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Long-Term industrial Transformation

A Comparative Study on the development of Social Metabolism and Land Use in Austria and the United Kingdom 1830-2000

Final Report of a Study Commissioned by the Breuninger Foundation

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Introduction

In the present work, two empirical studies on long-term development of land use, social energy systems and material flows – one for Austria and one for the United Kingdom – are comparatively evaluated and analysed. Our aim is to offer a further building block for a bio-physical perspective of the transformation processes in moving from an agrarian-based society to a modern industrial society and to present the fundamental changes in the society / nature relationship that are associated with such processes. One concentration within this study is on the observation of the development of an agricultural production system, which can be considered *the* central element in the pre-industrial energy system, which experienced a tremendous structural and functional transformation in the course of the industrial revolution (Martinez-Alier 1987; Sieferle 1997; Sieferle 2001b). Building on that, we focus on the transformation of the social energy system, i.e. the conversion of the pre-industrial solar energy system, into an energy system based on fossil fuel carriers. The description of this transformation process rests on a sound, empirical database that corresponds with the latest methodological standards of environmental reporting (Daniels and Moore 2001; Eurostat 2002; Haberl 2001a; Haberl 2001b; Schandl et al. 2002).

Among other things, this study aims to contribute to an environmental-historical expansion of the classical economical-historical perspective of the Industrial Revolution. Although physical aspects such as energy use, land use, agrarian production etc., play an important role in economic-historical perspectives, argumentation tends to refer only to (key) individual indicators often considered in isolation. These indicators serve to illustrate the natural (resource-economic) framework conditions of economic development and structure (Cipolla 1985; Maddison 1982; Sandgruber 1995). What is new, however, is a systematic description – conceptually and methodologically sound – of industrial modernisation as a transformation process of the society / nature relationship. In this context, the present work can be seen as a contribution to an ecologically based environmental history (cf. Winiwarter 2001).

The empirical basis for this comparative study is presented by data that has been published on social metabolism in Austria and the United Kingdom. The foundation for this pool of data was created by two studies, which were carried out by the authors of the present work in the framework of the research program *Der Europäische Sonderweg* (Europe's Special Course) through the foundation Breuninger Stiftung GmbH[1] (Krausmann 2001; Schandl and Schulz 2001). Building from these data pools, we were able to carry out a comparative analysis of

[1]See: (Sieferle 2001a), http://www.breuninger-stiftung.de/

selected aspects of the development of the *physical economies* of Austria and the United Kingdom.

The works that we use as a base, however, have different concentrations. In his study of Austria, Krausmann (2001) focussed on land use and biomass production as well as the energetic aspect of social metabolism. In their study of the United Kingdom, Schandl and Schulz (2001) dealt with social metabolism as a whole. The comparative evaluation is thus necessarily dedicated to those areas covered by both previous studies – the energetic aspect of social metabolism and the correlation of land use to biomass production.

Our comparative analysis thereby concentrates on an important aspect of the transformation of the social relationship to nature, without representing it in its entirety. We therefore do not provide a comprehensive picture of the material aspect of metabolism and also disregard the question of the social use of time. Although conceptual considerations of an integrated survey of the social relationship to nature are relatively well developed (Giampietro and Mayumi 2000; Schandl and Schulz 2002b), databases for a comparative analysis are missing at present.

Methods and Databases

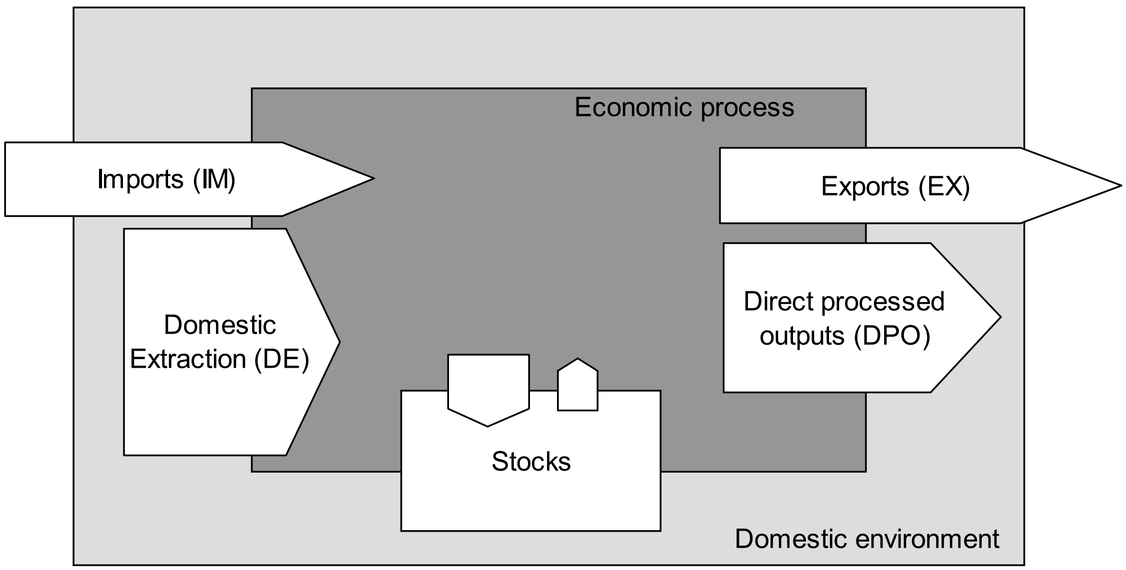
Social metabolism

The present comparative study is based on the concept of *social metabolism* and the methods of material and energy flow analysis (Ayres and Simonis 1994; Fischer-Kowalski and Haberl 1997). Underlying this concept is the basic assumption that societies are based on permanent throughput of matter and energy in order to build and maintain their biophysical structures (i.e., the population itself, livestock, and all artefacts such as buildings, transport infrastructure, production stock and durable goods). This physical dimension of socio-economic systems is described as social metabolism. Social metabolism is mediated, regulated, and controlled within the framework of the labour process.

The methods of material and energy flow analysis (MEFA) are able to describe and quantify consumption of resources in a systematically consistent way; changes in social supplies (stocks); the production of goods; and waste and emissions (Schandl et al. 2002). Figure 1 shows a general diagram of the system's basic borders, parameters, and indicators of material and energy flow analysis.

In view of the set borders of the system, the MEFA method is conceived in such a way that the physical indicators and parameters can be consistently linked with other socio-economic parameters, especially those of the national economy (GDP) (IMF et al. 1994) (Eurostat 2001). All methodological details of material and energy flow analysis as well as the special methodological requirements of historical approaches have already been thoroughly discussed elsewhere. On the MEFA method, see Ayres and Ayres (1998) Eurostat (2001), Fischer-Kowalski et al. (1997), Haberl (2001b), Haberl (2001a), Krausmann (2001), Schandl et al. (2002), Schandl and Schulz (2001).

Fig. 1: System borders, parameters, and indicators of material and energy flow analysis (MEFA)



This study focuses on the following main indicators derived from Material and Energy Flow Analysis (MEFA):

DMI/DIE......... Direct Material resp. Energy Input = Domestic Extraction (DE) + Imports (IM)

DMC/DEC....... Domestic Material- resp. Energyconsumption = DMI (DEC) – Exports

PTB............. Physical Tradebalance = Exports - Imports

Databases

For the comparative analysis, we refer to data that has already been published. For a detailed presentation of the primary data and its sources, please refer to the corresponding sources. The base data on the development of energy use, foreign trade, land use and agricultural production for the United Kingdom derives from Schandl and Schulz (2000), Schandl and Schulz (2001), Schandl and Schulz (2002a) and Schandl and Schulz (2002b).

For Austria, we rely on the detailed data on land use, social biomass metabolism and the social energy systems from Krausmann (2001) and Krausmann and Haberl (2002). Since the analysis of social energy systems in Krausmann and Haberl (2002) is limited to 11 data sets between 1830 and 1995, this data is expanded by a detailed energy flow analysis based on annual data. In addition, the existing annual data available from Krausmann (2002) on domestic extraction (DE, see figure 1) of biomass was consistently supplemented with data on the extraction and foreign trade of fossil fuel carriers and electricity as well as the foreign trade of biomass[2].

For the United Kingdom, the *Statistical Abstract for the United Kingdom* provides annual data after 1840 and comprehensive data after 1854. Mitchell's 1994 comprehensive data compendium *British Historical Statistics* presents a good summary. However, this data consistently adheres to the logic and focus of an economic-historical view; monetary flows are given priority over physical flows in the reports. Monetarily less important flows, which can be very relevant bio-physically, are often underrepresented or not represented at all. The biophysical data available in the framework of the statistical report also had to be adapted to the methodological guidelines for computing the material and energy flow calculation, which led to the restructuring and recalculation of the original data. A very detailed description of the data availability and data quality as well as the necessary data adaptations for the United Kingdom can be found in Schandl and Schulz, 2001a.

For Austria, all data clusters and indicators after 1910, or 1920, are based on statistical data broken down into years. Land use and domestic extractions of agricultural biomass for the year 1830 and the period from 1875 until 1910 are based on 5-year increments and linear interpolation is used for the intermediate years. For the domestic extraction of coal, statistical data is available in annual increments as of 1830. The lumber yield in 1830 and 1910 was reconstructed based on extensive data research during the years 1830 and 1870, 1900 and 1910, and interpolated for the intermediary years (c.f. Krausmann (2001)). Data on the foreign trade of coal in the 19th century was estimated from informational in the literature. For biomass, no foreign trade data was available for the 19th century. For further details on the statistical sources and the modelling of certain data pools (i.e. grazed biomass), see Krausmann (2001).

For the United Kingdom, it was possible to depict the entire period from 1854-2000 in yearly increments.

[2] Sources and data in the appendix

Data clusters

A fundamental technical-methodological requirement in a comparative analysis of the data pools was the selection and formation of suitable and consistent data clusters and derived indicators. The aggregation of material and energy flows resulted in the following main units:

The primary data from the official statistics is contained in *tons of fresh weight* (weight at the time of the harvest or extraction; weight at the time of import). Since we are primarily concerned with a study of the energetic aspects that are concentrated in social metabolism, in this work we report the cluster data primarily in *joules*. In contrast to the official energy statistics, which normally use heat (joules) or equivalent units (coal units; heating oil units), energy flow analysis requires a conversion of weight into calorific values (Haberl 2001a). Calorific values are 5-10 % above the corresponding heat values. Detailed information on calorific values can be found in Krausmann (2001), Krausmann and Haberl (2002), Schandl et al. (2002).

For certain subject areas (i.e. the analysis of nutritional systems), data was aggregated by grain units. This unit, common in economic statistics, refers to the food and fodder value of agricultural products (see Wagenführ (1970). The conversion uses the conversion table from the German statistical yearbook, *Deutsches Statistisches Jahrbuch*, for nutrition, agriculture and forestry (Bundesministerium für Ernährung 1992). The factors for the conversion of animal products into grain units do not refer to the immediate nutritional value of the product itself, but to the amount of fodder required for the production of the product. This differentiation is especially significant in the discussion of the significance of food imports as compared to the domestic food production. For further details on the data clusters and the conversion tables used, see Schandl et al. (2002), Krausmann (2001) and Schandl and Schulz (2001).

Generally speaking, a comparison also requires that the applied methods be tested again for consistency and defining aggregates in a way in which both data sets can be aggregated.

Along with data on the material and energy use, data on population developments and economic production (GDP) has been included for comparison purposes and for building indicators. For population data for Austria, see Butschek (1998) and Statistik Austria (2002); for the United Kingdom see Mitchell (1988). This work uses international comparative data compiled by Angus Maddison (Maddison 1995; Maddison 2001) for the GDP and the population.

General Description of the Study Systems

The territorial expansion of the study systems: system parameters

One of the first problems to be encountered in empirical studies of countries carried out over long periods of time is changing borders of territorial systems and the resulting discrepancies in historical comparisons. This applies to a lesser extent to the United Kingdom, and to a greater extent to Austria.

The United Kingdom, and our understanding of it in the context of this work, includes England, Scotland and Wales and, up to 1922, today's Republic of Ireland. With Ireland's secession in 1922, the territory of the United Kingdom was reduced by 23% and the population by ca. 6%. Accordingly, the average population density rose markedly, from 144 to 183 persons/km^2 (see Table 2). Ireland's secession had scarcely any effect on the area of agricultural land available per capita (c.f. Fig. 15), but very probably affected the pasture area. Before Ireland's secession, there were approximately 0.39 ha of pasture land available per capita. This value decreased between 1922 and 1923 by approximately 30% or 0.29 ha per person, as well as the number of cattle (about a 35% absolute decline). Energy consumption (absolute and per capita) changed only minimally through Irish secession, due to the limited degree of industrialisation and coal mining; the change remains within the annual deviation. This shows that the socio-economic consequences of Irish secession could be seen as negligible, and that the primary loss was of extensive surface areas.

For Austria, the question of regional status is more significant due to several dramatic changes during the study period. In 1867, the Austrian monarchy, with a total area of ca. 300,000 km^2 and a population of ca. 20 million, concluded a conciliatory agreement with Hungary and thus became a double monarchy (the *Austro-Hungarian Monarchy*) with common currency and tariffs, a total area of 670,000 km^2 and a population of 35.8 million. The "Austrian" sector of the double monarchy (the former Austrian monarchy) with the official title *die im Reichsrathe vertretenen Königreiche und Länder* (the kingdoms and provinces represented in the national parliament) is often referred to in the economic-historical literature as *Cisleithan* (Gross 1985). This double monarchy lasted until the end of World War I after which, in 1919, the treaty of St. Germain created the *Republik Österreich* (German-speaking Austria) with its current borders – an area of 83,800 km^2 and a population of 6.5 million. Analysed in terms of its political borders, the year 1918 in Austria would mark a system implosion and could be viewed according to its biophysical consequences. However, we did not choose this approach in this work.

All data used here in the comparative analysis (and with it the designation *Österreich, Austria, AUT*) refer to Austria with its current borders, or those in place since 1919 (with gaps in the data between 1938 and 1945). The data for the time frame from 1830 to 1919 includes a relatively small segment of the Habsburg Monarchy; the (German-Austrian) crownlands that comprised the Austrian Republic after World War I. These so-called Danube and alpine lands of the Habsburg Monarchy are the individual crownlands: Upper Austria, Lower Austria including Vienna, Carinthia, Salzburg, Styria, North Tyrol and Vorarlberg (cf. Sandgruber 1982). With this, the study system, even before 1918, deviates only minimally from the territory of the current state of Austria (for more details, see Krausmann 2001).

Drawing the system parameters in this way is widely represented in the economic-historical literature on the industrialisation of Austria, and much of the socio-economic data for the 19th century exists explicitly for the system described here as Austria (Butschek 1998; Sandgruber 1978a; Sandgruber 1978b; Sandgruber 1982). This approach produces a degree of continuity in the development of the study system, and allows for the avoidance of statistical leaps by a factor of 3-5, which would limit the ability to make time-based comparisons. Furthermore, the average per capita values for the natural area are not very telling due to the Habsburg Monarchy's extreme heterogeneity in terms of economic development (Matis 1987; Matis and Bachinger 1973). However, the informational value is also somewhat limited by the fact that Austria with its present borders was a part of the economic sphere of the Habsburg Monarchy until 1918 and in this sense cannot be seen as an independent socio-economic system. For that type of study, ideally, data would be considered for a territorially as well as economically continuous system. An extension of the study to the entire Habsburg Monarchy for the period between 1800 and 1918 (Krausmann et al. 2003) is planned for a future work.

Today's Austria in the context of the monarchy

Viewed as a whole, the 300,000 km^2 Habsburg Monarchy was distinguished by extreme spatial heterogeneity, both in terms of the natural design of the area and the economic and social development. Per capita income varied by a factor of 3 to 4 from the southeastern provinces of the monarchy, which included the least advanced regions of Europe, to the most advanced provinces of Lower Austria and Bohemia (Eigner 1997).

At the beginning of the 19th century, what is today's Austria encompassed approximately 25% of the population and about 30% of the total area, but only 12% of the agriculturally productive land of Cisleithan. Until 1850 more than 20% of the monarchy's coal and about three quarters of its pig iron production was done in today's Austria. In the 1840s, a total of 35% of Cisleithan's industrial production was carried out in today's Austria, 60% of this was done in Vienna and Lower Austria alone (Eigner 1997). However, in the early 19th century, the industrially advanced Danube and alpine lands[3] lost their leading role and, between the years 1841-1913, heavy industry and textiles pushed northward (above all into the Sudeten lands). One of the crucial reasons for this decline was the hesitation to assume modern English technologies. Both the richness in lumber as well as the lack of coal[4] in Austria stood in the way of a timely modernisation of Austrian heavy industry (Eigner 1997; Paulinyi 1974). In 1850, even in the capital city of Vienna, only about 10% of primary energy consumption[5] was covered by coal; in 1870 it was about 70% and in 1890 about 90% (Krausmann 2003a).

Agricultural modernisation was similarly heterogeneous. An intensification of agriculture was experienced in the 19th century, above all in the Sudeten lands, which were dominated by large estate ownership and commercial production. In contrast, agriculture in the Danube and alpine lands, was distinguished by predominantly rural structures with a high degree of self-managed operations often linked to secondary trades. Agrarian modernisation, i.e. the introduction of rotation crops, the reduction of fallow land and the year-round keeping of livestock in stalls took place for today's Austria in the 19th century at a comparatively slow pace (Hoffmann 1978). Only in the regions surrounding Vienna did a certain intensification and market production (especially horticulture) take place. The supply for the city – whose population rose fivefold between the years 1850 and 1910 to over 2 million – came primarily from the neighbouring areas of Bohemia and Hungary.

In 1918, Austria was torn from the monarchy's integrated and highly labour-divided economic realm. The newly created Austrian Republic contained 22% of the population, about 30% of the total area and 3/% of the net product of Cisleithan. The food and energy-economic basis for the new states was very narrow. Only half of the demand for agricultural products was covered by domestic production (Grossendorfer 1979). The situation for coal supply was even more dramatic: after World War I, only about 20-30% of coal consumption (measured in combustion values) came from domestic mining, which had already begun to sink dramatically. Before the war, the Austrian Republic had been a part of an extensively self-sufficient economic area, integrated into its internal infrastructure supplies. After 1918, energy carriers and food supplies had to be imported, with somewhat prohibitive trade restrictions in the remaining successor states. According to Bachinger et al. (1987), the interwar period was

[3] The traditional industrial provinces of the monarchy included, for example, Vienna and the Vienna basin (textiles and iron industries), Upper Styria (heavy industry), Vorarlberg (textiles).

[4] Austria has almost exclusively brown coal reserves. Brown coal has a significantly lower combustion value than black coal and is only poorly suited for industrial uses (especially iron smelting).

[5] Here, in the sense of energy flow analysis, primary energy consumption also includes the food supply for humans and animals.

characterised by a severe slump in growth and an unmistakable process of re-agriculturalisation. The industrialisation process experienced a sharp interruption, and the new situation forced a transformation in the industrial structure.

The economic development of Austria, the Habsburg Monarchy and the United Kingdom in the 19th century

The United Kingdom

In 1850, the United Kingdom was the most affluent and influential national economy in the world. The average income was higher than in any other country and most commodities were transported on British ships. British foreign investments were greater than those of all other countries combined (Floud 1999). The United Kingdom was the model for early industrialisation and poses a counter example to Austria's delayed industrialisation.

Early industrialisation of the United Kingdom was founded on a few generally recognised factors, which as a whole demonstrate a link to the physical economy. The presence of local, high-quality iron ore and coal met with an economic structure that was able, due to the limited number of land-owning farmers, to utilise the work force according to new forms of production.

