5. The local base of the historical agrarian – industrial transition and the interaction between scales

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5.1 INTRODUCTION

Profound changes in Austria's socioecological systems occurred during its transition from an agrarian to the present industrial regime in the years from 1830 to present, as already shown in Chapter 2 of this volume. In this chapter we proceed with an analysis of this transition process in three different local situations. We discuss one urban and two rural case studies and then try to demonstrate a fundamental change in the relations between local and national scales during transitions from an agrarian to an industrial regime.

In the course of the 19th and 20th centuries, Austria was transformed from an advanced agrarian society, in which farmers and their families made up three-quarters of the population, into a classical industrial society, in which manufacturing was dominant, and finally into a modern 'service economy', in which the lion's share of the GDP is produced in service sectors. Overall, total GDP rose almost 30-fold and per-capita GDP 12-fold throughout the period 1830–2000.

This transition was only possible because Austria switched from an area-dependent, biomass-based energy system to an energy system heavily reliant on (mostly imported) fossil fuels. While coal was dominant throughout the 19th century and well into the first half of the 20th century, oil, and later natural gas, gained importance in the second half of the 20th century. These changes in the energy system allowed an almost threefold increase in the amount of primary energy available per capita, and an approximately sevenfold increase in the per-capita availability of useful energy.[1] Because population more than doubled in this period, these increases in per-capita energy turnover implied an approximately sixfold increase in Austria's total primary energy throughput.

These changing patterns in the economy at large, and in the 'energetic metabolism' of society in particular, resulted in massive changes in cultural landscapes and ecosystems, and sustainability problems in general. In 1830, almost all of the energy available to humans in Austria was gained through harnessing the productivity of green plants through agriculture and forestry. This meant that almost all productive area was used either as cropland or as grassland to feed humans and livestock, or as forest to provide timber and woodfuels, and to support livestock through forest grazing and litter extraction. Ecosystems were thus used intensively, probably close to the maximum extent possible with the technology available at that time. Cultural landscapes, however, were highly diverse, and small-scale patterns of settlement, cropland, grassland and forest patches prevailed throughout the country, from the lowlands well into the mountainous regions. Sustainability problems in 1830 were those of an agrarian regime (Haberl et al. 2004a): the challenge was to maintain the often fragile balance between population growth and agricultural production, which might be more accurately described as a balance between the productive capacity of agro-ecosystems that severely constrained energy availability (and thus human and animal populations) on the one hand and the demand for human and animal labour (and therefore sufficiently large population numbers) required for agricultural production on the other (Boserup 1965; Netting 1993). Of course, technology and the organization of production played important roles in this transition process (Boserup 1981; Grübler 1998).

The introduction of fossil fuels alleviated the energetic restrictions experienced in Austria, but as this pattern continues to spread around the globe, new sustainability problems are arising: the dependency on non-renewable resources, including fossil fuels, and the emergence of unsustainable changes in atmospheric composition, in particular, the rising concentration of CO_2 in the atmosphere, which is highly likely to alter the Earth's climate fundamentally (IPCC 2001). While these implications have to be dealt with primarily on the global scale (even though the changes will be felt everywhere on Earth), there have also been important changes in Austria's ecosystems and landscapes. Some of them have been reviewed in Chapter 2, for example, the rising yields on croplands and grasslands, the surging use of mineral fertilizers, the deterioration of agricultural energy efficiency, the shrinking of agricultural areas, the expansion of forests and urban areas, the upward trend of net primary production (NPP) and the reduction in human appropriation of NPP (HANPP) this entailed.

This chapter is largely concerned with changes at local scales in both rural and urban settings, with changes in the relations between urban and rural areas, and with local–national linkages. More generally speaking, these are all issues of spatial organization of both society and ecosystems that are of high relevance for the evolution of cultural landscapes, including their spatial patterns (Peterseil et al. 2004; Wrbka et al. 2004).

The development of transport systems is of course of vital importance for understanding these issues, therefore this chapter places much emphasis on this aspect of technological change.

