occupied by Nazi-Germany and formed the *Protectorate Bohemia and Moravia*, while Slovakia became an independent state. After World War II the Czechoslovak Republic united Bohemia, Moravia and Slovakia in one administrative unit. After 1948 the Czechoslovak Republic was under communist rule and was renamed to Czechoslovak Socialist Republic in 1960. This lasted until 1989 when the so-called *Velvet Revolution* ended the communist rule and the new Czechoslovak Republic was formed. Three years later, Czechoslovakia split into the Czech and Slovak Republics, both of which joined the European Union in 2004.

Period	Name	Territory	System
1830-1918	Bohemia and Moravia (1830-1847 incl. Silesia)	75,000 km ² (85,000 km ²)	Lands of the Habsburg Monarchy and from 1867 Austro-Hungarian Monarchy
1918-1938	Czechoslovak Republic: consisting of Bohemia, Moravia including part of Silesia, Slovakia and Ruthenia)	140,000 km ²	Republic
1939-1945	Protectorate Bohemia and Moravia, Slovak state	49,000 and 38,000 km ²	The Protectorate was occupied by Nazi-Germany. Slovakia independent.
1948-1989	Czechoslovak republic: consisting of Bohemia, Moravia including part of Silesia and Slovakia (in 1960 renamed to Czechoslovak socialist republic)	128,000 km ²	Centrally planned economy; Comecon
1989-1992	Czechoslovak Federal Republic	130,000 km ²	Market economy
1992-	Czech Republic; Slovak Republic	79,000 and 49,000 km ²	Market economy; since 2000 EU members

Table 2. Regional reference systems

For the interpretation of the entire time series from 1830 to 2000, we attempted to avoid major statistical breaks resulting from territorial changes. For the period 1830 to 1915 the reference system includes the lands Bohemia and Moravia (that is, approximately the territory of the current Czech Republic) and for the period 1920 to 2000 it also includes the Slovak Republic (that is, the territory of the Czechoslovak Republic). The inclusion of Slovakia into the dataset

as from 1920 leads to some distortions due to structural differences between Czechia and Slovakia in the early 20th century: Slovakia had a more pronounced rural character compared to industrializing Czechia, population density was lower (61 cap/km² compared to 127 cap/km² in Czechia), the share of agricultural production was higher and industrial production was less developed (see Pavlinek, 1995). Despite the structural differences between the two regions, intensive variables correspond surprisingly well before and after World War I, and the long term time series results in plausible trends.

For reasons of simplicity, we will refer to the region of reference as *Czechia* for the period 1830 to 1915 and as *Czechoslovakia* for the period 1920 to 2002 throughout the rest of the paper. In order to minimize the resulting break in the data, we present most data recalculated as intensive variables, that is, either per unit of total area and year or per capita and year or as percentage of total (land use). For the periods of World War I and II and a number of subsequent years (1915 to 1919 and 1938 to 1950) no satisfactory data are available – these periods were thus excluded from the time series analysis.

Results

Biomass production system

The biomass production system is described on the grounds of data on domestic extraction (DE) of biomass, land use, agricultural yields, and the livestock. Figure 1 shows the development of biomass extraction; data are presented in energy units and, in order to reduce the impact of the changing territorial system, are expressed per unit of total area (TJ/km²). In 1830, total DE of biomass amounted to 2.8 TJ/km². Biomass production grew continuously throughout the 19th and early 20th century and doubled to 5.3 TJ/km² by 1914. Most of this increase was due to a growing harvest of agricultural biomass, above all on cropland. Harvest of crops and by products tripled during this period from 1.1 to 3.0 TJ/km². Wood harvest and extraction from grasslands (including grazing) increased only modestly. Further increases in crop harvest only occurred after World War II when production recovered quickly and grew from 2.2 TJ/km² in 1945 to 3.8 TJ/km² in the 1980s. In this period, the main drivers were increases in cereal and fodder crop harvest. Also extraction of wood went up significantly, doubling from 0.7 TJ/km² in 1945 to 1.5 TJ/km² in 1989. After the Velvet Revolution, total biomass harvest slumped dramatically from 6.9 TJ/km² in 1989 to 5.4 TJ/km² in the mid-1990s, owing largely to a steep decline in the harvest of forage and grazed biomass. Since then biomass extraction seems to have stabilized due to slight increases in the harvest of wood, oil seeds and other crops. At the end of the 20th century, agricultural harvest was at a similar level as in the interwar-period. Overall, biomass harvest grew by 50% between 1830 and 2000; however two distinct periods of growth, which are followed by periods of stagnation or decline, are discernible in Figure 1: A period of moderate growth between 1830 and World War I, and a period of rapid growth from the 1960s to the late 1980s.

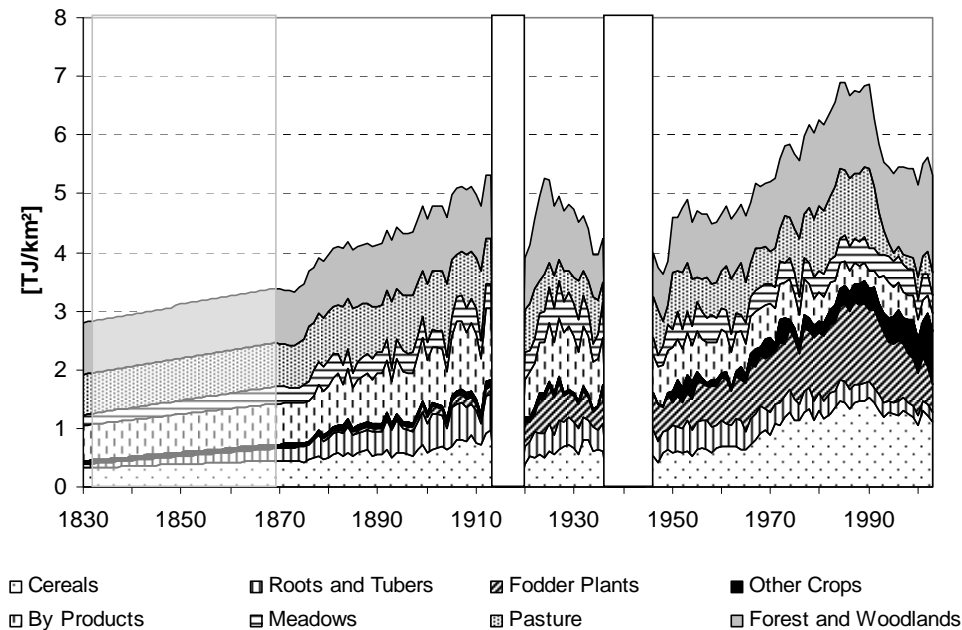


Figure 1. Domestic Extraction of biomass in Czechia (1830-1915) and Czechoslovakia (1920-2002), in unit of Energy per unit of total area. Data between 1830 and 1869 were interpolated due to lack of reliable sources (shaded area). Sources: own calculations, see text.