In 1750, the United Kingdom produced around 4 million tons of coal. Annual production grew exponentially until 1913 for a period of 160 years and reached a peak of 292 million tons. The volume of iron ore followed a similar course, although at a lower level, growing exponentially from 1750-1880, when a yearly extraction rate of 18 million tons was reached. During the entire period from 1870-1964, the yearly extraction rate was 15 million tons. However, after 1964 a sharp decline in production led to the eventual termination of iron ore production.

Population growth, which factors largely in biophysical approaches, led to low wages. Nevertheless, the middle class grew, creating a continuously increasing demand for domestic production and imported goods. Yet the increase in production could still not be fully absorbed by demand in the domestic market, which in turn boosted demand for export markets. This predisposed the United Kingdom to an opening of their economy, but also led to a dependency on the rest of the world (Adams 1982). Lutz (1989), among others, thus showed how extensively European economies were dependent on the functioning of export markets in the 19th century, since export crises could not be offset by domestic demand.

Thus, the United Kingdom was the first industrial economy forced to develop trade and foreign markets in order to avoid the stagnation of economic development. In the early 19th century, the 'Corn Laws' guaranteed that most food supplies would be the products of domestic agriculture. After 1840, the United Kingdom began to gradually lift import and export restrictions and pressured other nations to follow suit.

In 1850, biomass revenue (yield of farmland and lumber) was 69.6 million tons, around of which merely 7% came from imports. Whereas the volume developed relatively steadily (from 1875-1918 volume was around 100 million tons; from 1924-2000 about 80 million tons), the import quota increased steadily.

Table 1: Quantities of biomass imports compared to the total biomass revenue

	1850	1912	1918	1924	1938	1944	1956	1977	2000
Imported biomass, in millions of tons	4.6	28.9	12.7	40.0	32.9	14.3	34.0	39.9	37.7
As % of total revenue	7%	31%	13%	38%	44%	19%	39%	42%	37%

Already in 1912, 31% of the total biomass (or 28.9 million tons) was imported. Imports fell dramatically during both World Wars, due to the transport blockades caused by the war and the expansion of domestic production area (the 'ploughing-up campaign'). Imports nevertheless recovered quickly after both wars and continued to grow. Since the 1950s, the United Kingdom has imported approx. 40% of its yearly requirement of biomass.

Before 1950, exports were insignificant in terms of volume. In 1950, only about 1.2 million tons of biomass were exported; in 1972 about 1.8 million tons. After the 1970s however, also the exports of biomass increased steadily, reaching a level of over 15 million tons in 1996.

In 1850, the United Kingdom took over the central role in the world economy, replacing Holland (Wallerstein 1998), and reached a peak in economic and political influence. The United Kingdom produced two thirds of the world's supply of coal, half of the iron, five sevenths of the world's (low-grade) steel and half of the cotton fabric, yet other economies such as America (the northern states), France, Germany and Belgium were catching up steadily. In 1890, the USA and Germany surpassed the United Kingdom in steel production, a central resource for industrialisation (Hobsbawm 1999).

Floud (1999) attributes the decline of the United Kingdom to a reduction in total productivity ('Total Factor Productivity') and the concentration on foreign investments, which led to a decline in investments in innovative domestic technology. Adams (1982) proposes an energy explanation for the loss of predominance, namely that the export of coal (energy) spurred on the industrialisation of the recipient countries to such a degree that in the end the United Kingdom was left behind.

In the 1980s, the United Kingdom experienced an unprecedented, politically induced phase of de-industrialisation, which was also reflected in the United Kingdom's metabolic profile (Schandl and Schulz 2002b). While current gross consumption of energy is consistent with European levels, the yearly material use is approximately 25% below other comparable European industrial nations (EUROSTAT 2003).

Austria

In the mid-18th century, the Habsburg Monarchy, with a national land area of ca. 300,000 km² and a population of ca. 9-10 million, was the third largest country in Europe and therefore, both in terms of area and population, comparable in size to the United Kingdom.

In the economic-historical literature, the Habsburg Monarchy could certainly be counted among the pioneers of 18th century early industrialisation (proto-industrialisation[6]), especially considering the iron and textile industry in the Danube and alpine lands (Eigner 1997; Gross 1968).

Unlike England and other European countries, however, the monarchy was not generally characterised by a "take off" or a discontinuous industrialisation, but rather by a gradual process of industrialisation (Eigner 1997; Gross 1985).

It was above all at the close of the 18th and beginning of the 19th centuries that the economic development remained clearly behind that of England and the other European countries. While the United Kingdom presents the prototype of an early and dynamic industrialisation process, the Habsburg Monarchy of the 19th century was described as having "relative economic backwardness" (cf. Eigner (1997), Gerschenkron (1977)). In 1869, more than two thirds of the labour force were still employed in agriculture (Bairoch 1985), whereas in the United Kingdom, as early as 1841 only one fourth were employed in agriculture (Mitchell 1988). Despite rapid industrialisation in the second half of the 19th century (especially between 1848 and 1873, cf. Eigner (1997) and Brusatti (1973)), until the end of the monarchy, a great portion of the work force and capital resources were involved in agriculture. It was first the

[6] It should be noted here that proto-industrialisation is a problematic teleological concept. Bin Wong, for example, showed that there were also analogous occurrences (home industry, etc.) in 18th century China, that did not lead to industrialisation. The problem that is actually of interest is concealed by this term: In the early 18th century, Austria was at a similar level in the development of commercial trades and probably also in society's metabolism as the United Kingdom. There, industrialisation was maintained, if not caused, by the transformation in society's metabolism. Austria was able to follow this example without having any significant fossil fuel resources, and convergence was achieved rapidly (something which China was not able to do). Here, once again, the question of the energy system and the socio-cultural conditions arises more intensely.

final decades of the monarchy that were characterised by an intensive modernisation process and the development to an industrialised agrarian state (Matis 1987). At the beginning of the 20th century, agriculture and forestry were still essential elements of the monarchy's economic structure and approximately half of the labour force worked in these sectors in 1900; yet in the area of present day Austria, this figure is significantly lower at just 39%.

Factors which hindered economic development included economic-political factors, the incomplete emancipation from feudal organisational structures, national heterogeneity and lack of capital and industrialists, but above all the unfavourable natural environmental conditions (Eigner 1997; Matis 1987; Matis and Bachinger 1973). Added to these latter elements were: the difficult conditions of the terrain (the Alps, Karsts and Carpathians); the lack of advantageous waterways or economically efficient east-west transport connections; its inland European location and the peripheral location of the only bordering high-sea port, Trieste, as a hindrance for foreign trade as a crucial component for original capital accumulation; and the extremely unfavourable regional expansion and convergence of the major raw materials for heavy industry.

Railway construction, which was intensified as of the 1850s – thus relatively late compared to the rest of Europe – is what first enabled an overcoming of the location-based heterogeneity of resource availability. Moreover, the railroad, which was tied together with considerable investments, became a significant impulse factor for the relatively late conformity to industrialisation as of 1850-1860.

The Austro-Hungarian Monarchy as a whole – as opposed to the United Kingdom – can be considered as extensively self-sufficient.[7] It remained underrepresented in world trade. In 1880 the Habsburg Monarchy had a 3.5% share of world trade and 7.2% of European trade whereas Great Britain had a share of 20% in world trade and 33% in European trade (Gross 1973).

Comparison of significant structural parameters for Austria and the United Kingdom

Table 2 shows a comparison of a series of significant structural parameters for Austria and the United Kingdom in the first half of the 19th century and in 1995. For one, the two study

[7] This can be explained, on the one hand, through the inland-Europe continental situation, and on the other through an economic politics that was long oriented on self-sufficiency through the Austro-Hungarian monarchy.

systems are found at different scale levels: in 1830 the United Kingdom is larger than Austria by a factor of 4 with respect to area and a factor of 9 with respect to population and therefore significantly more densely populated (see below). Furthermore, both systems differ strongly with respect to their natural environments and economic development.

Geographically, Austria is characterised by the Alps, which comprise nearly two thirds of the land mass. Land use in the sparsely populated alpine regions is determined by livestock farming in conjunction with pastures and in the climatically and geographic-morphologically favourable valleys,[8] home to the larger urban centres, land use is largely characterised by the growing of grain.

The island of Great Britain can be divided into the zones of highlands and lowlands. The highlands are characterised by nutrient-poor, stony soil and moor areas that are primarily used as extensive and pasture land. They comprise approximately a third of the area of Great Britain, of which a great portion is in Scotland, but also a part in Wales. England contains many different kinds of soils and land uses range from intensive pastoral land in the West to farmland agriculture in the East.

Ireland is characterised by a central area with a calcium-rich base layer surrounded by higher lying coastal stretches of various geological origin.

Due to the strong influence of the ocean and the resulting longer vegetation period (up to 300 days) and higher precipitation, the climatic conditions in the United Kingdom are more favourable than the strongly continental climate of Austria, with long and cold winters and lower precipitation.

In 1830, Austria was still extensively determined by an agrarian economy with about 75% of the total population sustained by agriculture, while the corresponding figure for the U.K. had sunk to only about 30% of the population.[9] Due to greater population density, only about half of the farmland was available per person (0.27 ha/person), as compared to Austria (0.6 ha/person), although the average area yield was almost double (100t/km^2 in Austria and 190t/km^2 in the U.K.).

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[8] These basins lie predominently in the provinces of Upper Austria, Lower Austria, Burgenland and Styria.

[9] The density of the farming population, relative to the sum of the agriculturally productive and forested land is of similar proportions: 34 personen/km^2 in Austria and 25 persons/km^2 in the United Kingdom. Applied to the most intensely used agricultural areas (i.e., farmland, gardens and commercially used pastures), in the U.K. this figure (36 persons/km^2) is only half that of Austria (71 persons/km^2).

In terms of energy resources, as compared to the U.K. Austria is equipped with a very high availability of lumber but limited coal resources. Per capita availability of forest area in Austria is more than twenty times greater than in the U.K., while the English output of coal (per person) was 150 times that of Austria in 1850 and in 1870 still 13 times that of Austria. Also industrial production was significantly higher in the U.K: in 1855 Austria produced approximately 33 kg of pig iron per person; the U.K. produced 116 kg per person. A further important indicator of economic development in the 19th century was the extent of the railroad development. Railway construction followed in Austria much later than in the U.K. In Austria, 7.4 m of rail per km^2 had been laid by 1850, whereas the UK already had 33.7 m/km^2.

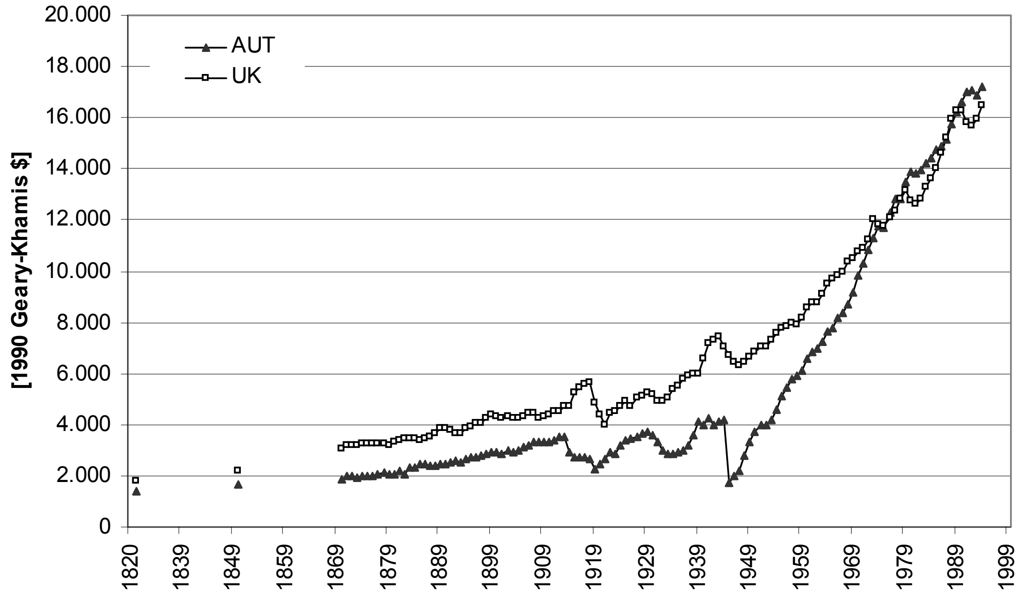
Relative backwardness in the industrialisation process was also mirrored by a significantly lower per capita income (GDP/person), which was $1,376/person in Austria and thus 25% under the GDP of the UK ($1,832/person). Figures 2 and 3 show the development of national production (GDP) in Austria (with its current borders) and the United Kingdom according to the calculation of the economist Angus Maddison (Maddison 1982). Data on the yearly growth rate of the GDP can be found in Table 4. According to this data, between 1850 and 1870 the U.K. economy grew significantly faster and the economic lead increased to about 40%. During the *Gründerzeit* (intense industrialisation period) (between 1860-1880) and into the early years of the 20th century, Austria showed high annual growth as compared to Europe as a whole (1.59% annually between 1880-1910) and the gap with the U.K. in per capita income decreased to about 20%. For the entire period between 1830 to 1910, interestingly, both countries show similar average annual growth rates of ca. 1.1% p.a. During both world wars, the Austrian economy showed a clearly strong slump. Between 1950 and 1980, the economy grew tremendously in both countries, with about 2.14% in the United Kingdom and in Austria even faster at 4.6% p.a.. For the first time in the mid-1970s, the Austrian domestic product surpassed that of the UK. The current GDP in Austria is about 10% higher than in the United Kingdom.

The sector-based composition of the GDP[10] in both countries is currently very similar (on a highly aggregated scale). In both countries agriculture comprises only a very small share of the GDP (2.5% in Austria and 1.8% in the UK). Industry including mining and the energy sector comprises 23% for Austria and ca. 26% for the UK and the building industry comprises 7.8% in Austria and 5% in the UK. Trade, services and the finance sector control the greatest part of the GDP with between 74% and 72% in both countries.

[10] GDP output approach according to (OECD 2002).

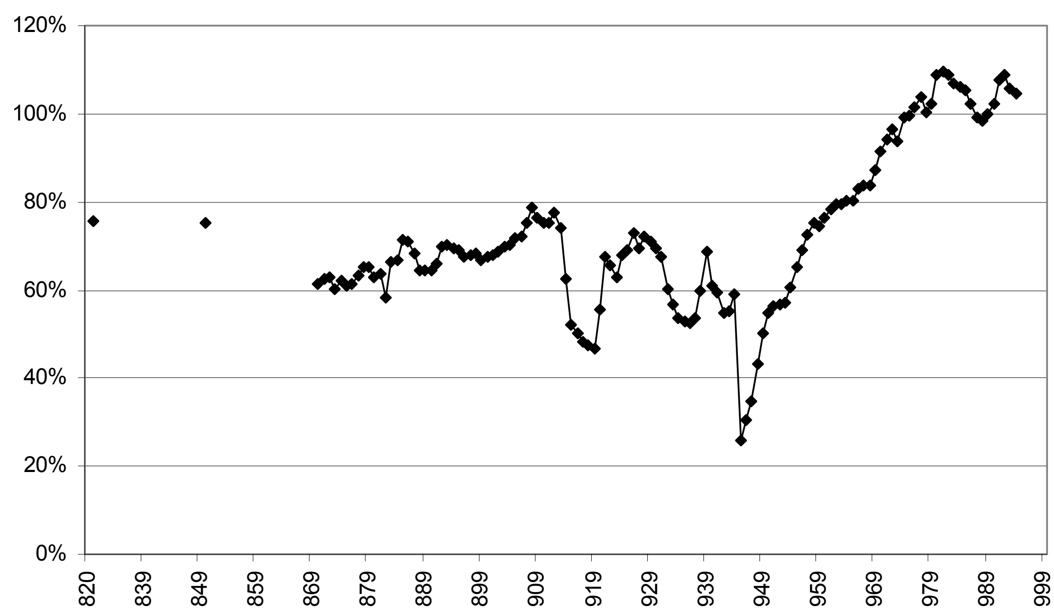
In view of the output of fossil fuels, the United Kingdom, one of the few oil exporting countries in Europe, is still currently ahead of Austria: In 1995 the UK produced about seven times as much coal and 110 times as much oil per person per year. Nonetheless, primary energy consumption is about the same in both countries at about 200 GJ per person. Interestingly, Austria today shows a significantly higher per capita production of pig iron (483 kg/person compared to 205 kg/person in the U.K.) and has a denser railway network (78 m/km^2 compared to 46 m/km^2 in the U.K.).

Fig. 2: Per capita development of the domestic product (GDP).



Source: Maddison 1995

Fig. 3: Comparison of per capita GDP in Austria and the United Kingdom (Austrian GDP as percentage of UK GDP)



Agriculture, although currently only a marginal economic sector in Austria as well as the U.K., has a relatively greater significance in Austria. The share of the labour force employed in agriculture is 4.5% (U.K: 2.5%); the segment of the GDP occupied by agriculture is considerably higher as is the per capita availability of farmland and forest area. The difference in the average land yields in the two countries has clearly decreased, although in the UK much more mineral nitrogen fertiliser per agricultural area is used (table 2).

Table 2: Comparative development of important structural parameters of the systems studied, Austria (AUT) and the United Kingdom (UK)

Parameters	[Unit]	AUT 1830[1]	UK 1830	AUT 1995	UK 1995
Surface Area	[km²]	85 906	314 672	83 858	240 860
Population	[1000]	3 592	32 814	8 080	59 009
Population Density	[Pers/km²]	41.8	104.3	96.4	245.0
Agriculture Population	[%]	75%	28%	4.5%	2.5%
Farmland	[ha/Pers]	0.6	0.27	0.19	0.11
Land Area, Average[2].	[t/km²]	100	190	550	670
Forest Area	[ha/Pers]	0.89	0.04	0.49	0.04
Coal Production	[t/Pers]	0.01	1.5	0.15	1.1
Oil Production	[t/Pers]			0.12	2.25
Iron Production	[kg/Pers]	33*	116*	483	205
Energy Consumption[3]	[TJ/Pers]	80**	140**	195	195
Railway Network	[m/km²]	7.4*	33.7*	78.7	46.3
GDP / Person	[US$/Pers	1 376	1 832	17 234	16 257
Mineral Fertiliser Use[4]	[kg N/ha]			49	126

[1]The data for AUT 1830 does not refer exactly to the current Republic of Austria. For details on the system borders of AUT 1830 see Krausmann (2001).
[2]Average gross yield of wheat, rye, barley, oats and corn
[3]Primary energy use according to EFA
[4]Average consumption of nitrogen commercial fertilizer per hectare of land used intensively for agriculture (i.e., without rough grazing and alpine pastures)

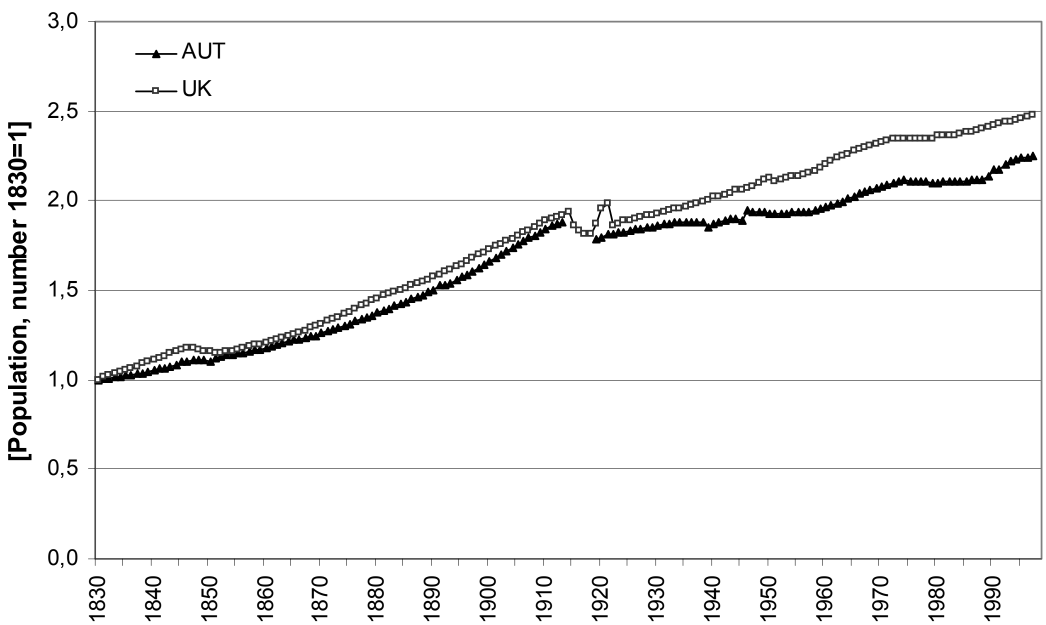
The following data does not refer to the years 1830:*1850; **1870.