5.2 TRANSITIONS IN URBAN–RURAL RELATIONS IN TERMS OF ENERGY FLOWS

Chapter 2 has revealed the high significance of changes in society's energetic metabolism for understanding socioecological change during transitions from the agrarian to the industrial regime. Thus we compare here per-capita energy flows in our three case studies, which refer to three very different municipalities, to the national average discussed in Chapter 2. Two local studies, Theyern and Voitsau, concern rural villages in very different ecological as well as socioeconomic settings. Vienna, Austria's capital and largest city by far is the third case study.

Characteristics of the Three Local Cases Studied

Theyern (elevation 250 m a.s.l.) is a mainly cropland farming-dominated lowland community in the Traisen valley near the provincial capital of Lower Austria, St Pölten. Theyern is located in a hilly area less suitable for agriculture than the surrounding lower regions. While it was intensively cropped in the 19th century, agriculture is currently receding. Cropland is being progressively abandoned, while part-time farming and specialized cultures such as orchards and non-agricultural uses are becoming more important. Voitsau (elevation 600–800 m a.s.l.) is located in the granite stock of the 'Waldviertel' area and is characterized by rougher climatic conditions than Theyern. In the early 19th century, grain production in combination with animal husbandry was the dominant type of land use in Voitsau. Current agriculture is dominated by cattle farming (both milk production and fattening) and a mix of cropland and meadows.

These two rural communities are compared with Austria's capital, Vienna. Data for Austria, Theyern and Voitsau refer to approximately 1830 and data for Vienna refer to 1800. No contemporary data are available for the small villages analysed in the historical study. For comparison, we use contemporary data for the municipalities in which the respective village is located, that is, Nussdorf (which includes Theyern) and Kottes (which includes Voitsau). Both are a little more than ten times larger than the villages analysed in the historical study. In the following we refer to Nussdorf/Theyern as a 'lowland system' and to Kottes/Voitsau as an 'upland system'.

Some basic indicators to describe these four systems are displayed in Table 5.1. These figures demonstrate both the huge differences between the systems and the changes between the pre-industrial period studied and the current point in time. It may be interesting to note that, while Austria's population increased by a factor of 2.25 within the period covered, population density remained about constant in the upland system, while its growth was much smaller than the Austrian average in the lowland system (a factor of 1.6). In Vienna, on the other hand, population grew by a factor of 7 – that is, much more rapidly than the Austrian average, indicating the significance of urbanization processes during the transition from the agrarian to the industrial regime. Population density in Vienna was two orders of magnitude larger than in the rural communities (see also Figure 2.1 in Chapter 2).

Table 5.1 shows that agricultural area covered as much as 91 per cent of the area of the upland system in 1830, while the corresponding figure for Austria as a whole was much lower (54 per cent). This can be explained by the fact that a large part of Austria's area is mountainous and hardly suitable for cultivation. The share of agricultural area declined in all three systems. Gross grain yields increased by factors of about 5.5–6.5 in all systems. The aboveground net primary production of agricultural land also increased considerably in all systems. Livestock densities were rather similar in Austria, the lowland and the upland system in 1800/1850, whereas they vary considerably today, with the upland system rearing three times as many animals per hectare of agricultural area than the Austrian average, and the lowland system keeping only one-third of the Austrian average. While ruminants accounted for most of the agricultural animal biomass in 1800/1830, their share had dropped considerably in the Austrian average in 1990/2000, but not in the upland and lowland systems studied.