Figure 2 shows the development of land use, data are presented as % of total area. In the early 19th century cropland was by far the most important land use type, covering just under half of the total land area. Grassland (meadows and pastures) accounted for 18% and forests for another 27% around 1830. The remainder (9%) was occupied by other land use types, including built-up land and associated areas and unused land. Throughout the 19th and early 20th century, the distribution of cropland, grassland and forests was comparatively stable. Major shifts of land use only occurred within cropland: The area of new crops such as root and tuber crops and leguminous fodder crops gradually was expanded and grew from 6% of the total area in 1830 to 16% in 1910. The expansion of cropped area was made at the expense of fallow which decreased from 9% to below 1% in the same period. The statistical break related to the changes in the territorial system after World War I (the territory of the reference system increases by 86% due to the inclusion of Slovakia, see

Table 2) causes only minor distortions in the overall distribution of land use: Due to the higher share of forest and grassland area in Slovakia the share of cropland decreased, while the proportion of forest and grassland was somewhat higher in the new republic. Major changes in land use occurred after WWII: Between 1945 and 1989, agricultural area decreased by 15% (arable land was reduced by 9% and grassland by 30%) while forest area grew by 10% and the extent of other land more than doubled, resulting from a conversion of agricultural land to construction land, mining areas and land used for other purposes (Bartos, 1987). In the 1990s, the decline in agricultural areas accelerated and by 2000 cropland was reduced to 35% of the total area (most of the reduction was due to a decline in the area of fodder crops), grassland to 14%, while forests had grown to 36% and other areas accounted for as much as 15%. It can be assumed, however, that a significant amount of land recorded in land use statistics as agricultural land (arable land or grassland) has actually been unused since 1989. The estimates of the amount of abandoned agricultural land in 2002 oscillate around 300,000 ha,

of which about 100,000 are former arable land (Ministry of the Environment of the Czech Republic (Editors), 2003). That is, the reduction of land used for agriculture is even more dramatic than it appears in Figure 2.

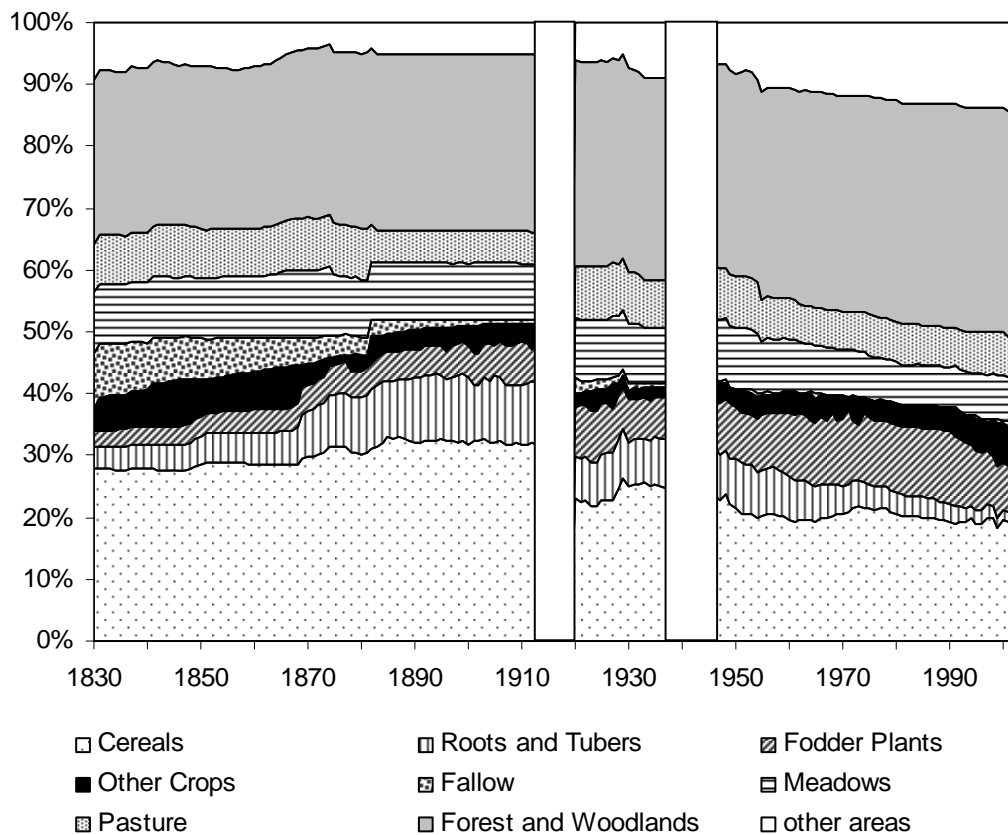


Figure 2. Land Use in Czechia (1830-1915) and Czechoslovakia (1920-2002) [% of total area]. Sources: Own calculations, see text.

Increases in biomass harvest and changes in land use are related to dramatic changes in agricultural yields (i.e. production per unit of cropped area). In the 19th and early 20th century, yields of most crops grew gradually. Cereal yields more than doubled from 1.2 TJ/km² (63 tons dry matter per km², t_{DM}/km^2) in 1830 to 3.0 TJ/km² (166 t_{DM}/km^2) in 1910 and yields of roots and tubers increased threefold from 1.8 TJ/km² to 6.3 TJ/km². Also wood yields increased during this period, however more slowly, from 3.2 TJ/km² to 3.8 TJ/km. In the interwar period yields stagnated and began to increase again only after World War II. Between 1945 and 1989 cereal yields increased four fold to 7.3 TJ/km², the yields of most other crops show a similar development. After the Velvet Revolution cereal yields declined by 15% until the mid-1990s and have hardly recovered since. Wood yields however, which had grown more slowly than yields of agricultural products, increased in the 1990s to 4.1 TJ/km². Thus, while in the 19th and early 20th century, rises in DE of biomass were related to both increases in area and yields, after World War II, increases in harvest can be attributed solely to rising yields for most agricultural products. The slump of DE of biomass after 1989 went along with both a decline in agricultural areas and yields.

Figure 3: Livestock in Czechia (1830-1915) and Czechoslovakia (1920-2002) in Livestock Units (LSU) per km² total area. Sources: own calculations, see text.