Sources: Maddison 1995 (GDP); Statistisches Jahrbuch 2002 (pig iron production 1995)
Mineral fertilizer consumption: kg pure foods according to the data bank of the International Fertilizer Industry Association (http://www.fertilizer.org/ifa/statistics/IFADATA/dataline.asp) referring to the area used for intensive agriculture. Oil production according to Eurostat Annual Energy Review

Population growth and population density

Table 3 shows the development of population density and annual growth of the population in Austria and the United Kingdom and for comparison, in Cisleithan and Great Britain (see also figure 4).

Figure 4: Population development in Austria and the United Kingdom, 1830-2000. Indexed depiction, 1830=1.



In 1750, the population of the United Kingdom, with 10-11 million people, was comparable to the population of Cisleithan and four times the population of Austria. At this time, population density was nearly the same in Cisleithan, today's Austria, the United Kingdom and Great Britain and amounted to 32-34 persons per km^2. Until the mid-19th century, the population in the United Kingdom grew significantly faster at 1.06 % p.a. than in Austria (0.36% p.a.) which as of 1830 significantly raised the population density in Great Britain (76 persons/km^2) as compared to Austria (42 persons/km^2) and Cisleithan (52 persons/km^2). Thus, between 1830 and the outbreak of World War I, the populations in Austria, Cisleithan and the United Kingdom grew at very similar rates (ca. 0.8% p.a.). In 1913 population density in the United Kingdom reached 150 persons/km^2, yet in Austria only about half of this value (78 persons/km^2). Also in the 20th century, the population in the U.K. grew somewhat faster than in Austria. The current population in the U.K. is about 8 times greater than that of Austria and the population density is about 2.6 times greater.

Table 3: Population density and average annual growth rate for Austria with its current borders (AUT), Cisleithan (CL), Great Britain (GB) and the United Kingdom (UK).

	Population density				Annual growth rate		
	AUT	CL [pers/km²]	UK		AUT	CL [%]	UK
1754	32		34	1754-1786	0.27%		0.70%
1786	35	39	43	1786-1800	0.13%		0.72%
1800	36		51	1800-1830	0.53%		1.35%
1830	42	52	76	1830-1880	0.64%		0.75%
1880	58	74	110	1880-1911	0.97%		0.87%
1911	78	95	144	1911-1922	-0.23%		2.21%
1922	76		183	1922-1960	0.21%		0.46%
1960	82		217	1960-1995	0.38%		0.32%
1995	94		243	1754-1995	0.45%		0.82%
				1754-1830	0.36%		1.06%
				1830-1911	0,77%		0,79%
				1920-1995	0,29%		0,39%

Source on population density: for the U.K. according to Mitchell (1988), Mitchell (1995); for AUT based on Sandgruber (1978a), Statistik Austria (2002), Mitchell (1995). Density and growth rates based on own calculations.

Land use, the Agrarian System of Production and Biomass Metabolism

Agricultural and forestry biomass are crucially important for social metabolism as a basis for the food supply of people and work animals, as technical energy carriers for the creation of process heat and work and as raw materials. This applies to both pre-industrial as well as modern industrial societies.

Essentially, the following factors determine the quantitative and qualitative structure of the biomass metabolism of a socio-economic system. The agricultural production system and the domestic production of biomass are especially determined by natural environmental conditions (e.g. climate, soil relations, terrain morphology, and surface cover) and technology (i.e. land use systems and cultivation methods). Nonetheless, in the 19th century, international markets and trade also greatly influenced agricultural production. Domestic production of biomass and international trade together determine domestic consumption (DMC) and the total input of biomass (DMI) (see fig. 1). The significance and development of individual factors – especially in light of the population's food supply – should be seen in close conjunction with the development of the population and the density of the population (see Boserup (1965) and Netting (1993)). In the following, the development of biomass metabolism will be investigated, particularly with regard to agricultural biomass and agricultural production systems in the United Kingdom and in Austria.

Land use

Figure 5 shows the development of land use in Austria (5a) and in the United Kingdom (5b) according to the main classes of land use. In the 19th century, land use in the United Kingdom was marked by the far-reaching lack of forests and a very high percentage of commercial pastures and rough grazing lands, comprising approximately half of the entire surface area. In 1850, farming areas comprised 30% of the entire surface area, or 54% of the agriculturally productive area.[11] The share of agriculturally productive lands as a percentage of total surface area decreased significantly during the period investigated: from approximately 60% in the

[11] In the following, only the intensively agriculturally productive areas will be termed agriculturally productive areas, which means the sum of the fields (including permaculture) and commercial pastures. Rough grazing areas in the United Kingdom and mountain pastures in Austria are not counted among the areas that are (intensively) productive for agriculture, as these in part natural grasslands are only very extensively grazed.

mid-19th century to 47% in the late 20th century. Through concerted reforestation programs the share of forest increased from 3% in the 19th century to a current 11%.

Figure 5: Land use: distribution of farmland, pastures, extensive grasslands, forests and other areas across the total area of Austria (5a) and the United Kingdom (5b):

Figure 5a: Austria

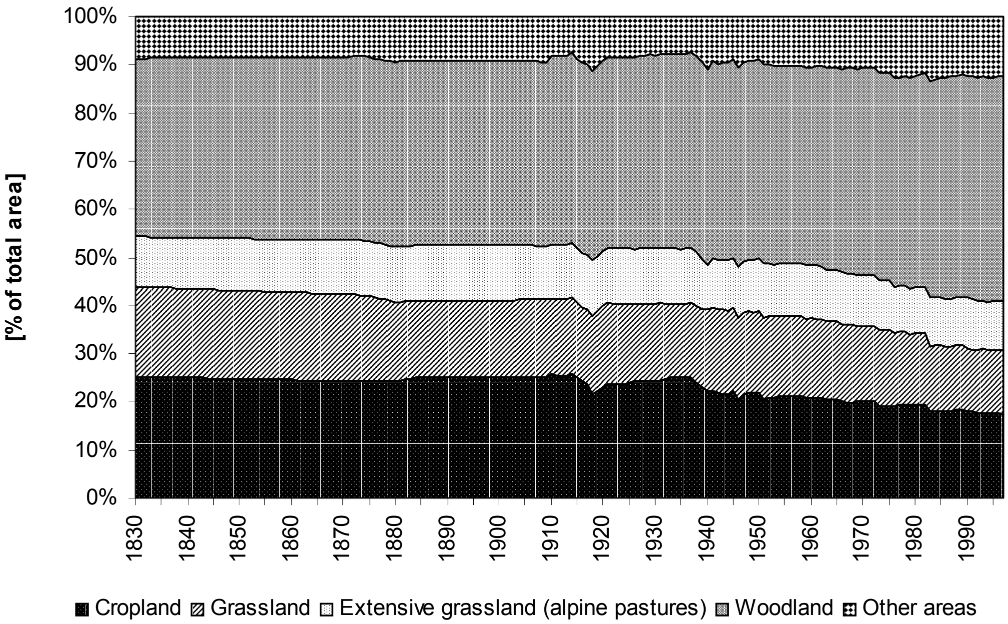


Figure 5b: United Kingdom

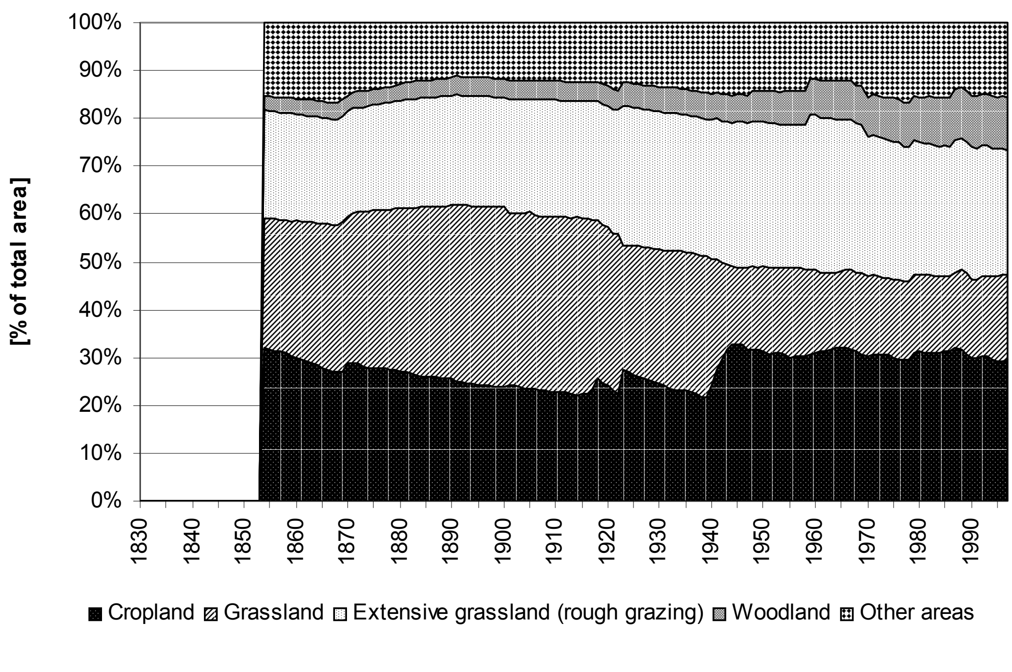


Table 4: Average annual growth rate of various parameters and indicators

	Population		Farmland		Grain harvests[1]		Grain yields[2]	
	AUT	UK	AUT	UK	AUT	UK	AUT	UK
1830/54-1880	0.64%	0.75%	-0.06%	-0.63%	-0.40%	-1.79%	0.32%	-0.30%
1880-1910	0.98%	0.87%	0.07%	-0.66%	-0.37%	-1.45%	0.47%	0.23%
1910-1920	-0.20%	0.07%	-1.14%	0.51%	-5.40%	0.93%	-2.46%	-0.49%
1920-1930	0.32%	0.17%	0.72%	-2.65%	6.24%	-4.20%	4.38%	0.94%
1930-1940	0.07%	0.45%	-0.73%	0.28%	-0.85%	2.02%	0.30%	0.54%
1940-1950	0.31%	0.48%	-0.60%	2.14%	-1.87%	1.70%	0.41%	1.15%
1950-1960	0.16%	0.40%	-0.26%	-0.19%	4.59%	2.30%	4.12%	2.59%
1960-1970	0.58%	0.56%	-0.44%	0.01%	3.82%	3.37%	3.87%	1.73%
1970-1980	0.12%	0.13%	-0.28%	-0.06%	3.28%	3.10%	2.33%	2.66%
1980-1990	0.26%	0.25%	-0.76%	-0.13%	0.75%	1.26%	2.29%	2.21%
1990-1995	0.72%	0.35%	-0.40%	-0.53%	-2.87%	-0.67%	0.26%	2.29%
1830-1910	0.77%	0.79%	-0.01%	-0.64%	-0.39%	-1.61%	0.38%	-0.01%
1910-1950	0.12%	0.29%	-0.44%	0.06%	-0.56%	0.08%	0.63%	0.53%
1950-1980	0.29%	0.36%	-0.33%	-0.08%	3.90%	2.92%	3.44%	2.33%
1980-1995	0.41%	0.29%	-0.64%	-0.26%	-0.47%	0.61%	1.61%	2.23%
1830-2000	0.48%	0.54%	-0.23%	-0.28%	0.35%	0.08%	1.14%	0.85%

Table 4: Continuation

	GDP per capita		Energy consumption /capita[3]		Energy efficiency[4]	
	AUT	UK	AUT	UK	AUT	UK
1830/54-1880	0.85%	1.21%	0.14%	1.30%	0.71%	-0.09%
1880-1910	1.59%	0.93%	0.45%	0.12%	1.08%	0.82%
1910-1920	-2.61%	0.55%	1.23%	-0.46%	7.04%	1.08%
1920-1930	2.94%	0.88%	2.37%	-0.34%	0.30%	1.17%
1930-1940	1.44%	2.65%	1.32%	0.41%	0.11%	2.22%
1940-1950	-1.13%	0.29%	-0.06%	0.78%	-1.04%	-0.46%
1950-1960	6.19%	2.19%	3.11%	1.08%	2.94%	1.10%
1960-1970	4.16%	2.45%	3.03%	1.66%	1.09%	0.78%
1970-1980	3.37%	1.79%	1.87%	-0.04%	1.49%	1.84%
1980-1990	1.98%	2.22%	0.15%	-0.26%	1.83%	2.48%
1990-1995	n.D.	n.D.	-0.05%	0.04%	n.D.	n.D.
1830-1910	1.13%	1.11%	0.26%	0.86%	0.85%	0.25%
1910-1950	0.14%	1.09%	1.21%	0.09%	1.55%	1.00%
1950-1980	4.57%	2.14%	2.67%	0.89%	1.84%	1.24%
1980-1995	n.D.	n.D.	0.08%	-0.16%	n.D.	n.D.
1830-2000	1.55%	1.35%	0.58%	0.59%	0.97%	0.78%

[1]Total grain harvests [tons]
[2]Grain yields per surface area unit [t/ha]
[3]Total primary energy consumption [GJ per capita]
[4]Primary energy consumption per unit GDP [GJ/US$]

In contrast to the United Kingdom, Austria is very rich in forests. In 1830, the portion of forest was approximately 37% and has since markedly increased to approximately 47% by 2000. In contrast, the portion of agriculturally productive areas (see footnote 11) decreased by nearly one third from 44% in 1830 to approximately 31% in present day Austria. Of significant importance for the agriculture in the alpine regions are the extended mountain pastures, which present 10% of the total surface area.

Table 4 shows the average yearly rate of transformation of farmland. Whereas the farmlands in the U.K. were transformed from cultivation to commercial pastures primarily in the 19th century at yearly rates from 0.6-0.7% (between 1854-1910), in Austria, the portion of cultivated lands remained steady to a great extent between 1830-1910. In the 20th century, however, Austria followed suit in this respect. After World War II, the yearly rate of transformation of farmland was between –0.33% (1950-1980) and –0.64% (1980-1995), whereas in the U.K. there was no major visible change over broad stretches of time. The average rate of transformation of farmland in the U.K. was –0.08% p.a. (1950-1980) and it was first in 1980 that the amount of farmland began to decrease sharply (0.28% p.a.).

The period between 1910 and 1950 forms a turbulent exception in the otherwise comparatively steady development of land use in which the United Kingdom and Austria display in part contrary patterns of development. In Austria, due to the war-related lack of an agricultural work force and the destruction of agricultural areas, the share of agriculturally productive areas clearly dropped during the war years. In the U.K., however, during both World Wars the heavy reliance on food imports led to an expansion of the area of farmed land (*ploughing up*) in order to increase the degree of self-sufficiency with foodstuffs (see below). Between 1910 and 1920 the farmland in the U.K. grew at an average annual growth rate of 0.51% and between 1940 and 1950 at 2.14%, whereas in Austria during these time periods, annual loss was 1.14% and 0.6%, respectively.

Figure 6: Use of farmlands: share of grains, root crops, fodder, oil seeds, other arable crops, and fallow lands, as percentages of the total surface area of farmlands in Austria (6a) and in the United Kingdom (6b)

Figure 6a: Austria

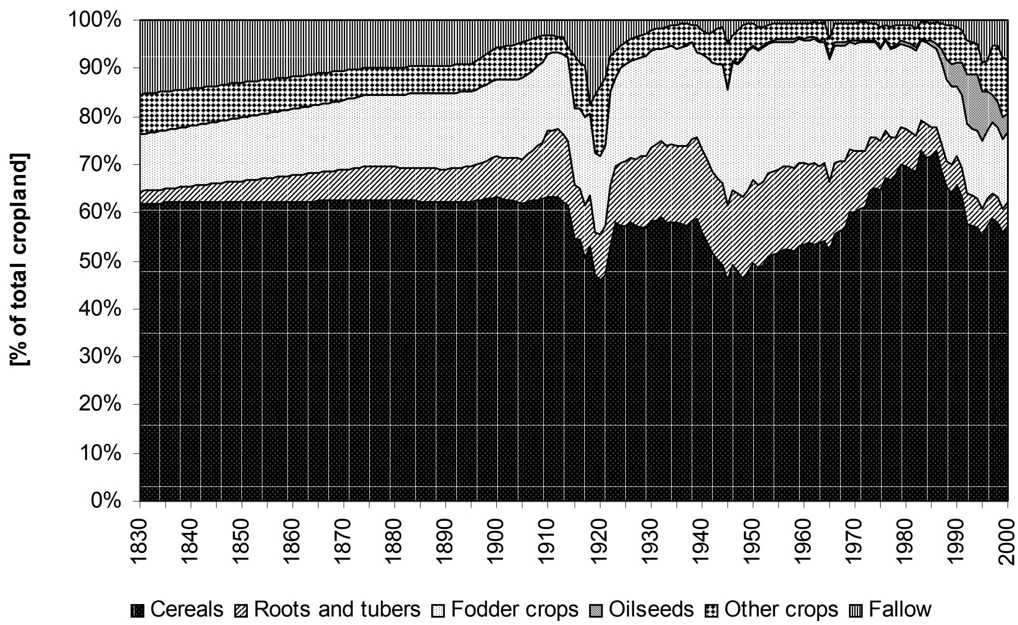


Figure 6b: United Kingdom

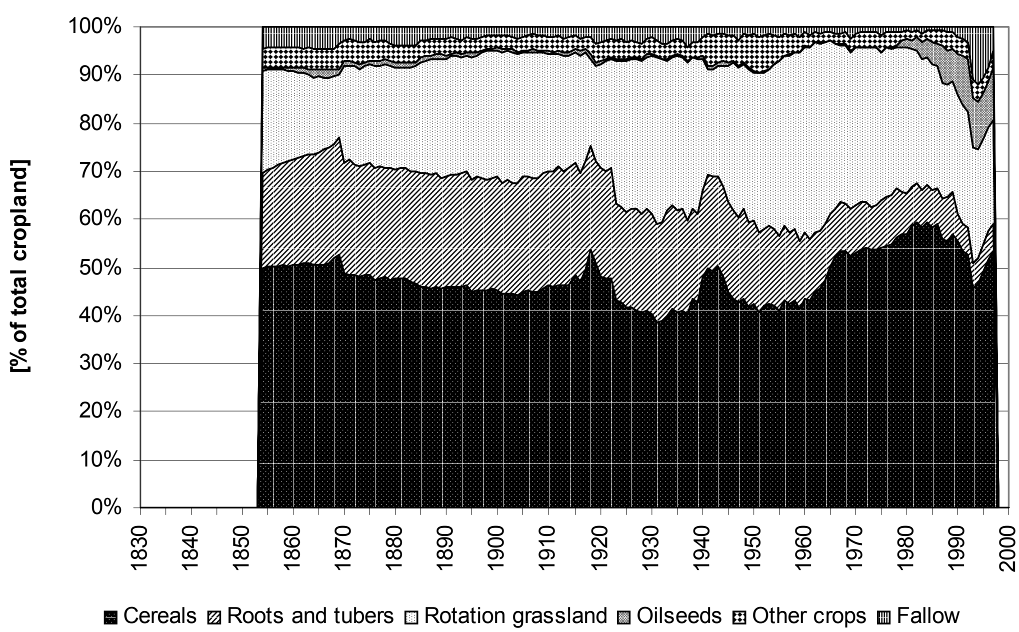


Figure 6 shows the development of the organisation of farmland in Austria (6a) and in the United Kingdom (6b). In the U.K., as early as 1850, crop rotation (mainly the so-called *Norfolk crop-rotation*[12]) was practised throughout the entire area of farmlands. The share of fallow land diminished to approximately 5%. Nearly half of the farmland was planted with grains (mainly barley and wheat) and 20% with root crops. A further 20% of the farmlands (with a strongly growing trend) were planted with so-called *rotation grasses*, a mixture of various types of grasses and legumes. Whereas the planting of grains and root crops showed a decreasing tendency until into the 20th century, the planting area of rotation grasses clearly expanded. It was first after World War II that the planting of grains once again increased at the expense of root crops and pasture areas.