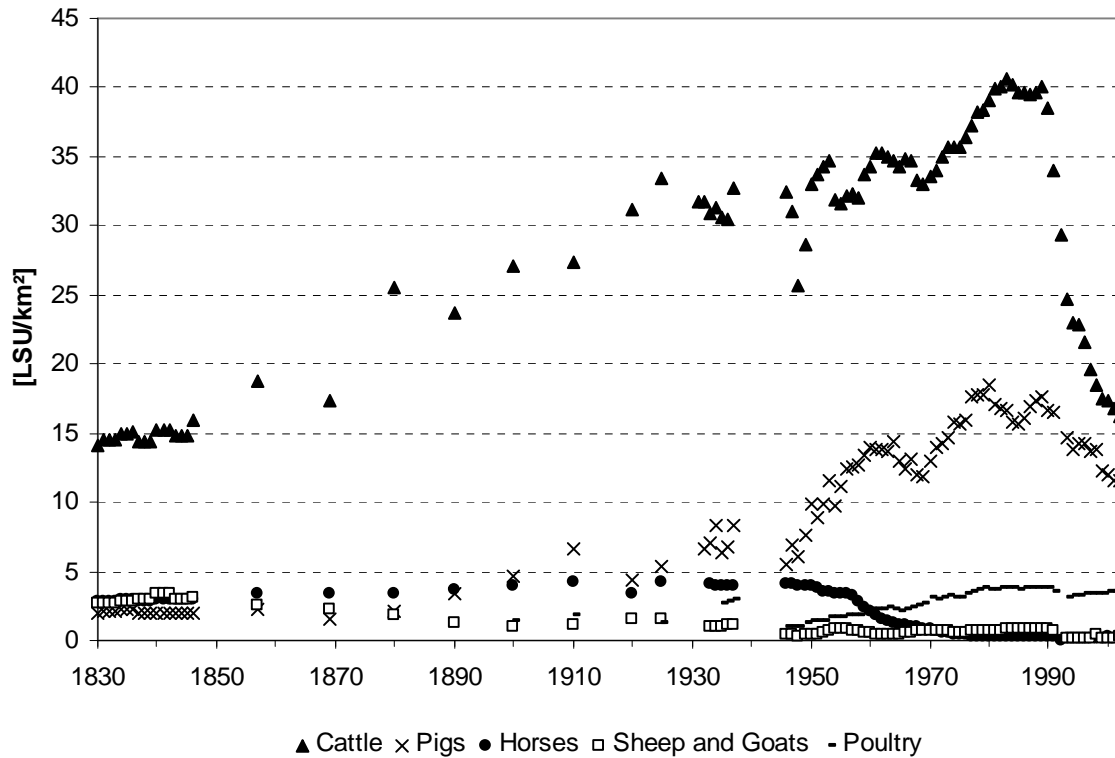


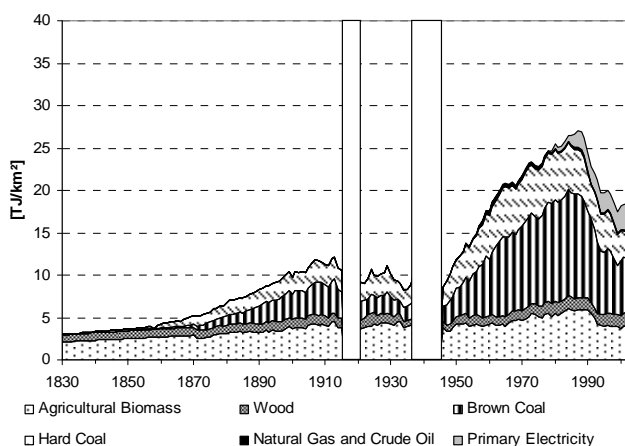
Figure 3. Livestock in Czechia (1830-1915) and Czechoslovakia (1920-2002) in Livestock Units (LSU) per km² total area. Sources: own calculations, see text.

Livestock is a key element in the agricultural system. The size of biomass flows and their socioeconomic use are closely linked to the stock of domesticated animals. Throughout the observed period 65-70% of all agricultural biomass (and more than 60% of total biomass harvest) was used as feed or bedding material in the livestock sector. Figure 3 shows major trends in livestock structure: Numbers of livestock are expressed in large animal units (LSU) and are presented as livestock density that is as LSU per unit of total area. Throughout the whole period cattle were the dominant livestock species in Czechia/Czechoslovakia. In 1830 cattle density amounted to 14 LSU/km² while that of all other species ranged between 2 and 3 LSU/km². Cattle density increased continuously throughout the period due to both increases in numbers and weight and reached a level of around 40 LSU/km² in the 1980s. The stock of pigs began to grow in the late 19th century and in particular after World War II (from 5 LSU/km² in 1945 to 19 LSU/km² in 1980). Similar trends can be observed in poultry stocks. The stock of horses, the major source of draught power in the 19th and early 20th century, doubled between 1830 and 1910 and then roughly stayed at this level until it rapidly declined after World War II. After 1989, stocks of the two most important livestock species, cattle and pigs, decreased dramatically: pig stocks were reduced by almost 40% and cattle stocks by even 70%, reaching levels similar to those of the 19th century. Even though the rate of decline has gone down, no stabilisation in cattle and pig stocks has occurred. Overall, between 1830 and 1989 livestock density grew from 21 to 63 LSU/km²; feed demand grew by 66% from 1830 to 1914 and by 50% from 1920 to 1989.