In Austria, at the beginning of the 19th century a major share of the farmed areas was laid out in a *three-field system*.[13] Around 1830, the share of fallow lands was still 20%. By the beginning of the 20th century, the share of fallow land was continually reduced to less than 5% through the planting of clover and root crops. Contrary to England, the area devoted to grain crops remained constant at about 60%, an upper limit under pre-industrial conditions due to the rotating crops. In connection with the war, the growing of grains was reduced at the expense of the higher yielding planting of root crops. Following World War II, it was first in the 1980s that the surface area used for growing grains was expanded to more than 70% of the farmlands.

Since 1985, grave transformations have been evident in both countries' spectrums of planted arable crops (see figures 6a and 6b). In order to lower agricultural subsidies, which have been on the rise and are associated with expensive export supports, grain growing has been reduced and the planting of so-called production alternatives along with the expansion of uncultivated areas has been supported through targeted agricultural policies. In Austria, between 1985 and 1995 the share of grain growing areas was reduced from 71% to 55%, the share of oil and protein plants has been increased in farming areas by 5% to 16%, and the share of fallow lands has been extended from 1% to 9%. The development in the U.K. was similar: Reduction of the

[12] The Norfolk 'four course system' emphasised the planting of fodder plants and is innovative in that there is no fallow period. In this novel system, in the first year wheat is planted, in the second year turnips, followed by barley which are sown along with clover and rye grass. The clover and rye grass are then cut or grazed in the fourth year, and the turnips are used as winter fodder for cattle or sheep. The novel system combined cumulative effects: the fodder plants allowed for the production of greater quantities of fertilizer, which was richer, because the animals were fed better.

[13] The classical three-field system is a crop rotation system in which a one year fallow period follows two years of grain growing (winter grains, summer grains). Thus, there is a fallow field on a third of the farmland and no crop is harvested (for more details see Krausmann (1998)).

share of grain growing areas from 58% to 49%, increase in the production alternatives from 7% to 13% and in fallow lands from 1% to 10%.

Development of yields

Figure 7 shows the development of the average grain yield (7a) and the average agricultural biomass yield (7b) in Austria and the United Kingdom (see also Table 4). In the 19th century the yield level for the most important grains was clearly higher in the United Kingdom than in Austria as was the average biomass extraction on agriculturally (intensely) productive lands.

The average grain yields, used here as a general indicator for area productivity, were approximately 3.25 TJ/km^2 in 1850 (equivalent to approx. 2.0 t/ha) in the U.K., whereas in Austria only about half of that yield value was achieved (1.45 TJ/km^2 or approximately 1.0 t/ha). The grain yields in the U.K. more or less stagnated between 1850 and World War I (rate of growth –0.01% p.a.), yet in Austria they displayed a clear upward tendency with an annual growth rate of 0.38% per year between 1830 and 1910 (see table 3). After the collapse of yields in Austria due to the war and a period of light growth in the U.K., in both countries grain yields began to grow rapidly after 1950, a result of the intensive use of fossil fuels and chemical fertilizers. Between 1950 and 1980, grain yields in Austria grew by 3.44% p.a. and in the U.K., based on higher original yields, 2.33% p.a.. The increase in yield growths subsequently slowed down in Austria. In the U.K., the area productivity (measured by grain yields) grew by a factor of 3.5 between 1830 and 2000, whereas in Austria it grew by a factor of 6. As a whole, the grain yields grew few faster in Austria than in England in the 19th and 20th centuries whereby the difference in yields between Austria and the U.K. narrowed from approximately 50% in 1850 to less than 15%.

The average area yields for total plant production (i.e., including harvested hay, grazed biomass and harvest by-products) offers a similar picture (Fig. 7b). In the 19th century, the yield levels in the U.K. were clearly greater than in Austria, and in both countries the average area yields increased. Nonetheless, after World Wars I and II the average biomass yields clearly increased more in Austria than in the U.K. By the 1980s, Austrian per capita yields were already 25% greater than those in the U.K. The dramatic decrease in yields in Austria in the mid-1990s can be attributed on the one hand to a series of bad harvests, and on the other to changes in the spectrum of arable crops that were planted.

Figure 7: Development of area yields in Austria and the UK:

Figure 7a: Average grain yields (average area yields of wheat, rye, barley, oats and corn)

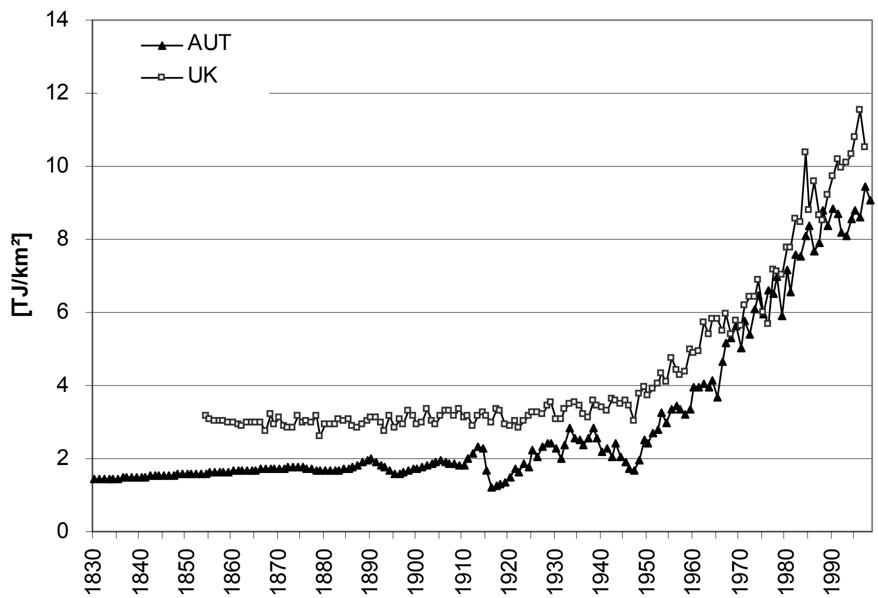


Figure 7b: Average area yields of agricultural biomass (average area yields of farmland, including harvest by-products, pastures, rough grazing and mountain grazing lands)

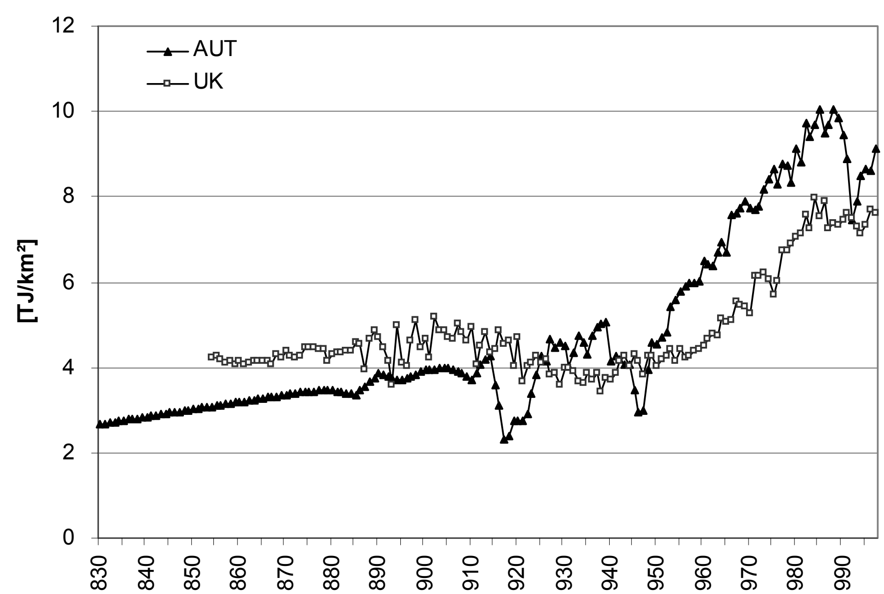
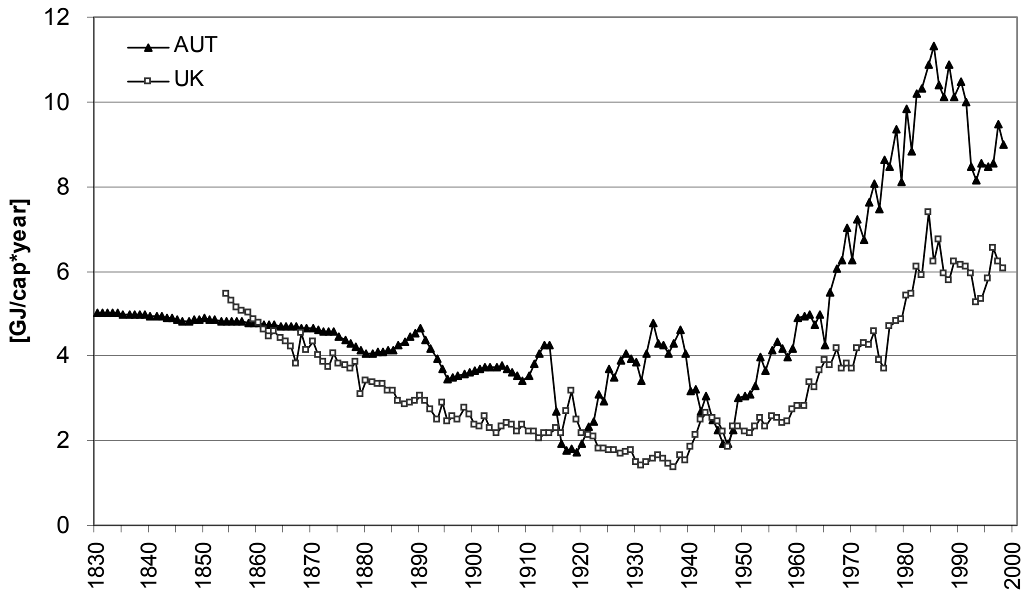


Figure 8: Per capita grain harvests



Domestic biomass production

The development of surface area use and area yields offers the following picture of the harvest (i.e., domestic extraction, see figure 1) of agricultural biomass:

The amount of harvested grain per capita in Austria around 1830 was 5 GJ/person, which by World War I saw a drop of 0.39% p.a. (see figure 8 and table 2). This decrease resulted from a rapid growth in population relative to the increase in yields. After a dramatic war-related grain harvest collapse to approximately 2 GJ per capita in the immediate post-war years, within just a few decades after World War II, the grain harvests grew from 2 GJ per capita to 11 GJ per capita in 1985. A subsequent decline led to a drop to 8-9 GJ per capita. In the U.K., between 1850 and the outbreak of World War II, except for a short-lived increase during the war years, grain harvests dropped more than 75% (i.e., -1.66% p.a.) to 1.3 GJ per capita.

Figure 9: Domestic extraction of biomass according to land use categories in Austria (9a) and in the United Kingdom (9b):

Figure 9a: Austria

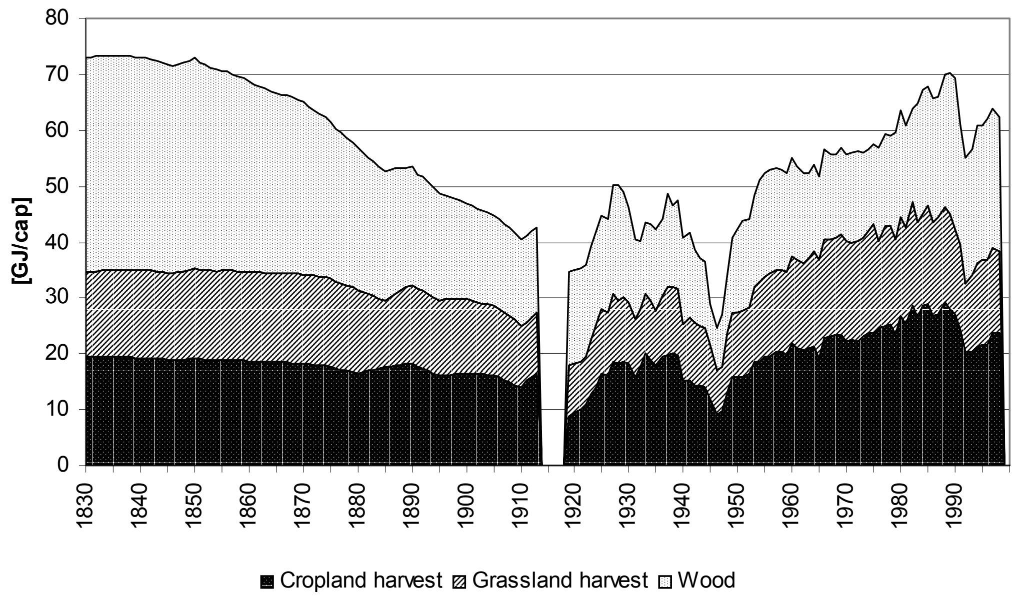
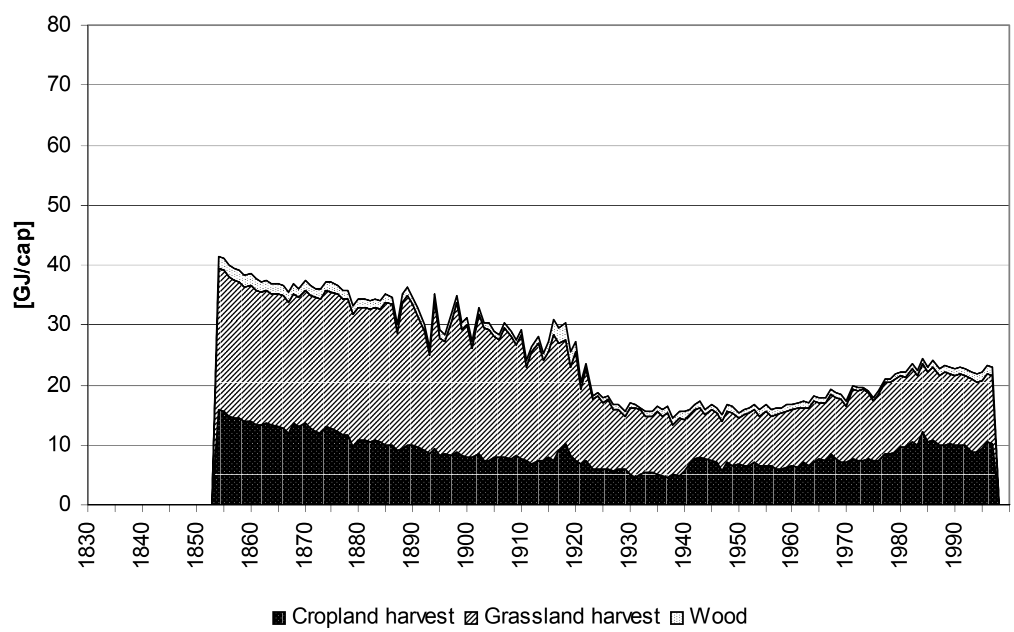


Figure 9b: United Kingdom



Beginning in the 1950s, although with a lower yearly growth rate, similar to Austria, they then showed a strong increase to 7.5 GJ per capita due to the agricultural industrialisation (growth rates in Austria between 1950 and 1980 approx. 3.9% p.a. and in the U.K. 2.9% p.a., see table 4).

Figure 9 shows the domestic extraction (harvest) of biomass in Austria (9a) and the United Kingdom (9b) arranged according to land use classifications. The harvest of agricultural biomass as a whole[14] in the first half of the 19th century in Austria was about 35 GJ per capita and in the U.K. about 40 GJ per capita. In both countries harvest yields dropped until the outbreak of World War I to just under 30 GJ per capita. In the U.K. the growth of the agricultural harvest after World War II was slightly less pronounced than in Austria: between 1950 and 1990 the harvest of agricultural biomass rose in the U.K. from 16 to 25 GJ per capita (factor 1.6) and in Austria from 21 to 45 GJ per capita (factor 2.1).

The share of farm production in the total agricultural harvest is relatively high in Austria and fluctuates only slightly across the entire study period between 55% and 65%. In the U.K., the portion of farm biomass decreased from 40% in 1850 to 25% in 1900 and then rose by the end of World War II through the *ploughing up* campaigns (see above) to just over 50% and has fluctuated between 40% and 50% since then.

Corresponding with the sparse forest area, the timber harvest plays only a very minor role in the U.K. The share of timber in the total biomass harvest (see Figure 9b) in the U.K. was only 5-10%, or 1-2 GJ per capita across the entire study period. However, what must be considered is that the numbers for timber extraction are presumably much lower than the actual amounts, especially in the 19th century, as one can assume that wood was also removed from agriculturally productive areas (hedges, woody river plants, tree stands on pastures) (see below).

In Austria, the timber harvest share decreased from 50% in 1830 to less than 30% in the 1960s and subsequently rose to 40% by the end of the 1990s. In absolute numbers the timber harvest dropped from 40 GJ per capita in 1830 to 15-20 GJ per capita at the beginning of the 20th century. It is presently about 20 GJ per capita.

The total per capita harvested agricultural and forestry biomass was markedly less in the United Kingdom than in Austria across the entire study period: until World War I, the per capita harvest in Austria was approximately a factor of 1.5-2 greater and as of the 1920s (with

[14] i.e. the entire biomass harvest from farmlands and grasslands (main harvested products including the harvest by-products and grazed biomass).

the exception of the World War II years) a factor of 2.4 to 3.4 greater than in the U.K. Between 1850 and 1930 the biomass harvest in the United Kingdom dropped from 40 GJ per capita to 15 GJ per capita and first increased to 23 GJ per capita after World War II, mainly through increases in agricultural yields.

In Austria, the biomass harvest in the first half of the 19th century was almost 75 GJ per capita, which dropped until World War I to just over 40 GJ per capita. After World War II, the biomass harvest increased quite rapidly to again reach over 70 GJ per capita and is currently 65 GJ per capita.