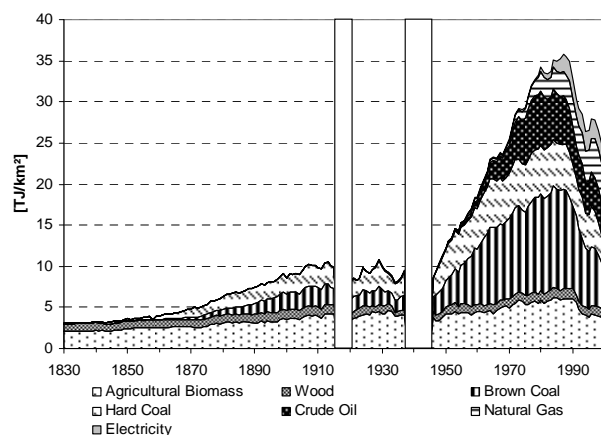
Energy System

Total energy flows, including domestic extraction (DE), domestic energy consumption (DEC) and the physical trade balance (PTB) are displayed in Figures 4a to 4d, data are given in TJ per unit of total area and GJ per capita, respectively. Between 1830 and the beginning of WWI total DE grew four fold (from 2.6 TJ/km² to 11.9 TJ/km²). Until the mid 19th century biomass accounted for more than 90% of DE. From the 1860s onwards the extraction of coal (in the beginning hard coal, but later increasingly brown coal) increased at a rapid pace, while biomass harvest continued to grow slowly. By 1895, extraction of coal surpassed that of biomass. Peak production of coal before World War I reached 6.6 TJ/km² (60% of which were brown coal). In the interwar period no clear trend is discernable and coal and biomass production roughly remained at a constant level. After WWII a new dynamic of growth set in. Within four decades coal production grew five fold, reaching a level of more than 18 TJ/km² (or 150 GJ/cap) in the mid-1980s. During this period, energy supply shifted from (high quality) hard coal to (lower quality) brown coal and by 1989 brown coal accounted for 70% of coal production. The extraction of biomass grew at a much slower pace in this period, leading to an increasing share of coal extraction of total DE: in the late 1980s coal accounted for 70% of total DE. The regime change in 1989 had dramatic impacts on the energy system: Coal production slumped and within a few years was down to about 50% of the level of the mid 1980s, biomass production declined by more than 25%. DE of other energy types (crude oil, natural gas, hydro- and nuclear power) was of minor quantitative importance throughout the period until 1989 (below 10% of total DE). Throughout the period hydropower played only a minor role in domestic energy production; in 1972 Czechoslovakia opened its first nuclear power plant and since the contribution of nuclear heat to total DE increased gradually. In 2002 hydropower and nuclear heat accounted for 18% of total DE (3 TJ/km²).

a)



b)



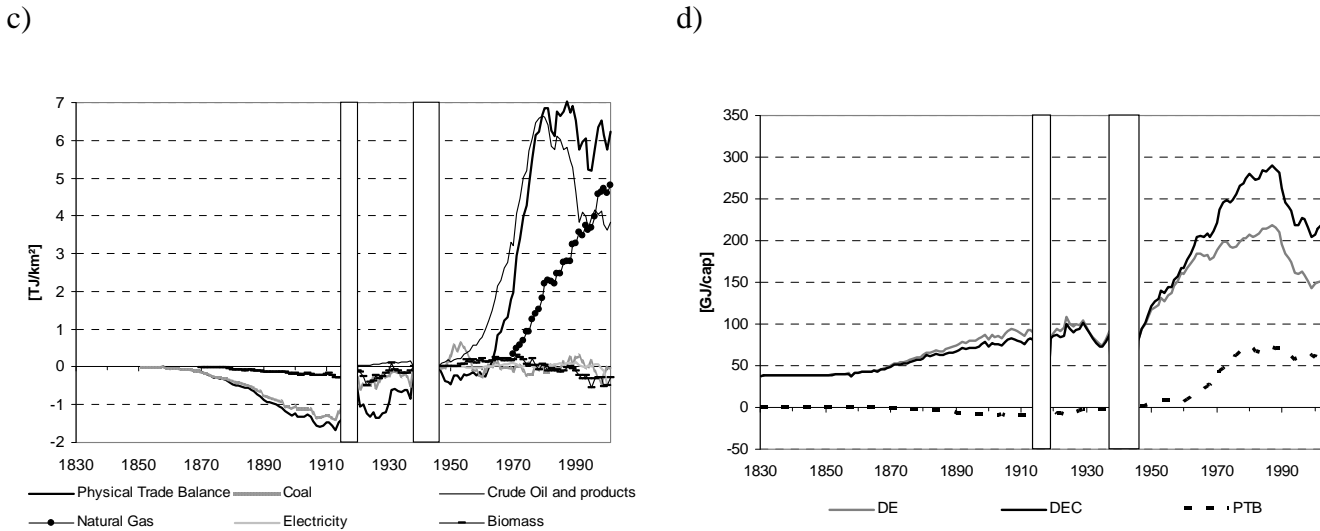


Figure 4. Socio-Economic Energy Flows of Czechia (1830-1915) and Czechoslovakia (1920-2002). a) Domestic Extraction (DE) per unit of area. b) Domestic Energy Consumption (DEC) per unit of area. c) Physical Trade Balance (PTB) per unit of area. d) Domestic Extraction (DE), Domestic Energy Consumption (DEC) and Physical Trade Balance (PTB) per capita. Sources: own calculations, see text.

Foreign trade was low compared to DE in the 19th century, but increased continuously throughout the time period. Throughout the 19th century Czechia appeared as a net exporting region. Exports consisted largely of brown coal, agricultural products such as sugar and cereals only gained some importance towards the end of the 19th century. In the interwar-period, exports stagnated, and some imports (mostly hard coal) are reported. Foreign trade grew moderately until the 1960s. Then imports of crude oil took off, rising quickly from 1 TJ/km² in 1960 to 5 TJ/km² in the early 1970s. From the 1970s onwards natural gas imports added on, rising slowly from 1 TJ/km² in 1970 to 2 TJ/km² in 1980. Imports of biomass played a minor role in energetic terms as compared to fossil fuels. Exports were significantly lower than imports in energetic terms from the 1960s, never exceeding 4 TJ/km², and in 1963 Czechoslovakia turned into a net-energy-importing country. Import dependency grew rapidly and by 1989 net imports accounted for 21% of domestic energy consumption (DEC). As opposed to DE which slumped after the Velvet Revolution, imports recovered quickly after 1989 and grew throughout the 1990s (from 9.3 TJ/km² in 1991 to 10.9 TJ/km² in 2000), contributing increasing shares to energy supply. Exports were dominated in the 20th century by hard coal. Some crude oil in the form of refined petroleum products was (re-)exported in the late 20th century. Also wood exports gained significance from the mid-1970s, making up for around 10% of exports.

Domestic energy consumption (DEC) is defined as DE plus imports minus exports – trends in DEC thus comprise the combined effects of all previously discussed energy flows. DEC grew gradually in the early and mid-19th century, from 2.6 TJ/km² in 1830 to 4.7 TJ/km² in 1870. Only from the late 1860s, driven by the massive exploitation of first hard coal and then increasingly brown coal deposits, DEC began to increase more rapidly and doubled until 1910 to 10 TJ/km² - by this time, fossil fuels made up for around 50% of total DEC, distributed equally between brown coal and hard coal. The upward trend continued until the economic crisis in 1929 when DEC declined from 11 to 8 TJ/km² in just a few years. The decades after World War II saw a surge in energy consumption. Between 1950 and 1981 DEC grew more than four fold and reached 35 TJ/km². During this period, the share of biomass in DEC

declined from 41% to 20%, while the share of fossil fuels went up. In the 1950s and 60s, the main driver for the increasing DEC of fossil fuels was increasing brown coal extraction, while from the 1970s onwards, imports of crude oil and natural gas contributed more and more to DEC. In the 1980s growth of DEC slowed down and DEC even began to decline in 1985. The regime change in 1989 was related to a dramatic slump in DEC. Between 1989 and 2000 DEC declined by roughly one third to 23 TJ/km² and has increased slightly since then. Imports contributed greatly to DEC at up to 40%. Fossil fuels made up for 81% of DEC, of which just over one half consisted of coal.