Figure 10: Physical balance of trade for biomass according to biomass categories in the United Kingdom (10a) and in Austria (10b)

Figure 10a: United Kingdom

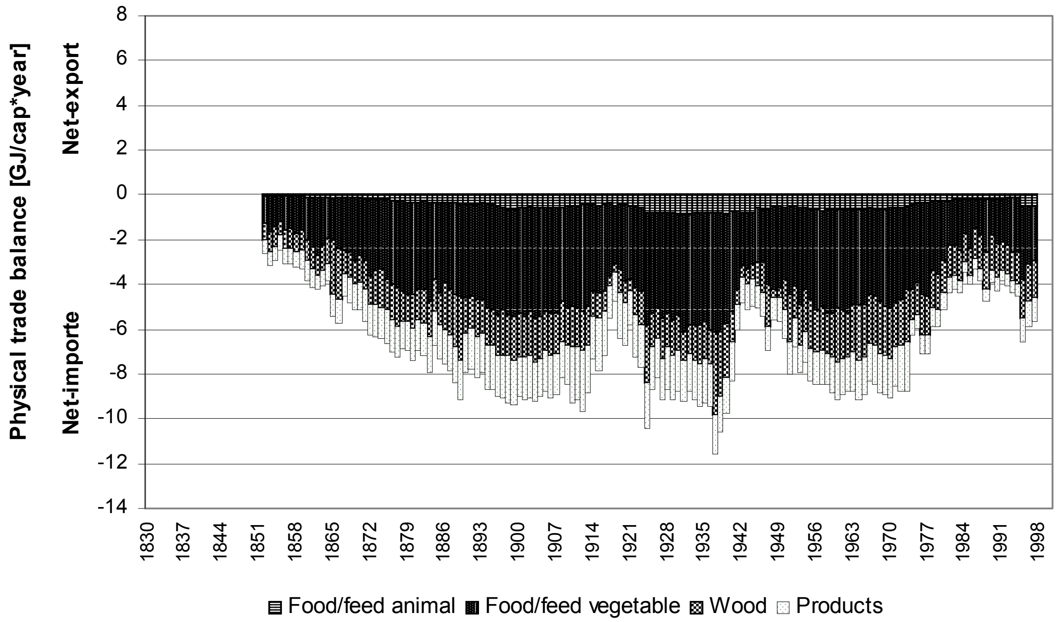


Figure 10b: Austria

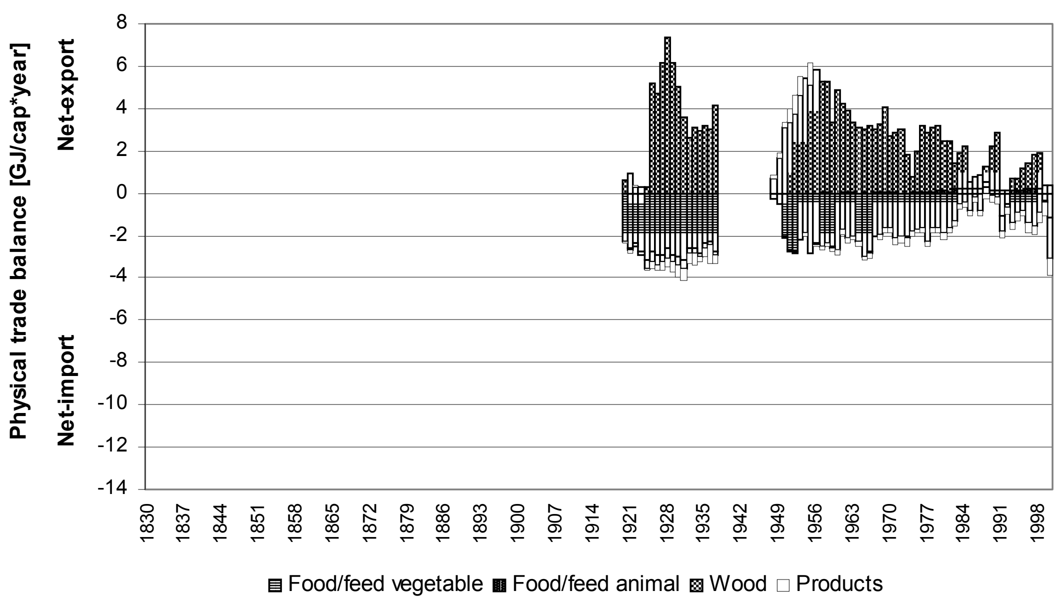
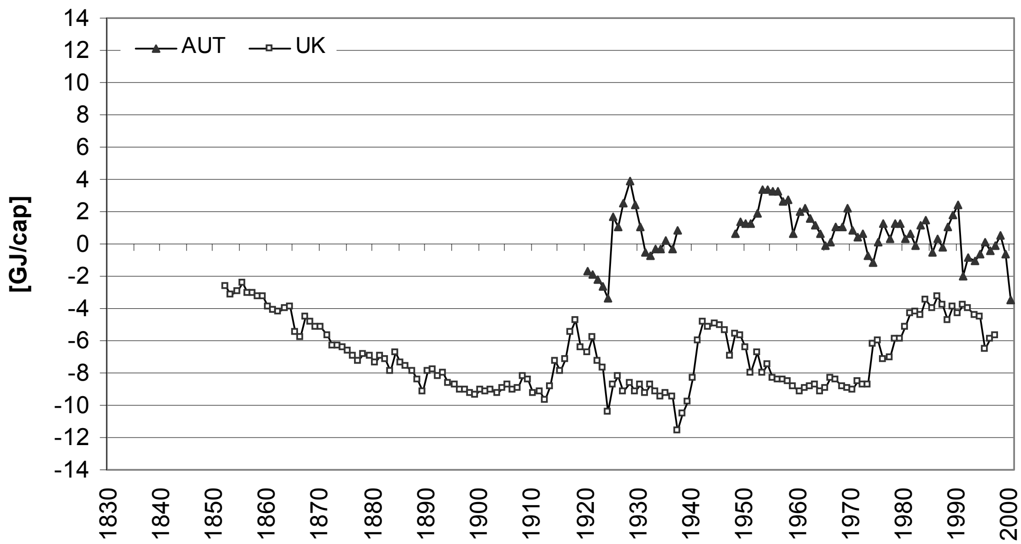


Figure 11: Development of the physical net foreign trade in biomass



Foreign trade in biomass

Figure 10 shows the development of the physical balance of trade[15] for biomass categories in the United Kingdom (10a) and in Austria (10b). Figure 11 shows the development of net foreign trade (export minus import) with total biomass and Figure 12 shows the degree of self-sufficiency with biomass (domestic extraction as a percentage of use).

In terms of agricultural and forestry biomass supply, the United Kingdom has been significantly dependent on (net) imports since the mid-19th century. The majority of imported biomasses are food and fodder: between 1855 and 1900, food and fodder imports grew from 1 GJ per capita to over 5 GJ per capita and in 1938 reached a peak value of 6.1 GJ per capita. During World War II, food imports dropped significantly (to 3 GJ per capita) and then subsequently rose once again to 5.3 GJ per capita by 1960. With the increase in domestic production through the industrialisation of agriculture, in the mid-1970s the U.K. began to export significant amounts of foodstuffs and fodder for the first time. Net imports of biomass

[15] Physical trade balances show the net foreign trade (export minus import) according to material categories. Positive values indicate a net export and negative values indicate a net import.

decreased steadily to values of fewer than 2 GJ per capita in the mid-1980s. Since this time they have remained between 2 and 3 GJ per capita with the tendency to increase.

As shown in Figure 12a, in 1850 the domestic production of biomass in the U.K. still covered some 96% of the total domestic consumption of biomass. Until the outbreak of World War I, the degree of self-sufficiency[16] with biomass decreased steadily to about 80%. During both World Wars self sufficiency with biomass rose briefly (from 79% to 90% during World War I and from 62% to 82% during World War II) and then once again dropped to 70% at the beginning of the 1960s. With increased agricultural production through agricultural industrialisation after World War II, also the degree of self sufficiency grew from 70% to 90% between 1960 and 1987.

In the U.K. the dependency of the food supply on foreign trade becomes even more obvious when one considers the marketable agricultural biomass (i.e., the agricultural biomass excluding fodder and harvest by-products) (see Figure 12b). Measured in grain units,[17] the degree of self sufficiency in the U.K. was 80% in 1855. Until the outbreak of World War I, the degree of self sufficiency sank to approximately 30% and in 1931 reached rock bottom at 16%. After World War II, the degree of self sufficiency then rose steadily to 75% by the mid-1980s and is currently around 50%.

For Austria, data on foreign trade are first available as of 1920. Due to its wealth of forests, Austria has traditionally been a timber exporting country. In terms of food supplies, Austria is dependent on imports. In total, timber exports and food imports provide a relatively well balanced or slightly positive physical balance of trade for biomass over the entire time period. This means that Austria tends to be a net exporter of biomass. In the 1930s, net imports of foodstuffs and fodder reached a peak of over 3.5 GJ per capita and then decreased slowly but steadily into the 1980s. In the 1980s and 1990s, values fluctuated between net exports of around 1 GJ per capita and net imports of 1.5 GJ per capita. With reference to marketable agricultural biomass (measured in grain units), the degree of self sufficiency after World War I was around 50%, and then increased more or less steadily until it reached over 100% at the beginning of the 1980s. Austria has now become a net exporter of marketable biomass (Figure 12b).

[16] Degree of self sufficiency is understood here as the proportion between domestic extraction (DE) and domestic material consumption (DMC).

[17] Grain units allow the aggregation of agricultural products through their nutritional and fodder values. At this point we should once again point out that the factors for the recalculation of animal products into grain units does not refer to the direct nutritional value of the product itself, but to the production of the necessary amounts of fodder.

Figure 12: Development of self sufficiency (DE as a percentage of the DMC) with biomass as a whole (12a) and with marketable agricultural biomass (12b).

Figure 12a:

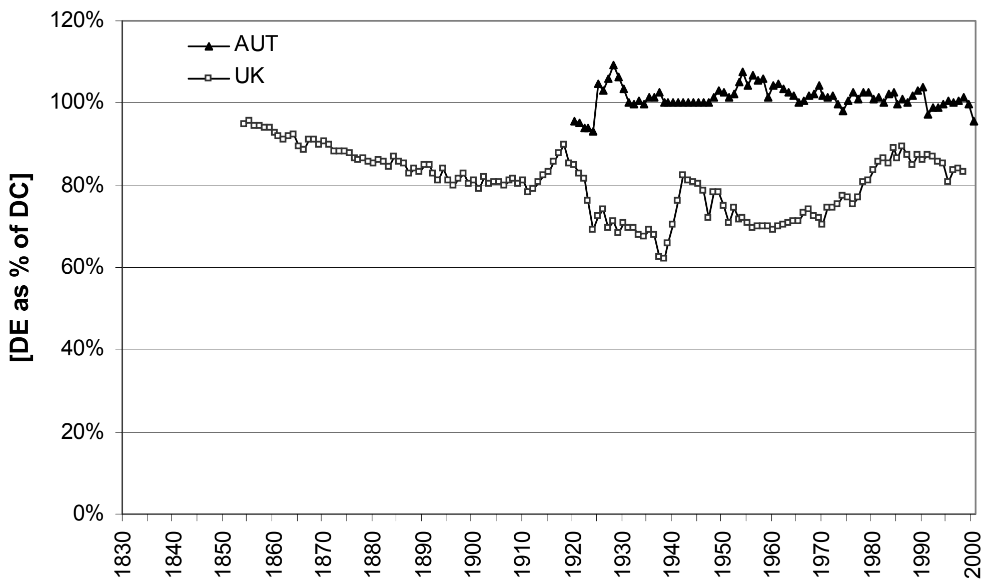
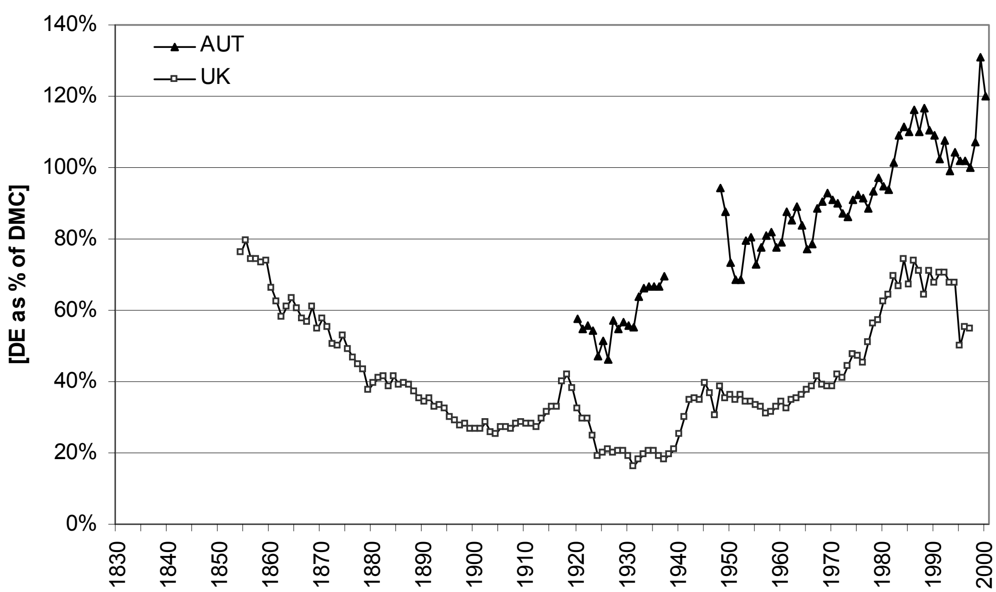


Figure 12b:



In the early 19th century, a time for which no statistical data on foreign trade are available, a large portion of Austria (today's borders) was organised around subsistence economies based on agricultural production, and rural populations were only minimally integrated into markets. With the exception of the few urban agglomerations, the population was supplied with food from regional agricultural production. In the 19th century, for the food supply for the city of Vienna in particular, there was a great reliance on imports from Hungary, Transylvania and the Sudeten lands. Exact figures for food imports in the 19th century are not available, however a significant amount of imports relative to the domestic harvest was first achieved with the expansion of the railroad network and the rapid growth of the city of Vienna. It is possible to assume that food imports before World War I were not significantly greater than import figures for the 1920s. Since also in the 19th century wood was exported from Austria, it is possible to assume a relatively well balanced physical balance of trade with reference to biomass for the 19th century.

Domestic biomass consumption

The domestic material consumption (DMC_{bio})[18] of biomass results from the previously described, common paths of development of domestic extraction and foreign trade for the individual categories of biomass. The development of DMC_{bio} per capita in Austria and the United Kingdom is shown in Figure 13.

The per capita biomass consumption at the beginning of the 19th century in the United Kingdom was 30-40% below the value for Austria. In both the United Kingdom and Austria, the DMC_{bio} clearly decreased during the entire 19th century and at the beginning of the 20th century was approximately 40 GJ per capita in Austria and 35 GJ per capita in the U.K. Whereas this figure dropped after World War II to 20 GJ per capita in the U.K., in Austria it fluctuated between 40 and 50 GJ per capita during both World Wars and rose after World War II to over 60 GJ per capita. In the United Kingdom this increase was markedly less pronounced but biomass consumption nonetheless also increased here by 30% to just about 30 GJ per capita.

[18] Biomass, following the previously explained MEFA logic, includes the total biomass harvested from farmlands and pastures (including harvest by-products and grazed biomass) and also total timber harvest including exports of biomass (wood, plant and animal foodstuffs, fodder, raw materials as well as products derived from biomass such as paper, drinks, etc.).

Figure 13: Domestic biomass consumption (in GJ calorific value per capita)

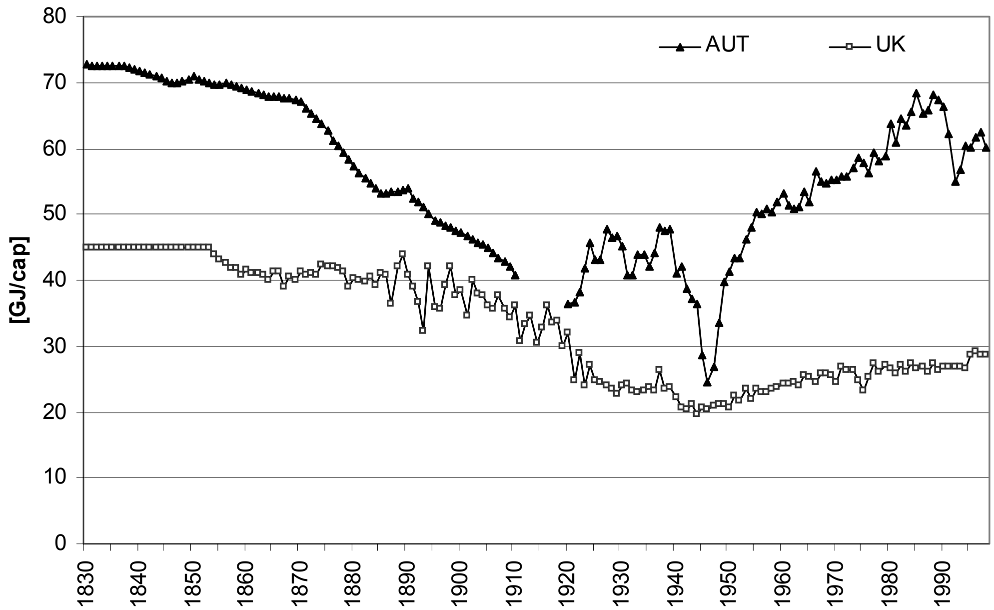
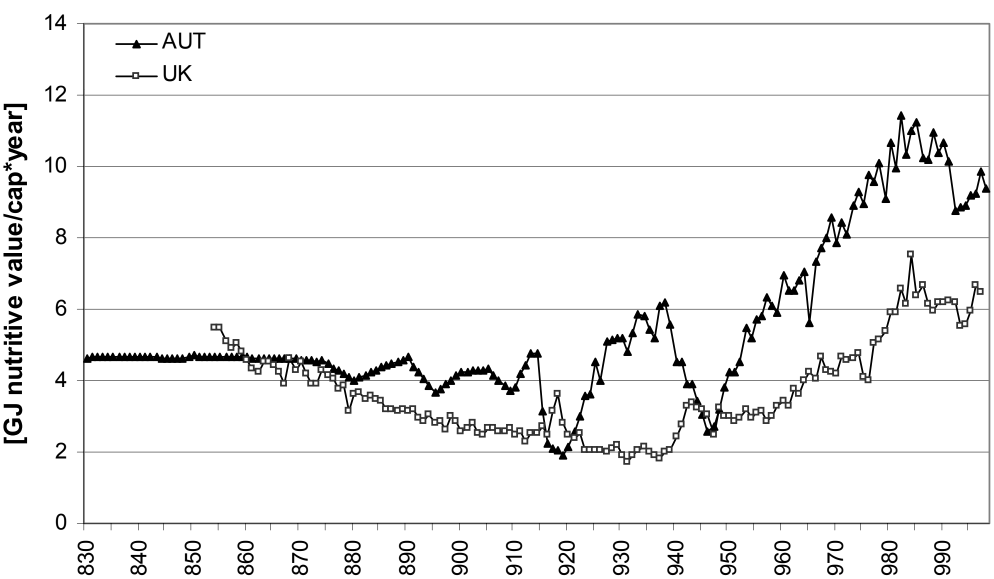


Figure 14: Domestic consumption of plant foodstuffs (in GJ nutritional value per capita)



Discussion

In 1750, the population density in the United Kingdom and in Austria was roughly equivalent at just over 30 persons per km^2; in the following decades this figure rose more strongly in the U.K. than in Austria and was already twice as high in 1830. Interestingly, at the beginning of the 19th century, also the agricultural surface area yields in the U.K. were 2 times greater than those in Austria. Unfortunately, at the present time we do not have any comparable yield figures available for the middle of the 18th century[19] in order to derive statements about the connection between population density, population growth and the systems of land use or intensities of land use[20] as postualted by Boserup (1965) and Netting (1993).

The yield level in the U.K. tended to be above the level in Austria due to more advantageous climatic conditions (higher precipitation, longer vegetation periods). In addition, the yields in the U.K. were elevated to a clearly higher level than in Austria through the 18th century agrarian modernisation phase. The pre-industrial growth potential of the "advanced organic economy" (Wrigley 1988) had already been largely exhausted in the United Kingdom by the start of the 19th century, and the availability of inexpensive agricultural imports hindered further increases in area productivity. Increases in production efficiency and area yields thus remained more or less constant in the U.K. during the 19th century. In Austria, agricultural modernisation began at a time when it had, for the most part, already finished in the United Kingdom. The introduction of a rotating crop system with the planting of new root crops (potatoes, corn, and fodder) at the cost of fallow lands and the more efficient food management of the associated stall fodder led to clear yield growths during the 19th century which minimized the deficit in surface area productivity as compared with the U.K.

A further important factor influencing the development of land use was foreign trade in agricultural products. The United Kingdom, through its "island situation," as opposed to the

[19] On the long-term development of harvest yields in Austria and the U.K., see Turner et al. (2001). These data are, however, not directly comparable (Sandgruber 1978a).

[20] In addition, an isolated comparison of the grain yields in this context seems sufficient. More meaningful would be a comparison of the net soil productivity of the system, i.e., the total effective food output (thereby including animal products) as related to the surface area unit – however, we also have no adequate database available for this. In Austria, at the beginning of the 19th century, on average around 3 GJ of food was created per hectare of agriculturally productive land. With that, one hectare of agriculturally productive land could, on average, feed approximately 0.9 persons. Grains represented 60% of the total produced plant and animal products (primarily milk – approximately 35%) (Krausmann 2003b).

landlocked Austria,[21] was in an advantageous position in terms of transportation technology. Under pre-industrial conditions, high seas shipping presented the only possibility for the efficient transport of mass quantities of raw materials over great distances.

In the first half of the 19th century, the domestic production of plant biomass for food in both countries (calculated in nutritional value) was around 4.5-5.5 GJ per capita[22] (see Figure 14) and thus corresponded approximately – with the deduction of 30% for seeds, storage and processing loss – to annual average per capita nutritional requirements of around 3 GJ. Whereas in Austria this value remained at approximately this level in the 19th century, in the United Kingdom it sank steadily to about 2 GJ per capita. Parallel to the decrease in domestic production, imports of foodstuffs and fodder rose steadily in the U.K. The increasing shift from domestic production to imports of foodstuffs and fodder grains affected the entire agricultural production system in the United Kingdom. Imported grains, mainly from the U.S., contributed significantly to the clear reduction in surface area used for farming and grain production in the U.K. Some 50% of the lands used for farming were no longer cultivated by 1937 and instead were mainly managed as pastures. During this time period, the amount of grain growing areas dropped by nearly 60%. As a whole, grain imports caused a shift towards livestock farming (cattle production), which was more attractive for English agriculture due to their market economy.

No similar development can be observed in Austria. It was mainly the rapidly growing population in the city of Vienna that relied on food imports from abroad or from other parts of the monarchy. In the remaining parts of Austria, the slowly growing non-agricultural population could be supplied from local agriculture's increased yields. Food imports did not have the same effects on domestic agrarian production in Austria as in the U.K., which in Austria to a high degree was directed at a subsistence economy. Instead, food imports supported the hesitant modernisation of agriculture in Austria in the 19th century.

In the so-called *ploughing up* periods, as the war-related reorganisation of English agriculture was called, import dependency in terms of foodstuffs was obvious: In the years of World Wars I and II there was an expansion of cultivated lands (i.e., ploughing up) in order to raise the

[21] That also applies, by the way, in reference to the Habsburg Monarchy, which as a whole was highly "autarkic" and could only participate in international sea trade through a very peripherally located high sea port in Trieste.

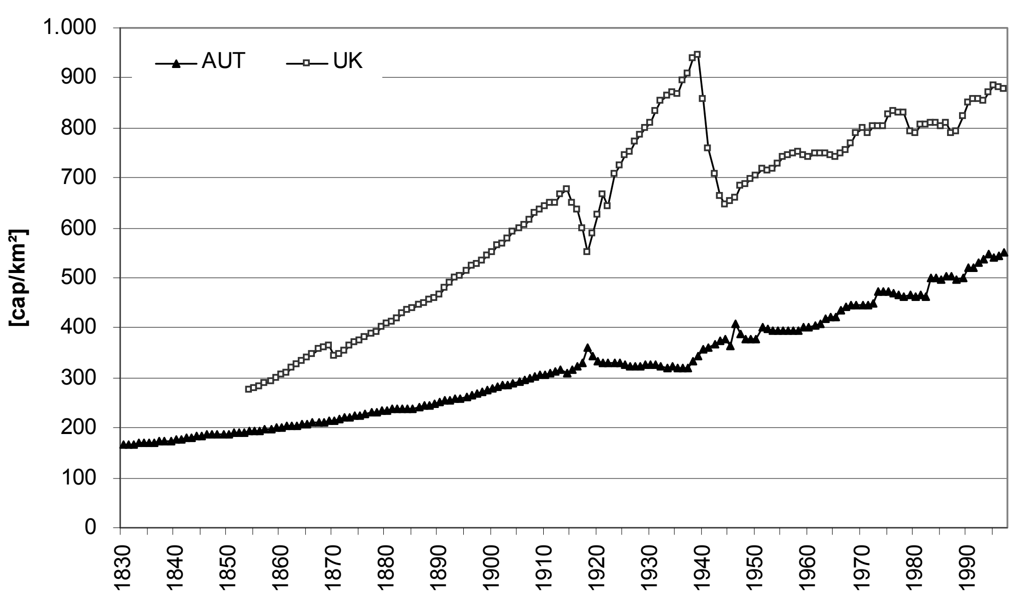
[22] This value refers to the production of all agrarian products potentially suitable for human consumption, including also those fodders that could also serve as human foodstuffs (oats and potatoes) but were at least partially used as fodder. Not included are animal products such as milk and meat, whose contribution to the food supply in the 19th century was probably about 1 GJ per capita (Krausmann 2003b; Sandgruber 1982; Teuteberg 1986b; Teuteberg 1986a).

degree of self sufficiency in terms of foodstuffs. Through this, cultivated areas increased between 1914 and 1918 by 15% and between 1940 and 1945 by almost 34% at the expense of permanent pastures. The grain growing areas nearly doubled between 1937 and 1945 (75% increase).

This development was also evident when considering the population density in relation to the farmland (Figure 15). This increased in the United Kingdom from 275 to 946 persons per km² between 1855 and 1939. With the ploughing up in WWII, a short-term minimum of 653 persons per km² was reached.

In Austria, the population relative to area of farmland increased steadily through population growth and a reduction in farmland from 168 to 561 pers/km². The U.K. had already reached this value by 1900. Throughout the 19th century in particular, the number of persons per km² of farmland grew much more rapidly in the U.K. than in Austria (between 1855 and 1939 growth in Austria is recorded as an increase of 77%, and in the U.K., by contrast, 239%, which must be seen in the context of the increasing importance of food imports to supply the population.

Figure 15: Development of population density in relation to farmlands



After World War II, agricultural industrialisation in the two countries synchronised the paths of development. Through the use of fossil energies, mainly in the form of artificially produced fertilizers and as substitutes for animal and human labour, an unanticipated increase in area yields and the physical output of agriculture was achieved. Within just a few decades the structure and significance of the agricultural production system was fundamentally changed. Agricultural draught and work animals, for whose nutrition a quarter to a third of the agriculturally productive lands was necessary until World War II, disappeared from the production system within two decades. The use of artificial fertilizers produced with a high use of fossil fuels allowed a functional and spatial separation of agriculture and livestock and thereby regional specialisation of agrarian production. Beyond that, the use of artificial nitrogen fertilizers enabled an overcoming of the traditional limitation of foodstuffs and area yields were able to rise to hitherto unseen levels. Industrialisation led to a loss in importance of yield differentiations due to the natural environment and in the 1970s yield levels in the two countries became comparable at a very high level.

In combination with modern cultivation methods for plants and breeding of work animals, the area productivity and especially the work productivity of the agrarian sector rose enormously. In Austrian agriculture for example, between 1830 and 1995 the area productivity[23] rose by a factor of 5 (from 500 GJ to 2400 GJ/km^2) and the work productivity[24] by a factor of 33 (from 12 to 390 GJ per capita).

The use of fossil fuels and the technologies which rest on them also caused a functional transformation of the agrarian system of production. It changed from a traditional source of socially usable energy (food for humans and work animals) to an energy drain (see Martinez-Alier (1987), Stanhill (1984)). Figures for Austria[25] (see appendix) have shown that in 1830 each unit of socio-economic energy input in agriculture achieved an output in the form of six food units. Through the industrialisation of agriculture, the output was elevated by a factor of 3, but at the same time the social energy input was increased by a factor of more than 20. In 1995 more energy was put into agriculture than was created in the form of end products.

Whereas the increase in area yields in the U.K. seems to have pushed ahead without restrictions, the growth rates in Austria clearly dropped off in the mid-1980s. Beginning in the 1980s, in both countries, agricultural policy measures were taken to lower the agricultural

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[23] Area productivity is understood here as the physical end products of the agrarian sector (plant and animal end products) in relation to the agriculturally productive areas.

[24] Work productivity is understood here as the physical end products of the agrarian sector (plant and animal end products) in relation to the number employed in agriculture.

[25] There are no comparable figures available for the United Kingdom.

surplus, which was exported with high state subsidies. These measures had grave effects on the structure of land use (instead of the growing of grain, growing of alternative crops and subsidized fallow areas) and also on the intensity of the farming and subsequently on yield levels.

The extent and structure of domestic extraction and domestic consumption of biomass (domestic extraction, harvest) differ greatly in Austria and the United Kingdom. The relative share of farm products, hay and grazed biomass and timber are naturally strongly influenced by land use.[26] In general, one can assume that the available bioproductive areas are, for the most part, used to capacity and thereby the level of biomass consumption is tied to population density. The relative capacity of bioproductive areas also depends on the climate, soil quality and available technology and work intensity. Under pre-industrial conditions, there were relatively narrow borders that essentially co-determined the extent and structure of social biometabolism of pre-industrial societies (see Malanima (2001)). It was possible to overcome these limitations to a certain degree through the use of fossil fuels and the technologies that are reliant on them.

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[26] In addition to the natural environmental conditions and the associated system of land use, the level and structure of the social biomass metabolism is also dependent on the relative importance of imports of food and fodder. Through the import of agricultural products, a considerable portion of the social biomass metabolism can be "externalised." For the Austrian agricultural system it has been shown that per Joule of agricultural end product (and agricultural imports are agricultural end products such as grains, meat, milk, etc.) the 5 to 10fold amount of agricultural biomass can be converted into the agricultural system (i.e. seeds, harvest by-products, losses, conversion losses in animal improvement, etc.). A high dependency on imports in terms of food and fodder can therefore clearly reduce the domestic consumption of agricultural biomass, which can be a reason for the relatively low consumption of biomass in the U.K. as compared internationally (see Eurostat (2002)).

Domestic extraction

Figure 16 shows the development of the domestic extraction of primary energy in the United Kingdom (16a) and Austria (16b). In Austria, extraction of primary energy in the early 19th century was limited exclusively to biomass and with that, to equal parts of timber and agricultural biomass. Quantitatively, coal and hydropower only played a minor role (each clearly below 0.5 GJ per capita). In comparison, coal mining in the U.K. was already at 30 GJ per capita in 1830. Until the outbreak of World War I, coal mining grew (per capita) in the U.K. with an average growth rate of over 2% p.a. whereas the extraction of biomass decreased by about 0.7% p.a. (table 4). But also in Austria, coal mining rose rapidly, with an average growth rate of over 4%, whereas the extraction (per capita) of biomass sank at a rate of 0.6% p.a. (table 4).

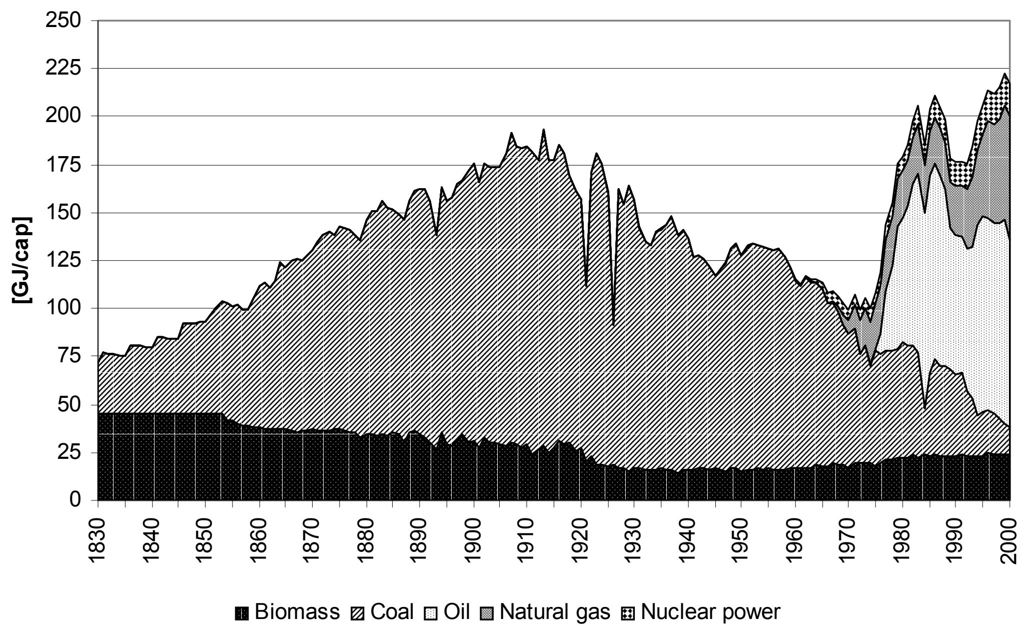
Despite a very high growth rate in both countries the per capita coal mining rates diverged in two orders of magnitude at the beginning of the 20th century: in the U.K., mining in 1914 was about 166 GJ per capita and in Austria just over 5 GJ per capita.

After World War I, coal mining in the U.K. began to drop quickly and sank by about 2.7% p.a. in the period from 1920-2000, whereas in Austria it rose until after World War II. After World War II, in both countries the extraction of natural gas and petroleum increased as well as the construction of hydroelectric power and atomic energy for the creation of electricity. In Austria, domestic output of these energy carriers remained in a relatively modest range with a maximum 10-20 GJ per capita (fig. 16b).

In the United Kingdom, the extraction of natural gas and petroleum from the North Sea began in the 1970s and within less than ten years output rose to over 100 GJ per capita. In 2000 the domestic extraction of primary energy in the United Kingdom was about 220 GJ and in Austria just over 90 GJ per capita and annum (fig. 16).

Figure 16: Domestic extraction of primary energy in the United Kingdom (16a) and in Austria (16b)

Figure 16a: United Kingdom



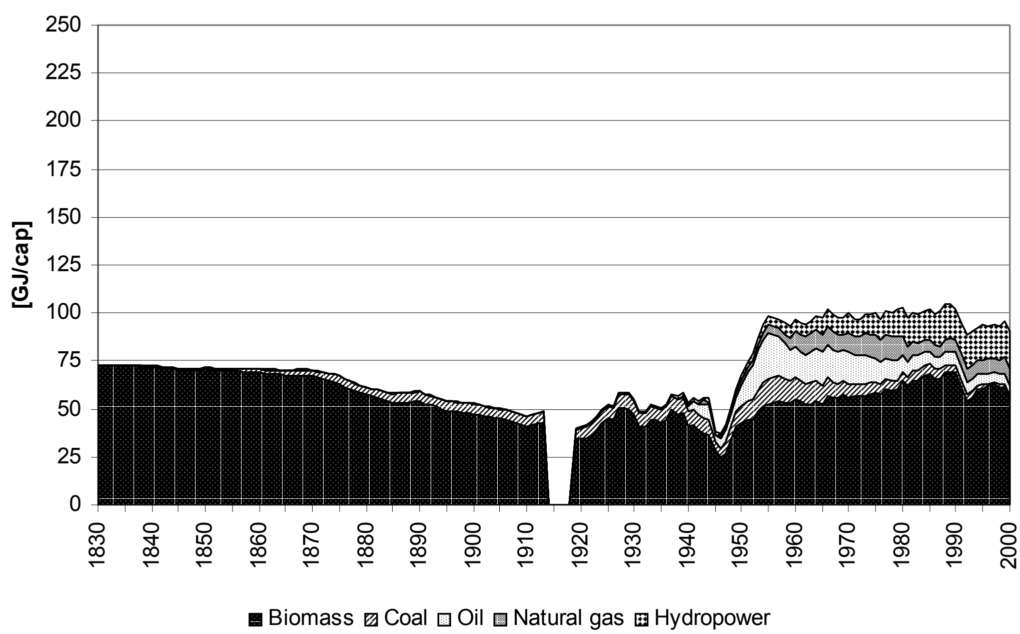


Figure 16b: Austria

Figure 17: Physical balance of trade for primary energy carriers in the United Kingdom (17a) and in Austria (17b) and a comparison of net foreign trade (17c).