The per-capita trends of energy use differ from the per-area calculation presented above in periods of dynamic population development. Between 1830 and 1860 DEC per capita remained fairly constant around 40 GJ/cap, indicating that physical growth was mainly driven by population growth in the first half of the 19th century. Only then did physical growth substantially outpace population growth, and by 1910, DEC had doubled to 80 GJ/cap. The break resulting from the inclusion of Slovakia into the dataset after WWI did not significantly distort values of per-capita DEC. In the decades after WWII, the rapid physical growth was accompanied by modest population growth and per capita DEC increased rapidly and reached a peak in the late 1980s at almost 300 GJ/cap. Since the population in Czechoslovakia remained more or less constant since 1980, the slump in Energy consumption after the Velvet Revolution is just as pronounced in per-capita as in total values: DEC per capita went down by almost one third. In the late 1990s the steep downward trend came to a halt at around 220 GJ/cap.

Discussion: the socio-ecological transition in Czechia/ Czechoslovakia

The 170 year time period observed in this paper was a period of tremendous economic, political and socio-ecological change for Czechia and Czechoslovakia. Appearing as an agriculturally dominated region with only little manufacturing at the beginning of the 19th century, the region experienced extensive industrialization and economic growth under changing political conditions.

	GDP [intl. \$]	Population [number]	GDP/cap [intl. \$/cap]	DEC [TJ/ha]
Long term trends				
1820-1910	298%	70%	135%	224%
1948-1989	258%	26%	189%	238%
1920-2000	439%	21%	346%	211%
Periods of disruption				
1914-1920	-10%	-2%	-8%	-7%
1929-1934	-17%	3%	-20%	-26%
1937-1948	-8%	-14%	7%	9%
1989-1993	-18%	1%	-18%	-19%

Table 3. Long term trends and periods of disruption in Czechoslovakia: GDP, population and energy use Source: Maddison, 2003 (GDP and population); own calculations (DEC)

		1850	1880	1910	1950	1985	2000
Population density^a	[cap/km ²]	92	111	135	95	121	123
GDP/cap^b	[USD/cap]	1,079	1,334	1,990	3,501	8,367	8,630
DEC per capita	[GJ/cap]	39	59	78	121	283	207
Share of biomass in DEC	[%]	94	64	51	39	20	18
Share of fallow in cropland	[%]	14	6	1	1	0	2
Agricultural population^c	[%]	59	49	38	20	12	8
Coal extraction^a	[t/cap]	0.1	1.3	2.9	3.5	8.3	4.6
Iron production^d	[kg/cap]	8	13	81	252	975	635
Fertilizer application^d	[kg/ha agricultural land]				43	348	82
Railroads^d	[m/km ²]	-	65	119	103	103	74
Motorization^d	[cars/100 P]				1.0	18.0	31.1
Draught animals^c	[horses/100 P]	4.8	4.1	4.2	5.1	0.3	0.2

Table 4. Industrialization in Czechia (1850-1910) and Czechoslovakia (1950-2000). Sources:

a. statistical yearbooks, see text, b. Maddison, 2003, c. Sandgruber, 1978, d. Mitchell, 2003 (1850-1880 pig iron; 1950-2000 crude steel)

Between 1820 and 2000, according to Angus Maddison's (2003) estimate, per-capita GDP grew tenfold from 849 \$/cap to 8,629 \$/cap, population doubled from 7.7 mio. to 15.7 mio., and total GDP increased by a factor of 21 (see Figures 5a and 5b). Economic growth, however, was not a continuous process but was interrupted by periods of severe disruption and radical political change (Table 3): In the 19th century (1820 to 1910), GDP grew by 223 % and population by 59%, per capita income (GDP/cap) doubled. World War I and the collapse of the Habsburg Empire caused a decline in GDP and population between 1913 and 1920 by 10 and 2%, respectively and after only a few years of rapid recovery, the economic crisis of 1929 saw a slump in GDP by 17%. WWII and the post war struggles caused economic disruptions similar to those of WWI, leading to a decline in GDP of 8%, while population slumped by 14%, which was largely due to the transfer of between 2 and 3 mio. (mostly German speaking) inhabitants. World War II and the subsequent strong decrease in population left Czechoslovakia's agricultural output surprisingly unharmed. While agricultural production per area was 10 to 20% lower directly after the war than it had been before, per-capita values stayed fairly constant. Production of wood and fossil fuels was even less affected by war disruptions.

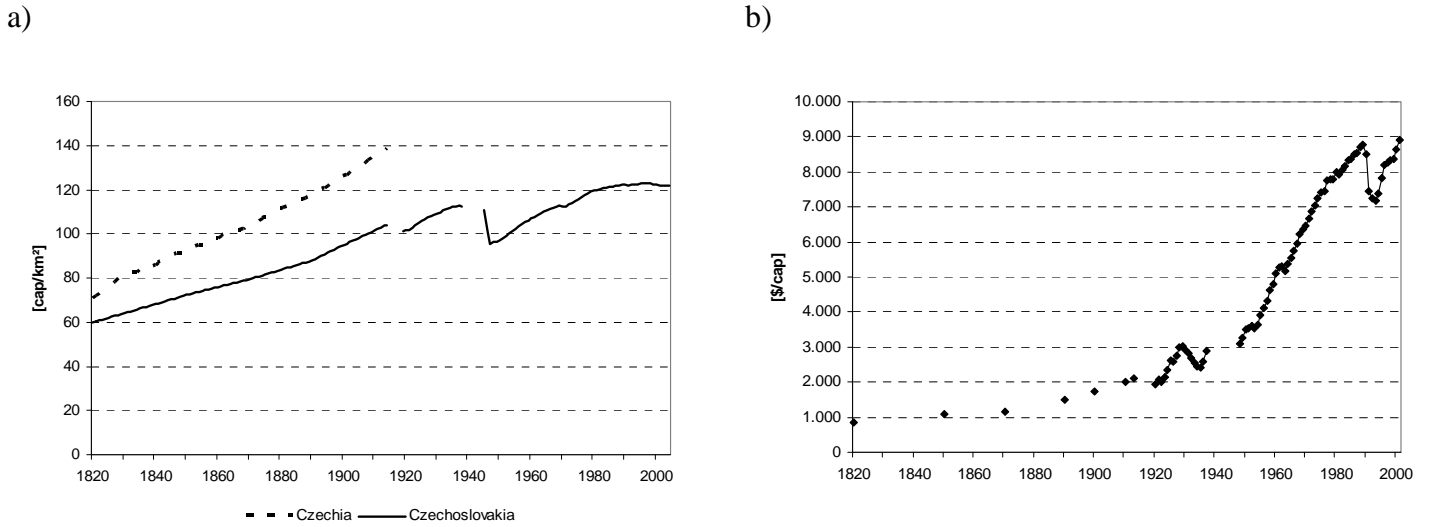


Figure 5. Demographic and economic development in Czechia/Czechoslovakia 1820-2000. a) Population density in Czechia (1820-1915) and Czechoslovakia (1820-2002). Sources: own calculations, see text. b) Gross Domestic Product in Czechoslovakia in international Geary-Khamis-\$ per capita 1820-2002. Source: Maddison, 2003

During the communist period the economy grew rapidly (260%) and population grew by over 25% until it stabilised in the 1970s. The velvet revolution marks a significant economic disruption in the whole period with a GDP decline similar to that of the economic crisis in 1929. Between 1989 and 1993 GDP (absolute and per capita) slumped by 18%, but recovered quickly and reached the former level in the year 2000. The whole period between 1920 and 2000 saw an increase in GDP by 429% and of population by 21%, per capita GDP grew by 346%. In the following section, we will discuss how economic growth and disruptions and political change are reflected in changes of the social metabolism and the biophysical variables investigated in our study.

Four periods of change with distinct biophysical dynamics were identified: The “long 19th century”, from the beginning of our analysis until the outbreak of World War I, the interwar-period, the communist era from 1945 until 1989, and the restructuring as a market economy from then on. The long-term trends in these periods will be discussed below. Table 4 presents a number of key indicators for Czechia/Czechoslovakia’s industrialisation.

5a: 1989		Czechoslovakia	Austria	United Kingdom	EU15	Japan
GDP/cap	[intl \$/cap]	8,709	15,762	16,110	15,633	17,185
DEC/cap	[GJ/cap]	281	194	191	199	148
DEC/GDP	[MJ/intl \$]	32	12	12	13	9
5b: 2000		Czechoslovakia	Austria	United Kingdom	EU15	Japan
GDP/cap	[intl \$/cap]	8,630	20,097	19,817	19,160	21,069
DEC/cap	[GJ/cap]	201	199	189	209	193
DEC/GDP	[MJ/intl \$]	22.8	9.7	9.4	10.9	9.1

Table 5. International comparison: Income (GDP/cap), Energy consumption (DEC/cap) and Energy intensity (DEC/GDP) for selected industrialised countries in 1989 (5a) and 2000 (5b). Sources: Haberl et al., 2006; Krausmann et al., 2008c; Maddison, 2003.

1830 – 1914: Coal based growth

The gradual changes of the late 19th and early 20th century represent the take-off phase of Czechia's transition from an agrarian to an industrial socio-ecological regime. During this period, Bohemia and Moravia were lands of the Habsburg Empire and its system of gradually increasing internal division of labour. Like the rest of the Empire, Bohemia and Moravia were late comers with respect to the industrial revolution: In the mid-19th century, around 60% of the population were engaged in agriculture, urbanisation was low and iron production amounted to less than 10 kg per capita (Table 4). Biomass was the most important energy carrier until the mid 19th century accounting for more than 95% of DEC until 1840. Only then, the exploitation of Bohemia's and Moravia's coal deposits gained significance, exceeding a level of 100kg/cap and year in 1846 and gradually increasing domestic extraction and domestic energy consumption to unprecedented levels until the collapse of the Empire. In the 1860s, the economic boom of the *Gründerzeit* affected the economy of the Czech lands (Bideleux and Jeffries, 2007). Bohemia and Moravia had been connected to the steam railway system since the 1830s, but increased railway construction took place from 1848 to 1867, extending the network to over 5,000km of railway lines (Mrazek, 1964). Only from the 1860s on, Czechia rapidly replaced Styria as the centre of the Empire's iron industry (Hwaletz 2001). The once backward lands Bohemia and Moravia evolved as dynamically growing industrial regions with a boosting coal production.

At first, the use of coal was restricted to industrial processes, replacing (and adding to) wood as a key resource and significant amounts of coal were exported to other provinces of the Empire, above all to Vienna and Lower Austria. During the 19th century population increased by 60% and the pressure on agriculture to raise the production of food and feed grew. Like in many other central European regions, agricultural output was increased by a series of technological innovations and an optimization process generally termed the first agricultural revolution (Sandgruber, 1978). New crops, above all potato, clover, fodder and later also sugar beet allowed to replace the traditional three field rotation by more sophisticated crop rotations and the share of fallow of total cropland declined from 19% in 1830 to 2% in 1900 (Table 4). The surge in available fodder allowed to increase the number of draught animals and livestock densities in total almost doubled. More manure, better fertilizer management and Nitrogen inputs from leguminous crops helped to raise agricultural yields by 50% and more, and the annual growth rate of cereal output even exceeded that of population growth in that period. Czech agriculture increasingly supported other parts of the empire with agricultural production.

At the outbreak of WWI, Czechia appears to be a typical industrializing Central European region: During the long 19th century GDP had grown by 300%, population by 70% and per-capita GDP by 135% to a level similar to that of the Austrian lands of the empire (Table 3). Coal production per capita had increased from 20 kg in 1830 to more than 3,000 kg and total DEC had more than doubled to a level of 81 GJ/cap, coal accounting for roughly half of its total (Tables 3 and 4). Agricultural population had declined to a third of total population and iron output surged to more than 100 kg/cap. Agricultural production by and large kept pace with population growth, despite the fact, that throughout the 19th century, the agricultural production system did not yet substantially benefit from the new energy source. The supply of agriculture with power still fully relied on draft animals and humans (only 2% of all agricultural machinery used fossil fuels, see Sandgruber, 1978). Industrial sources for the replacement of plant nutrients were hardly existent.