Figure 17a: United Kingdom

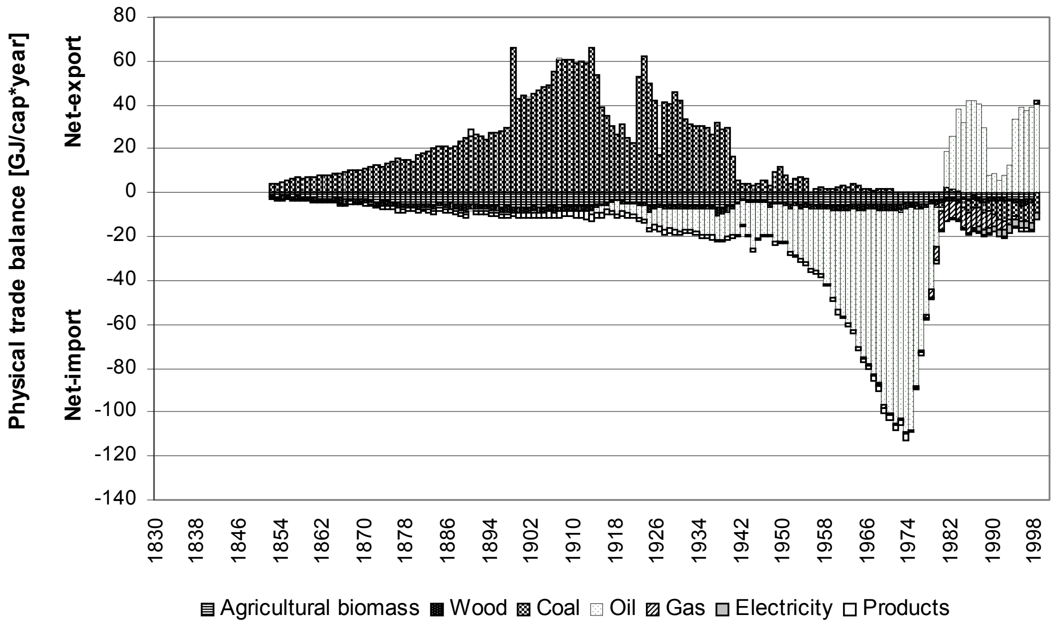


Figure 17b: Austria

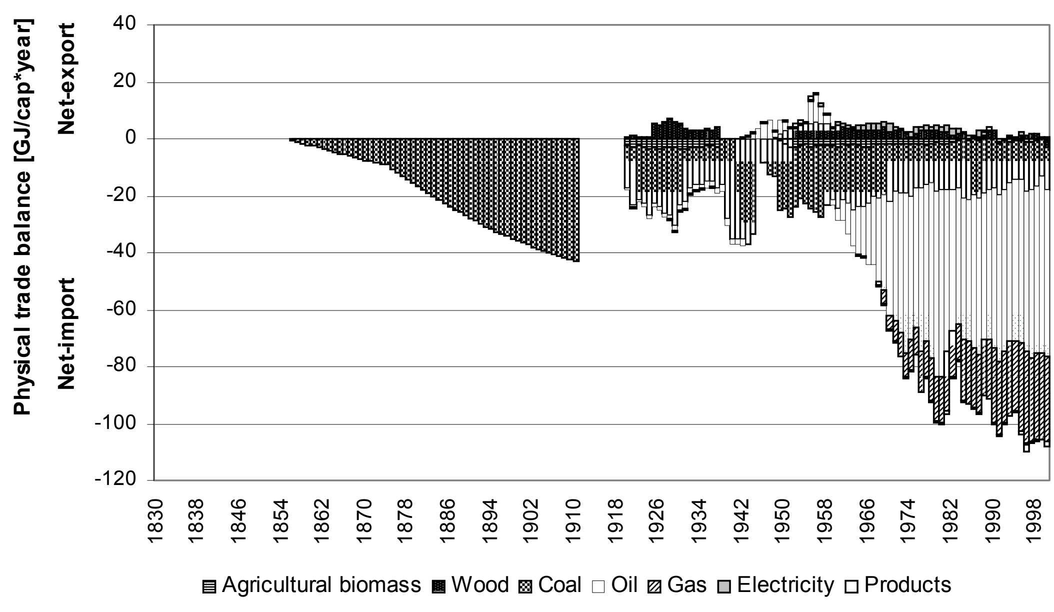
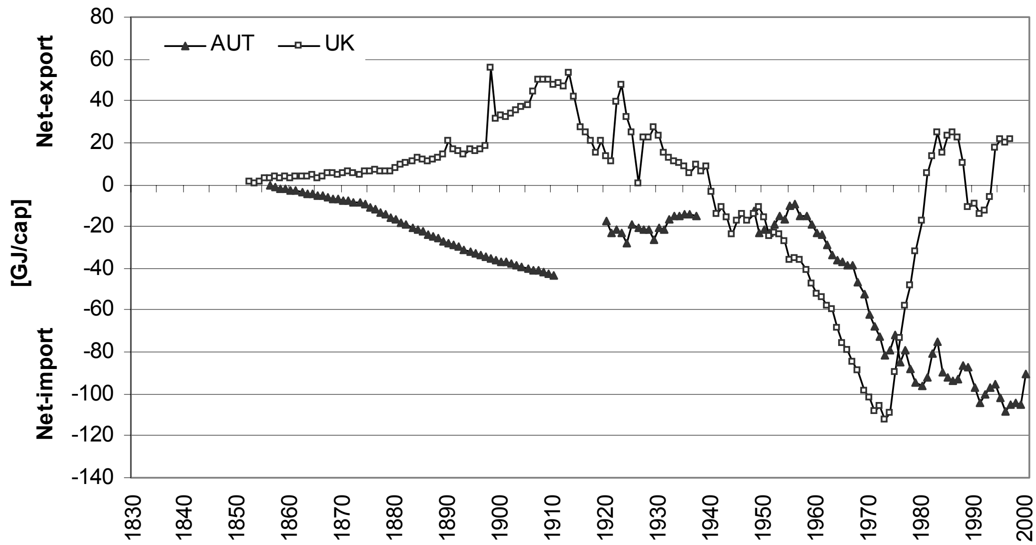


Figure 17c: Comparison of physical net foreign trade with primary energy



Import and export of primary energy

Figure 17 shows a comparison of the physical balance of trade in Austria (17a) and in the United Kingdom (17b) according to carriers or forms of energy and per capita value (17c). In the United Kingdom, an increase in coal mining was accompanied by an increase in net exports of coal. Between 1854 and 1914, exports climbed from around 4 GJ per capita to over 60 GJ per capita, which exceeds Austria's per capita consumption of coal at that time. At the peak of this development, the U.K. exported approximately 36% of all mined coal. In contrast, Austria's domestic mining could cover only a fraction of its coal requirements. Prior to World War I, the domestic extraction covered only 10-15% of the demand and approximately 40 GJ per capita were imported, primarily from other provinces within the Habsburg Monarchy. After World War I, Austria's coal imports did not return to this level. In the 1920s, both the U.K. and Austria began to import petroleum, but it was first after World War II that petroleum imports rose explosively. Petroleum imports rose sixfold in both countries in less than 30 years. In the mid-1970s, petroleum was imported in the amount of 50 GJ per capita in Austria and 100 GJ per capita in the United Kingdom. The picture changed in the context of the 1973/1979 oil crisis. The United Kingdom, through rapid construction of North Sea oil extraction, became a net exporter of petroleum within just a few years (already approximately 40 GJ per capita and year at the beginning of the 1980s). In Austria, there was no continued increase in imports, which fluctuated between 50 and 60 GJ per capita, and increasing amounts (20-30 GJ per capita) of natural gas were imported.

Primary energy consumption

Figure 18 shows the development of primary energy consumption in the United Kingdom (18a) and in Austria (18b) according to energy carriers and comparison of the per capita value as a whole (18c). In the United Kingdom, fossil fuels (i.e., coal) already had an important position at the beginning of the 19th century: in 1830 coal covered some 40% of the total primary energy consumed and in 1850 the consumption of coal and biomass were nearly equivalent. Coal consumption rose more or less linearly with an average growth rate of 1.3% p.a. until into the 1880s and remained at a level of 105-110 GJ per capita until the outbreak of World War I. At the peak of the coal phase before the outbreak of World War I, the coal's share in primary energy consumption was over 75%.

As a whole, energy consumption in the U.K. rose continually from approximately 70 GJ per capita in 1830 until the beginning of the 1880s and then stayed at a level of 140-150 GJ per capita where it remained for the most part until after World War II.

In Austria, fossil fuel played only a (quantitatively) secondary role until well into the 19th century and in 1850 still amounted to barely more than 1 GJ per capita. Beginning in 1850 coal consumption also began to rise rapidly in Austria and the share of coal as primary energy consumption climbed to over 20% by the mid-1870s and by the outbreak of World War I it was over 50%. In 1910, some 50 GJ coal per capita was consumed in Austria, which corresponds with only 40% of the amount consumed in the United Kingdom at this time. In Austria energy consumption between 1910 and 1950 fluctuated between 20 and 90 GJ per capita due to dramatic collapses caused by the events of war, economic crisis, and intermediary periods of recovery.

After World War II, in both systems there was a clear increase in energy consumption. Between 1950 and 1980 average annual growth rates of energy consumption in the U.K. were approximately 0.9% p.a and in Austria 2.67% p.a. – due, among other factors, to the very low initial values after World War II (see Table 4). Added to the rapid growth dynamics at this time were also structural transformations in energy consumption. Beginning in 1950, the share of petroleum clearly began to increase at the expense of coal and biomass. In 1980, at the peak of this development, the share of petroleum in the U.K. was 35% and in Austria 37%. In the 1980s the period of rapid growth of energy consumption came to an end.

Figure 18: Use of primary energy according to energy carriers in the United Kingdom (18a) and in Austria (18b) and a comparison of the development (18c)

Figure 18a: United Kingdom

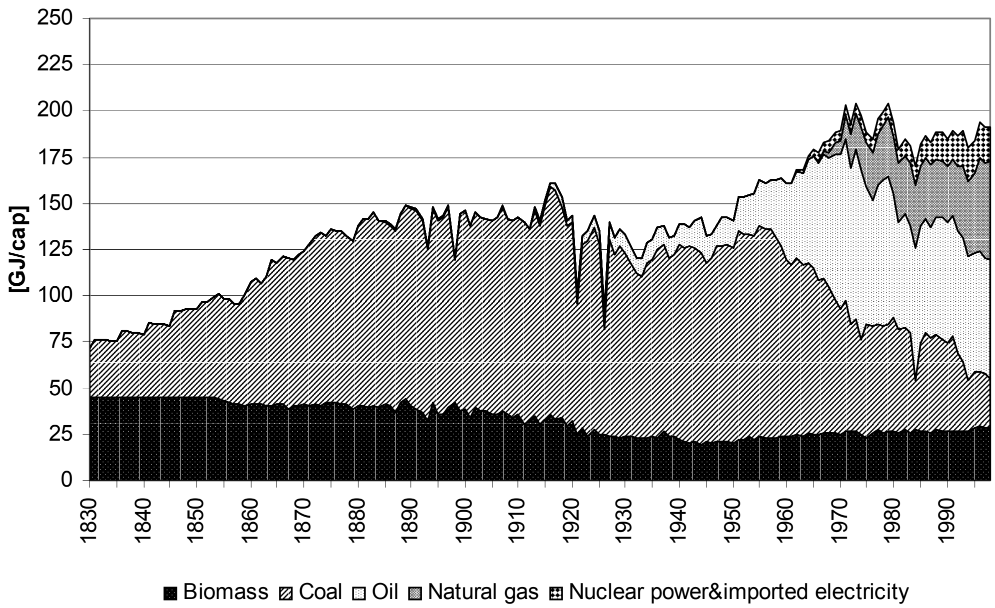


Figure 18b: Austria

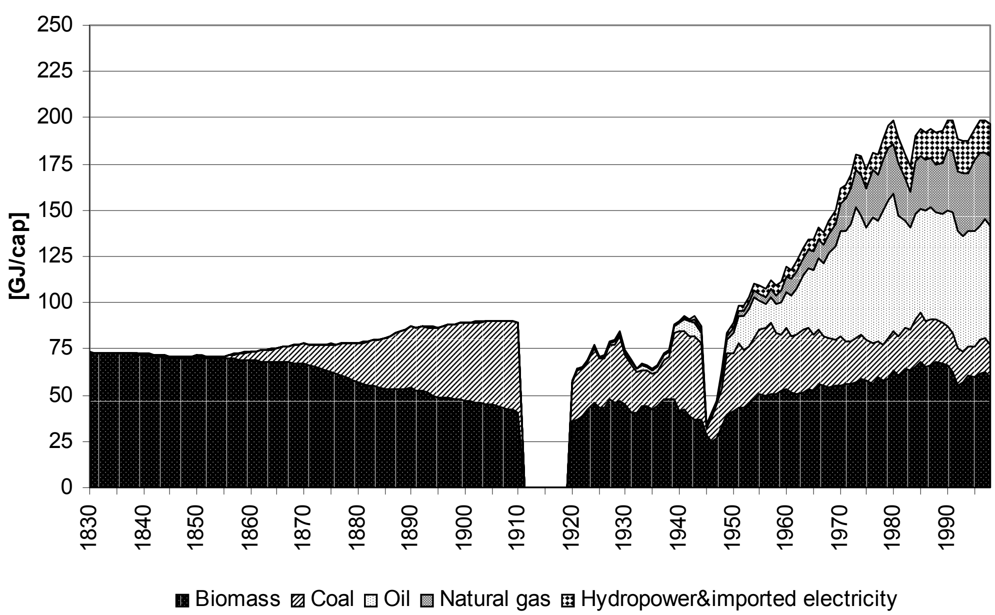
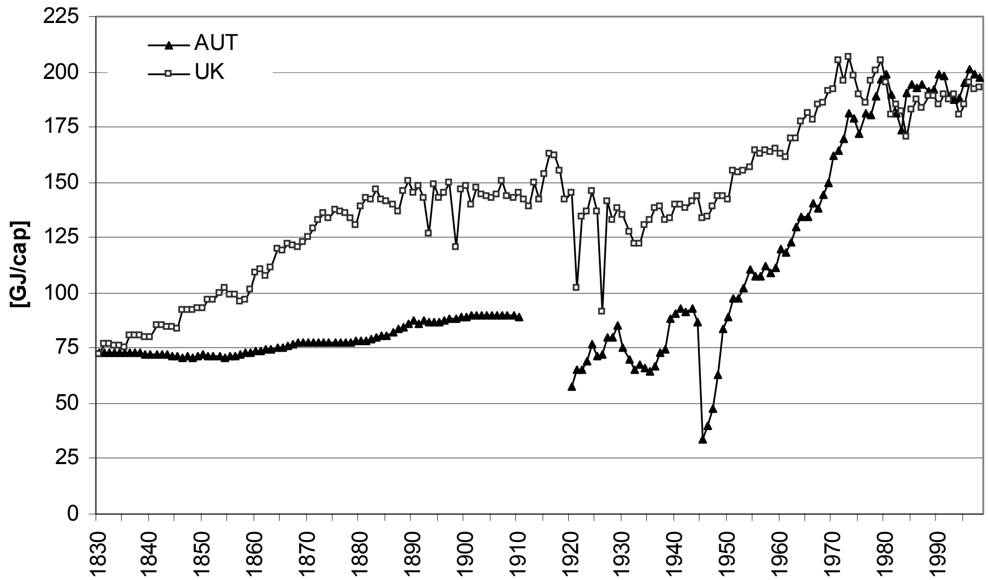


Figure 18c: Comparison of the development of primary energy consumption in Austria and the United Kingdom



The share of petroleum relative to total consumption decreased due to increases in natural gas and electricity.[27] Energy consumption in both countries remained between 180 and 200 GJ per capita. The share of biomass in primary energy consumption is currently 28% in Austria and 15% in the United Kingdom.

Carbon dioxide emissions

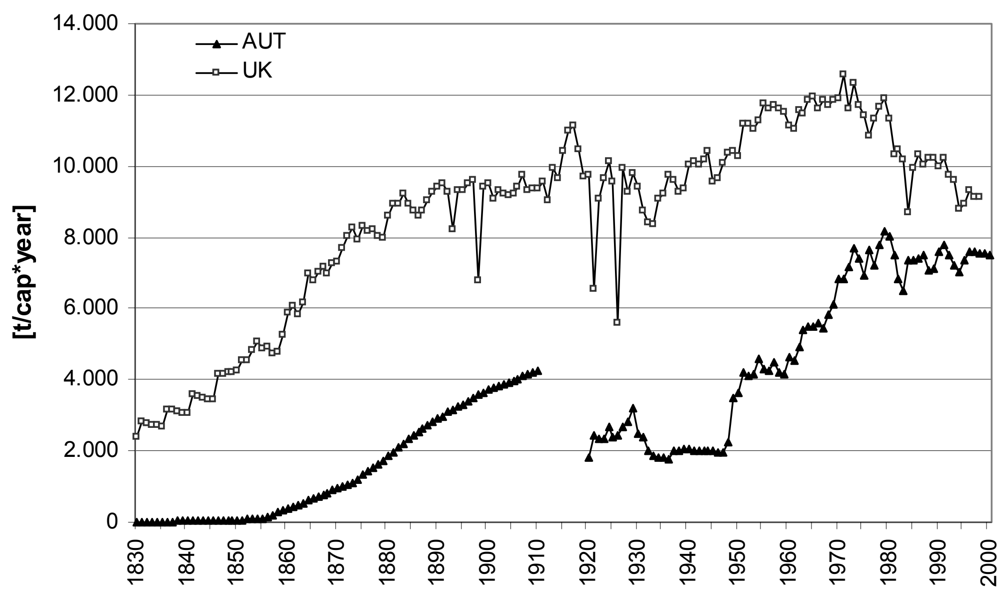
Figure 19 shows the development of carbon dioxide emissions from the burning of fossil fuels in the United Kingdom and in Austria.

In the United Kingdom, in 1830, carbon dioxide emissions were already more than 2,000 kg per capita and annum, a value that was first reached in the 1880s in Austria. In the United Kingdom there was already as much carbon dioxide emitted per capita in 1870 as in Austria at the end of the 1970s (ca. 8,000 kg per capita and annum). At the peak of the coal phase in the U.K. (between 1910 and 1930) some 10,000 kg CO_2 were emitted per capita and per year, and this value rose until the late 1970s when it reached over 12,000 kg CO_2 per capita. This figure

[27] At the level of primary energy consumption, we are dealing exclusively with electricity from hydroelectric plants and atomic energy (and other non-caloric forms of energy production) as well as net imports of electricity.

has since declined by more than 25% due to the substitution of natural gas and atomic energy for coal and petroleum. Today, in the U.K., with a per capita emission of some 9,000 kg per year, there is still significantly more carbon dioxide emitted than in Austria (7,500 kg per capita), which can be traced back to the comparatively high share of renewable energy sources within total energy consumption in Austria. Figure 19 mainly elucidates the relevance of a historical perspective in connection with environmental problems such as CO_2 emissions. Whereas current CO_2 emissions are comparable in Austria and the U.K., with a cumulative view (which is appropriate for a cumulative environmental problem such as CO_2 emissions) the picture shifts dramatically. Across the total time period there were 2.5 times more emissions per capita in the U.K. than in Austria.[28] Per capita, the population currently living in the U.K. would have emitted a total of 1100 t CO_2 and in Austria 430 t CO_2. This difference in the cumulative emission values is naturally even more distinct if one compares the emission levels from countries of the South with levels from Western industrial countries.

Figure 19: Carbon dioxide emissions from the burning of fossil fuels



[28] This factor is equally valid for the cumulative CO2 emissions per capita of the current population and the CO2 emissions in terms of the sum of the total human years lived.

Energy consumption and economic growth

In both countries, GDP has grown dramatically in the last 170 years; in Austria by a factor of 28 and in the U.K. by a factor of 22 (see Table 4 and Figure 2). In contrast, energy consumption (absolute) in Austria has grown by a factor of 6 and in the United Kingdom by a factor of 6.7. The relatively weak growth in energy consumption relative to GDP can be described as an increased energy efficiency of the economic system. Figure 20 shows the development of energy efficiency, expressed as GDP$ per GJ primary energy consumption in both countries:

As a whole, the development of energy efficiency is quite similar in both countries despite the different speeds of their industrialisation processes. In 1830, the energy efficiency of the Austrian economy was still significantly lower (19$/GJ) than in the U.K. (26$/GJ) however by 1850 they were already at the same level. The energy efficiency rose, following an exponential function ($r^2 = 0.94$ in both cases) throughout the period investigated. The average growth rate in Austria was 0.97% p.a. and in the U.K. 0.78% p.a. whereby, according to the exponential growth, the growth rates increased over time. At the present time the energy efficiency in both countries is just over 90$/GJ.

Figure 21 shows so-called Kuznet depictions (EKC, Environmental Kuznet Curve) of the connection of per capita energy consumption and per capita GDP. For Austria, this connection follows a saturation curve. At a per capita income of $13,000-$14,000 energy consumption remains somewhat stable whereas GDP continues to grow. The "fork" in the lower area of the curve is related to the collapse of the GDP and the economic crisis during the two World Wars, which obviously had a stronger effect on GDP than energy consumption. Also for the U.K., for incomes starting at approximately $11,000 a de-coupling of energy consumption and economic growth is visible. However, what is interesting is that in the U.K., at an income level between $3,000 und $7,000, a similar de-coupling is already ascertainable, although for incomes beginning at $7,500 energy consumption once again increases.

Figure 20: Energy efficiency

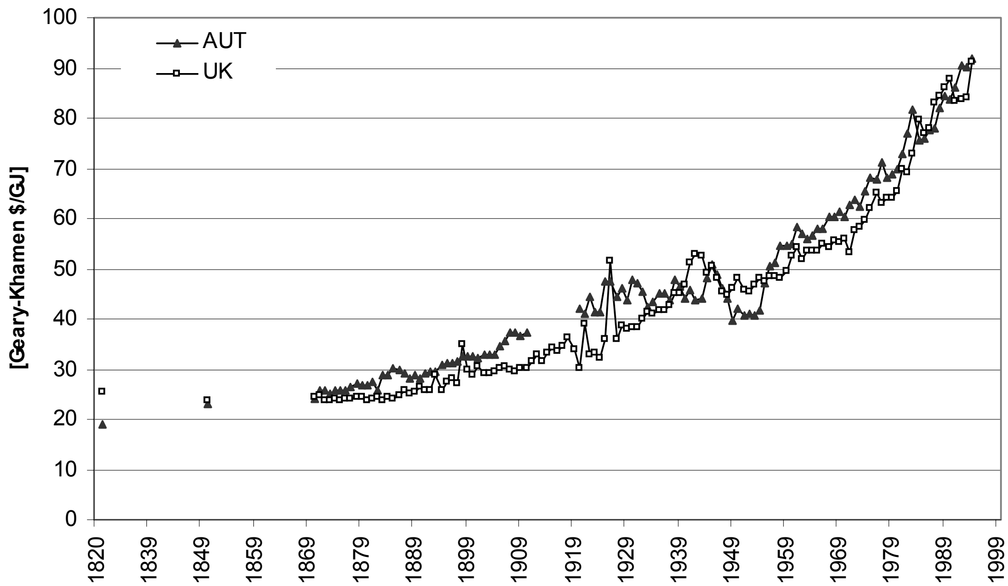
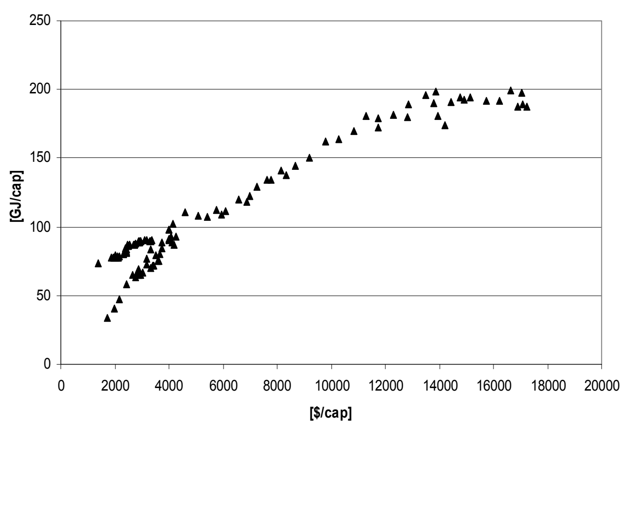
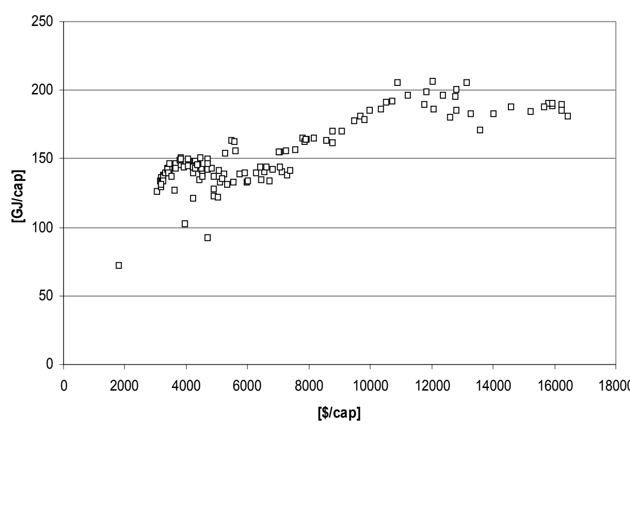


Figure 21: Kuznet depiction of the connection between income and energy consumption: per capita incomes and primary energy consumption per capita in Austria (21a) and in the United Kingdom (21b)

21a: Austria



21b: United Kingdom



Discussion

With Austria and the United Kingdom, we are considering two countries that were at different stages in the socio-economic transformation process from an agrarian to an industrial society at the beginning of the 19th century, but that showed, however, approximately the same gross primary energy consumption per capita. Thoroughly plausible is that the use of agricultural biomass (excluding timber) was approximately the same in both countries (between 40 and 45 GJ per capita). However, in Austria, despite the significantly lower level of industrialisation, energy consumption for the production of process heat and heat (firewood and coal) was also nearly the same per capita as in the U.K.[29] Comparatively unfavourable climatic conditions in the alpine areas, coupled with a higher availability of firewood as well as a higher share of rural households (with inefficient fireplaces and a high demand of wood) could have also led to an average household energy consumption significantly higher than the values in the United Kingdom. In addition, one can assume a certain underestimation of the household energy consumption in the U.K. since the collected firewood from agricultural areas and peat were not included in the figures (see below).

In the United Kingdom, at this time already 35 GJ per capita were consumed in the form of coal, and fossil fuels covered nearly half of the total energy consumption. Thus, in the U.K. the transformation of the social energy system was already far advanced in the first half of the 19th century. Biomass played a negligible role in the production of heat and process heat, and the replacement of animal and human labour by technologies based on fossil fuels already played a crucial role in domestic production.

In Austria, firewood presented the most important technical fuel (in the classical sense) until well into the 19th century. Through the country's rich forests and the high per capita availability of forested areas (0.89 ha per capita in Austria as compared with 0.04 ha per capita in the U.K.), wood was an abundantly available resource for which the corresponding technology as well as the structure of demand was optimised. The high availability of timber

[29] It must be pointed out that once again the base of data to estimate primary energy consumption in both countries is very meagre. For Austria there is no data on foreign trade in the 19th century, but one can assume that imports and exports of coal, wood and foodstuffs first reached a quantitatively relevant amount after 1850/1870 (see also foreign trade data for the U.K.). Additionally, domestic extraction of timber in Austria is wrought with considerable uncertainty (see Krausmann 2001). Nonetheless, assuming an overestimation of timber consumption for the first half of the nineteenth century and the drop in consumption after 1870 does not significantly change the overall picture. Assuming that firewood consumption in 1830 was overestimated by 30%, total consumption would be approx. 65 GJ per capita (rather than 76 GJ per capita) and the rise in energy consumption in the 19th century would be comparatively greater.

and the sparse coal storage sites in Austria are key reasons for the relatively late transformation of the social energy system. Both the supply of households with process energy and heat as well as the technology of energy-intensive heavy industries were equipped for wood and wood and coal, and due to economic and technological reasons coal could only slowly establish itself. The import of coal in larger amounts and under competitive conditions was first possible with the expansion of the railroad. Corresponding with the expansion of the railroad network, the consumption of coal also rose rapidly. At the beginning of the 20th century, coal consumption in Austria was some 50 GJ coal per capita and in all of Cisleithan 30 GJ of coal per capita – thus still significantly less than in the United Kingdom. Also the energy consumption as a whole (90 GJ per capita) was clearly below that of the U.K. (145 GJ per capita). After World War I, the new Republic of Austria was cut off from the energy resources of the monarchy's eastern provinces. In the post-war years, the monarchy's disintegration and the economically disastrous situation led to a delay in the industrialisation process and a restructuring of industrial production in Austria. Under the extreme energy scarcity, it was primarily energy intensive branches of heavy industry that suffered and were gradually removed in the 1920s.

In contrast to Austria, the United Kingdom had almost no extensive forest areas available at the beginning of the 19th century. Therefore, wood was not available in any form as a mass fuel. What nonetheless remained open was the question of when and how the transformation of energy systems could have taken place in the U.K. Large scale deforestation had already taken place in the United Kingdom long prior to the 18th century (Simmons 2001; Rackham 1976), nonetheless, wood was supposedly a quantitatively significant fuel well into the 18th century – primarily at the household level. According to a rough estimate based on information from Hatcher (1993) and Clark (1999),[30] the firewood supply from agriculturally productive areas (hedges, stock trees on pastures, etc.) in the U.K. could have still amounted to 10-15 GJ per capita between 1700 and 1750, which was by and large the same as the per capita consumption of coal at this time (see Hatcher 1993). Hence, at this time biomass would still have a share of 80-90% of total energy consumption.[31] The energy demand (heat and process energy) of English households could therefore have been based largely on firewood in the 18th

[30] This calculation rests on the assumption of a 10% share of hedges and wooded areas of the total area of the United Kingdom and an average wood yield of 2.5 t/ha. From that arises an energy potential of 80-90 PJ in the form of firewood.

[31] Behind this figure is the assumption that agricultural biomass and timber from the forestry industry comprise 45 GJ per capita, timber from agriculturally productive areas approx. 15 GJ per capita (calculated according to Hatcher (1993)) and coal approx. 10 GJ per capita.

century, despite the lack of actual forest areas. The significance of coal would then first grow with increasing urbanisation and industrialisation.

A synchronisation of developmental paths and final transformations of the social energy systems began in both countries after World War II with the increasing significance of petroleum. In both countries energy consumption began to rise dramatically and in both countries this rise was based on imported petroleum. In the mid-1970s, Austria had overtaken the over 100-year-long deficit in primary energy consumption as compared to the U.K. With the oil crisis in 1979, in both countries energy consumption began to stabilise at a level of some 200 GJ per capita, or three times the value of 1830. In both countries the dominance of petroleum was minimized and natural gas, water and atomic power as well as biomass were attributed with increasing importance.

Considered comprehensively, it seems plausible that the two countries had a relatively similar level of energy consumption in 1700, somewhere around 55-65 GJ per capita, with a 90% share of biomass. With urbanisation and industrialisation in the 18th century, the U.K. speed ahead in the consumption of coal (although without any major effects on biomass), so that in 1830 the social energy system's transformation process was already well advanced – in contrast to the development in Austria where early industrialisation was based on firewood.

In the U.K., energy consumption stabilised in the coal based system in 1880 at 150 GJ per capita, and remained steady for nearly 70 years. In Austria, the industrialisation process occurred with a certain delay and energy consumption first stabilised at the end of the 19th century at 90 GJ per capita.[32] Directly after World War II, petroleum produced a growth dynamics that is described in the literature as the 1950s syndrome[33] (Andersen 1996; Pfister 1994) and as a "Fordist pattern of production" (Boyer 1979). This growth dynamic, which can be observed at various levels of socio-economic development, should be seen as having a fundamental connection to the transformation of the social energy system, which took a further decisive step with the integration of petroleum and the accompanying opening of technological possibilities. In the context of the oil crisis, in the 1970s a restabilisation in energy consumption became evident at a level of some 200 GJ per capita.

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[32] Due to the events of the war and the economic crisis in Austria there were continuous dramatic collapses in the energy consumption so that one can only speak conditionally of a stabilisation of the level.

[33] The term "1950s syndrome" appears problematic, however, as it describes a phenomenon that presents a particular characteristic of the politically "disturbed" development in Europe which in the U.S., for example, is not so clearly recognizable.

Summary and Prognosis

The events presented portray the transformation of the social energy systems in Austria and in England in the period from 1850 until the present day. In England – one of the starting points of industrialisation in Europe – in the 19th century this transformation was more heavily advanced than in Austria. Whereas in Austria firewood was substituted at least in part by coal in the 19th century, this is hardly the case in the United Kingdom where coal was already used in addition to biomass. In the second half of the 19th century more or less differentiated energy systems based on coal and agricultural biomass began to stabilise in both countries, whereby the level of energy consumption in the U.K. was clearly higher than in Austria. Industrialisation based on coal is the first and most crucial step in the emancipation of the energy system from the land mass.

A simple thought experiment shows that coal consumption in the United Kingdom in 1850 had already reached well beyond the potential capacity of the solar energy system. If one assumes that the energy content of a fossil fuel were to be covered 100% by firewood or another biomass, then coal consumption in 1850 would correspond with a forest as large as the United Kingdom; 100 years later the surface area would have to increase to five times as great; in 2000 the surface area would be approximately 19 times as great (see Sieferle 2001b).[34] In Austria, which is significantly less densely populated and requires less fossil energy, the virtual forest area of the consumed fossil energy first reached the extent of the country's surface area in the mid-20th century, it currently is 2.5 times as great (see Figure 22).

[34] Behind this calculation is the assumption that per ha of forest some 5m2 of firewood can be sustainably harvested. Since a cubic meter [m2] of firewood has a calorific value of approximately 10 GJ, a PJ of fossil energy is comparable with a forest area of some 210 km². A ton of coal (with a calorific value for coal of 30GJ/t) according to this calculation corresponds with a forest area of 0.6 ha. The area for gaining a PJ diesel from rape seed oil is similar. The calculation of the potential of a forest area can only serve as an illustration of the dimensions of the fossil energy system and in no way presents a realistic replacement scenario. For that purpose, here the assumptions would be too generalized.

Figure 22: Virtual areas of used fossil energy in comparison to the entire area in the United Kingdom (22a) and in Austria (22b)

Figure 22a: United Kingdom

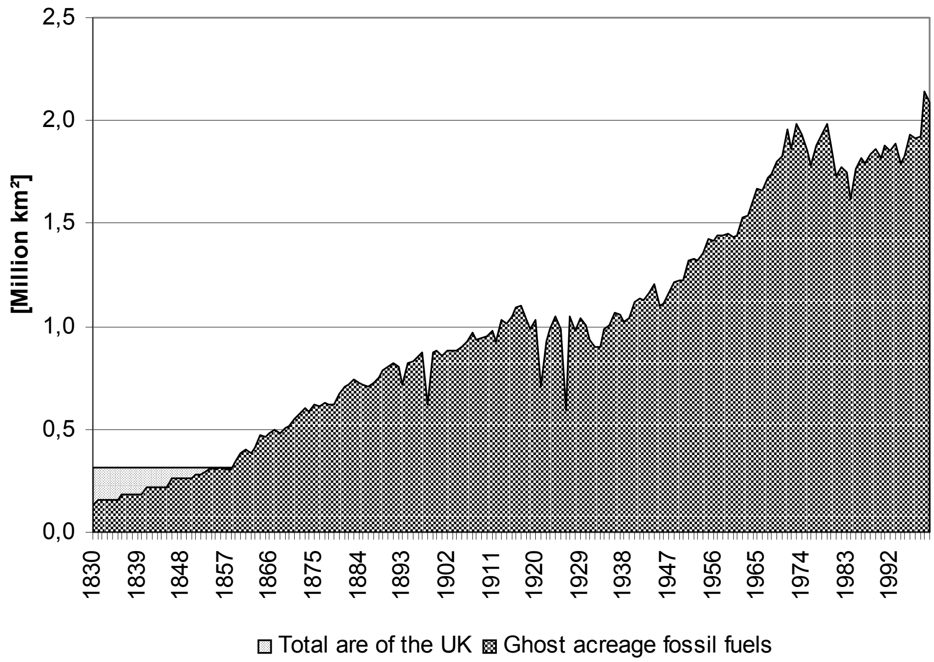
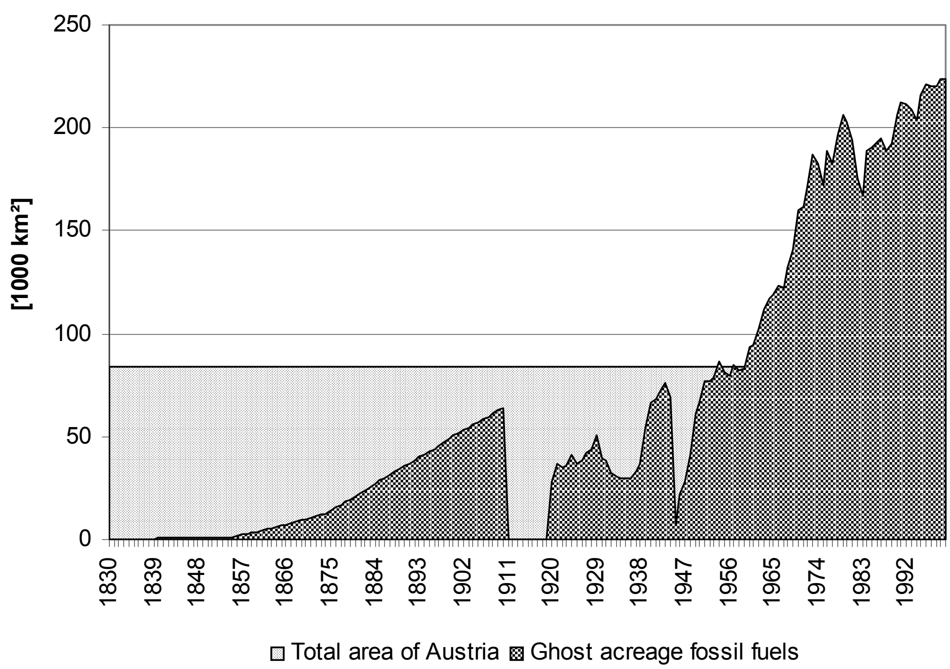


Figure 22b: Austria



It was first after World War II that petroleum introduced a new dynamics into the development of the social energy system. The changeover from coal to petroleum and the related technological possibilities somehow synchronized the development in Austria and the United Kingdom. Until the oil crisis in the 1970s, both countries experienced rapid growth in energy consumption and per capita energy consumption reached almost identical levels. The institutional restructuring in the 1950s (the Fordist regime) can be used as description of part of a 200-year long transformation of the social energy system. The use of petroleum, following the use of coal, is a further decisive step towards a comprehensive differentiation of the fossil energy system. It was only after the implementation of petroleum that human and animal labour became marginalized within the energy system, which enabled industrialisation of the agricultural production system. This resulted in an extensive de-coupling of the energy systems from biomass and surface area. This de-coupling, however, in no way meant that biomass would become marginal within the energy system. On the contrary, through industrialisation of the agricultural system, biomass consumption rose considerably. What changed was the limited aspect of biomass and the function of the implementation of the surface area for the provision of socially usable energy. Surface area usage transformed from an agent that provided energy to an energy drain.

Interestingly, since the 1980s, beginning with the oil crisis, renewed stabilisation of the social energy consumption at 190 to 200 GJ per capita has become evident in both countries.

As our study illustrates, the development of the social energy system does not show any type of constant pattern, but rather, can be described as an alteration of phases of distinctive growth and those of stabilisation. Whether the stabilisation since the 1980s is permanent and the structure and level of energy consumption can be considered as typical for fully developed industrial societies, remains questionable.

In order to test the general validity of the process of transformation of the socio-ecological regime with the advent of industrialisation as described for Austria and the United Kingdom, further studies offering national comparisons would be necessary (see Myllyntaus and Mattila 2002; Kander 2002). An expansion of the analysis to the entire Habsburg Monarchy in the 19th century and a further successor state (such as Czechoslovakia and the Czech Republic) in the 20th century as well as e.g. the United States of America would be a necessary and informative next step in comparative research.

Abbreviations

AUT .... Austria with its current borders
DE .... Domestic Extraction
DMC .... Domestic Material Consumption
DMI .... Domestic Material Input
GJ .... Giga Joule (10^9 J)
Ha .... Hectare; 1 ha equals 10 000m^2
MJ .... Mega Joule (10^6 J)
p.a. .... Per annum
PJ .... Peta Joule (10^{15} J)
PJ_{GCV} .... Peta Joule Gross Calorific Value
U.K. .... United Kingdom

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