1914-1948: Major disruptions: decline and recovery

World War I ended a long period of economic and physical growth and marked the beginning of a series of severe disruptions. After the disintegration of the Austro-Hungarian Monarchy, the former Austrian lands Bohemia and Moravia together with Slovakia (formerly Hungarian territory) now formed the new Czechoslovak Republic. According to Maddison (2003), the period 1914 to 1920 saw a 10% decline in GDP but only 2% in population (Table 3). The economic starting position of the newly founded Republic was favourable: Czechoslovakia was endowed with large deposits of coal and, as it contained the monarchy's centres of heavy industry, a large industrial legacy. This contributed to the fact that Czechoslovakia's energetic metabolism was surprisingly little affected by the collapse of the Austro-Hungarian Empire: Despite the inclusion of the less industrialised Slovakia, DEC (per unit of area) in 1920 was only 7% lower than in the years preceding the war (Figure 4b). After the war growth continued until the economic crisis in 1929 severely hit the Czechoslovak economy (Häufler, 1984). Within only five years GDP slumped by 17% and DEC declined even by 26% (Table 3). The period of recovery was short and World War II and its aftermath constituted the next major disruption. Three years after the war, in 1948 GDP was still 8% below the value of 1937, while energy consumption, which had rapidly recuperated after 1945 was already 8% above the pre-war level. The period, however, saw a 14% decline in population which was mostly due to the transfer of 2-3 mio. people, mostly Germans from borderlands (see Figure 5a). This had a considerable impact on land use and agriculture, as it left large border areas uncultivated and enforced reforestation (see e.g. Bicik and Stepanek, 1994). However, agricultural output was comparatively constant before and after the war. This might be a result of farmers' organisation efforts for cooperation which continued until 1948 and could have alleviated the war damages (Kubacak, 1995). Overall, the period 1914 to 1948 experienced a considerable growth with respect to GDP (37%) and a less pronounced increase in DEC (17%) but a decline in population (-7%) (see Table 3). The disruptions were severe, but were followed by periods of steep economic and physical growth.

1948 to 1989: the socio-ecological transformation under communist rule

Profound changes in Czechoslovakia's physical economy only occurred after World War II. Industrialization and boosting industrial and agricultural production were among the key priorities of the communist administration and Czechoslovakia became tightly integrated into the system of spatial division of labour among the members of the Council for Mutual Economic Assistance (Comecon, see Bideleux and Jeffries, 2007). Economic development

focused on the expansion of coal mining and heavy industry and the Czechoslovak Socialist Republic became a centre for industry (iron, steel and chemical industry) and manufacturing within the Comecon (Blazek, 1959): steel production increased by almost 300% between 1950 and 1985 (Table 4).

Coal production and consumption was greatly enhanced and in 1955 low quality brown coal replaced hard coal as key energy carrier (Figure 4a). In the 1960s imported crude oil and later also natural gas, both available at low prices from Russia (Bideleux and Jeffries, 2007; Sirucek, 2007), began to supplement domestic coal in significant quantities, but coal (and above all brown coal) remained the quantitatively most important source of technical energy (Figure 4b). The extensive use of coal went along with CO₂-emissions much higher than those of oil-based industrialised countries (Kuskova, 2004). Until the 1980s, energy consumption went up very steeply (annual growth rates of 3%), reaching levels around 300 GJ/cap which by far exceeded those of other industrialized countries (see Table 5); a significant share of this energy was used for the production of industrial export products aimed for the Comecon markets. Also agriculture was subject to far reaching restructuring and was industrialized at a fast pace in the decades after World War II. Collectivisation was rapidly enforced. Between 1950 and 1980 the proportion of farm land in cooperatives and state farms increased from less than 10 to more than 80%, a development which created huge farm enterprises: In 1980 the average size of a cooperative was 2,500 ha and that of a state farm 6,800 ha (Bartos, 1987). Between 1955 and 1975 the number of tractors increased to 137,000, draught animals disappeared and agricultural labour force declined by 50% (Table 5). The application of artificial fertilizer surged to 350 kg/ha of agricultural area. This allowed for the tremendous increases in agricultural yields, biomass output and livestock numbers and the decline in agricultural areas observed in the decades after WWII (see Figures 1 and 3). Mining land and built-up land used for infrastructure or urban areas also contributed to decreasing agricultural land (Stys, 1987). Between 1963 and 1979 almost 500,000 ha of farmland (7%) were lost, a significant fraction for construction and mining (Bartos, 1987, see also Bicik et al., 2007). Wood extraction also increased considerably during the 20th century. While wood was successively replaced by fossil fuels for combustion in the early 20th century, it was used more and more for non-energy purposes such as timber and paper production – by 1980, the non-energy use of wood accounted for 90% of domestic wood consumption (Kubacak, 1995). Wood also became an increasingly important export product with up to 40% of domestic extraction used for exports.

The dynamics of biophysical growth which prevailed in centrally planned Czechoslovakia in the decades following WWII very much resembles the picture which has been observed in Western European countries (Gales et al., 2007; Kander, 2002; Krausmann and Haberl, 2002; Schandl and Schulz, 2002; Krausmann et al., 2008c): During a comparatively short period of two to three decades, GDP, material and energy throughput multiplied and a new type of social metabolism emerged. In contrast to the 19th century when population growth determined the pattern, growth in this period was driven by per capita growth and led to a completely new level of per capita income and energy use. Christian Pfister refers to this period of socio-ecological restructuring as 1950s Syndrome (Pfister, 1995). The particular dynamic of growth has been attributed to a transition towards a society of mass production and consumption and was facilitated by new, petroleum and electricity based technologies, declining energy prices and massive political efforts (Grübler, 1998; Krausmann et al., 2008c). Czechoslovakia followed this basic pattern in many ways. It seems that the surge in energy use, the industrialization of agriculture and the trends in land use were even more pronounced under the conditions of the planned economy than in Western Europe. Compared to Austria and the UK, where comparable data exist (Krausmann et al., 2008c) per capita

DEC grew at extremely high rates (2.4% per year) to a significantly higher level (see Table 5). While the first oil price shock in 1973 marks the beginning of a period of stabilization in DEC in many countries (Haberl et al., 2006), it hardly had any effect on the Czechoslovak economy. The system of low price oil transfers within the Comecon countries prevailed even after 1973 (Bideleux and Jeffries, 2007; Sirucek, 2007) and Czechoslovak oil imports and DEC continued to grow at a high rate until 1979 (Figures 4b and c). Only the period after the second oil price shock in 1979 was characterized by a stabilization of DEC at a very high level, and a modest decline after 1985. The immoderate energy throughput may partly be attributed to the specialised role of the Czechoslovak economy as a centre for heavy industry within the Comecon, but in its later phase it is also related to over industrialization, a lag in technological development and obsolescing industrial facilities. Although the Czechoslovak economy grew at high annual rates, GDP not even nearly reached the level of Western European economies such as Austria or the UK. In contrast to Austria or the UK, Czechoslovakia's energy intensity (unit of DEC per unit of GDP) did not decline substantially during this period. In 1989, immediately before the regime change, it was 2.7 times higher than in Austria or the UK (Table 5).

1989-2000: the Velvet Revolution and its impact on the biophysical economy

The end of communism was accompanied by dramatic changes in Czechoslovakia's economy (Scasny et al., 2003) which are in its economic and physical dimensions only comparable to the economic crises of the 1930s (see Table 3). The period 1989 to 1993 saw a massive decline in GDP in absolute terms and per capita (-18%). The shift from a planned to a market economy was related to temporary recession and massive restructuring of the economy: With the collapse of the Soviet Union the major trading partner vanished and Czechoslovakia had to adapt to new export markets. High volumes of industrial and agricultural production were reduced, inefficient production and allocation structures eliminated and industries restructured. The recession in the years after the Velvet Revolution and the subsequent economic restructuring resulted in a significant decline in energy consumption. DEC was diminished by almost one third during the 10 years following the Velvet Revolution (Figures 4b and 5b): Coal production slumped by 19% between 1989 and 1993, and also agricultural production declined significantly (Figure 4a). Primary energy supply shifted from domestic coal towards imported crude oil and natural gas, a shift which also helped to drastically reduce CO₂-emissions from 19 t/cap in 1989 to 12 t/cap in 2000 (Kuskova, 2004).

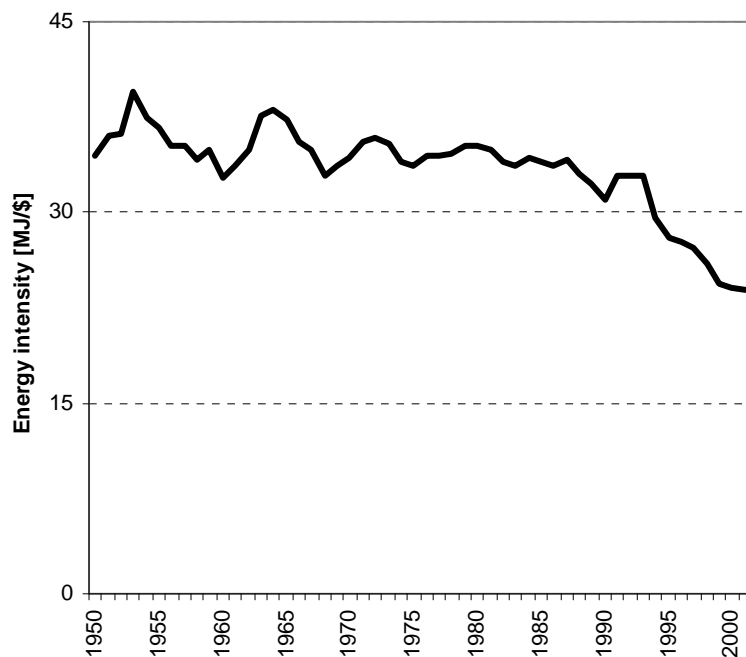


Figure 6. Energy intensity (DEC/GDP) in the Czechoslovak economy 1950 to 2002. Source: own calculations based on Domestic Energy Consumption (DEC) and Gross Domestic Product (GDP) in international Geary-Khamis-\$ from Maddison, 2003.

The changes in agricultural production, i.e. declining agricultural production and livestock numbers (Figures 1 and 3), reflect the end of high agricultural subsidies as they prevailed under communist rule (Bicik et al., 2001; Bicik et al., 2007). The privatisation of agriculture triggered a process of structural change. Large areas, especially grasslands were abandoned, agricultural production in general was de-intensified (Bicik & Jancak, 2007).

The aggregate effect of declining GDP and DEC was a significant reduction in the energy intensity of the Czechoslovak economy. The restructuring of the economy after 1989 accelerated a process of declining energy intensity which can be recognized as a general trend since the 1950s (Figure 6). In the years between 1989 and 2000 energy intensity declined by 25%, however, with 23 MJ/\$ energy intensity was still twice as high as in Austria or the UK (Table 5b; Krausmann et al., 2008c). Per capita DEC declined to a level of 200 GJ/cap, very similar to that of other industrialized economies (see Table 5b).

A similar development as in Czechoslovakia's energy system has been observed for material flows. According to material flow accounts which have been compiled for the Czech Republic (Scasny et al., 2003), domestic material consumption (DMC) declined by 40% during the five years after the velvet revolution. Since then, DMC remained stable since at a level very similar to those of Austria and the EU15 average (ca. 17 t/cap, Weisz et al., 2006).

Summary and conclusions

During the 170 year period investigated in this paper, Czechia/Czechoslovakia went through a fundamental transition process which resulted in a new size and pattern of social metabolism. The observed development resembles some of the key characteristics of the socio-metabolic transition process during which the exploitation of fossil fuels allowed to abrogate traditional limits of growth related to a land based controlled solar energy system of the agrarian metabolic regime (Sieferle et al., 2006; Krausmann et al., 2008c). We discern two distinct phases of this transition in Czechia/Czechoslovakia, each characterised by specific patterns of change of both the agricultural production system and the energy system. (1) The take-off of industrialisation in the “long 19th century” under Austro-Hungarian rule when the exploitation of coal deposits began to boost energy use. This period saw considerable population growth and an intensification of the traditional land use system. Increases in DEC were met by a growing population and energy use per capita grew only modestly. This development is very similar to what has been observed for other lands of the Habsburg Empire and other late coming economies (e.g. Krausmann and Haberl 2007). (2) The period of rapid industrialization and growth in per capita energy use during the communist era. In contrast to Western European countries coal remained the most significant energy carrier for a long time but increasingly imported crude oil and natural gas changed the energy system and boosted agricultural production. The Velvet Revolution and the subsequent turn towards a market economy in the last decade of the 20th century constituted a turning point which resulted in structural adaptations and an acceleration of already ongoing changes in the energy system: The economic restructuring adapted the energy system and the size and structure of social metabolism to typical Western European patterns (cf. Scasny et al. 2003). Despite fundamental institutional and political differences, the path of the metabolic transition in Czechia/Czechoslovakia appears very similar to that observed in Western European economies and resulted in a comparable metabolic profile (cf. Haberl et al., 2006; Krausmann et al., 2008c).

In the case of Czechia/Czechoslovakia radical political change had only limited effect on the overall socio-ecological pattern. Even very different institutional and economic settings compared to Western European economies led to similar general patterns of material growth. Although the development over time saw a number of periods of severe disruption and dramatic changes in the general economic-political conditions it seems that the biophysical impact of these events remained of limited significance. World War I, the Economic Crisis, WWII and the Velvet Revolution all had dramatic short term impacts on GDP and DEC but after a short period of time growth prevailed again, often at a faster pace than before. Surprisingly, the relative impact of the Velvet Revolution on biophysical parameters was the most significant disruption during the whole time period. The remarkable similarity in the pathway of the metabolic transition and the resulting metabolic profile support the hypothesis that industrialisation constitutes a very general socio-metabolic transition pattern (Krausmann et al., 2008b; Fischer-Kowalski and Haberl, 2007).

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