Energy Flows Around 1830 and 2000: Comparing Local and National Scales

In Table 5.2 we present a comparison of energy flows in these four systems in the early 19th century and the last decade of the 20th century. Data on biomass flows in the upland and the lowland systems and in Austria as a whole are taken from previous work by the authors (Krausmann 2004, 2006a; Krausmann and Haberl 2002). Data on energy flows in Vienna were largely taken from official statistics (see Krausmann 2005).[2]

The results for the lowland and upland systems are compared with the Austrian average obtained from the official Austrian energy balance for 1991 (Alder and Kvapil 1994) in Table 5.2. It shows that total household use of technical final energy per capita calculated for the lowland and

Table 5.1 *Basic socioeconomic and agro-ecological indicators of the lowland and upland systems, Vienna and Austria in the 19th and 20th centuries*

	1800–30				1990–2000			
	Austria	Lowland	Vienna	Upland	Austria	Lowland	Vienna	Upland
Population [1000 inh.]	3 592	0.10	230	0.13	8 092	1.45	1 618	1.67
Population density [inh./km²]	42	45	4 200	40	96	75	3 899	33
Agricult. population [1000]	2 694	0.10	n.d.	0.13	400	0.54	n.d.	1.10
Agricult. labour force [1000]	1 567	0.07	n.d.	0.09	223	0.23	n.d.	0.46
Agricult. population [%]	75	100	n.d.	100	5	37	n.d.	65
Area [km²]	85 906	2.25	55	3.25	83 400	19	415	51
Agricult. area [km²]	46 627	1.42	n.d.	2.96	33 360	8	79	31
Agricult. area [% of total]	54	63	n.d.	91	40	41	19	61
Farm size [ha agr./farm]	n.d.	8.3	n.d.	11.0	7.2	13.2	n.d.	15.6
Cropland/grassland	0.71	8	n.d.	1.9	9.4	1.9	n.d.	0.8
Gross grain yield [kg/ha]	890	819	n.d.	732	5 708	5 007	n.d.	4 004
Product. agric. land [GJ/ha]	33	38	n.d.	26	84	76	n.d.	114
Livestock density [LU/km²]	17	24	n.d.	24	26	8	n.d.	61
Of which ruminants [%]	95	90	n.d.	96	50	91	n.d.	82

Sources: Krausmann (2004, 2005, 2006a).

Table 5.2 *Per-capita flows of energy [GJ/cap/yr] in the lowland system, the upland system, Vienna and Austria as a whole in the 19th and 20th centuries*

	1800/50				1990/2000			
	Austria	Lowland	Vienna	Upland	Austria	Lowland	Vienna	Upland
DE	*73*	*78*	*0*	*91*	*93*	*76*	*1*	*278*
Biomass	73	78	0	91	61	76	1	278
Fossil fuels	0	0	0	0	15	0	0	0
Hydropower	0	0	0	0	17	0	0	0
Import	*0*	*0*	*35*	*0*	*152*	*77*	*107*	*59*
Biomass	0	0	34	0	23	5	7	8
Fossil fuels	0	0	1	0	124	58	94	41
Electricity	0	0	0	0	5	14	6	10
DEI	*73*	*78*	*35*	*91*	*245*	*153*	*108*	*337*
Biomass	73	78	34	0	84	82	8	286
Fossil fuels	0	0	1	0	139	0	94	0
Hydro/electr.	0	0	0	0	22	0	6	0
Export	*0*	*2*	*0*	*2*	*48*	*36*	*1*	*71*
Biomass	0	2	0	2	24	36	1	71
Fossil fuels	0	0	0	0	19	0	0	0
Electricity	0	0	0	0	5	0	0	0
DEC	*73*	*76*	*35*	*89*	*197*	*117*	*107*	*265*
Biomass	0	76	34	89	60	46	7	215
Fossil fuels	0	0	1	0	120	58	94	41
Hydro/electr.	0	0	0	0	17	14	6	10

Note: DE denotes 'domestic extraction', DEI 'direct energy input' and DEC 'domestic energy consumption'.

Source: See text and Appendix 5.1.

upland systems is similar to total household use of technical final energy according to Austria's official energy balance. Energy use in the lowland system is highest at 51.4 gigajoules per capita per year (GJ/cap/yr) and the upland system uses 50.6 GJ/cap/yr, whereas the Austrian average is 48.5 GJ/cap/yr. Thus, given the uncertainty of such an assessment, we can conclude that household final energy use in the lowland and the upland systems is essentially equal to the Austrian average.

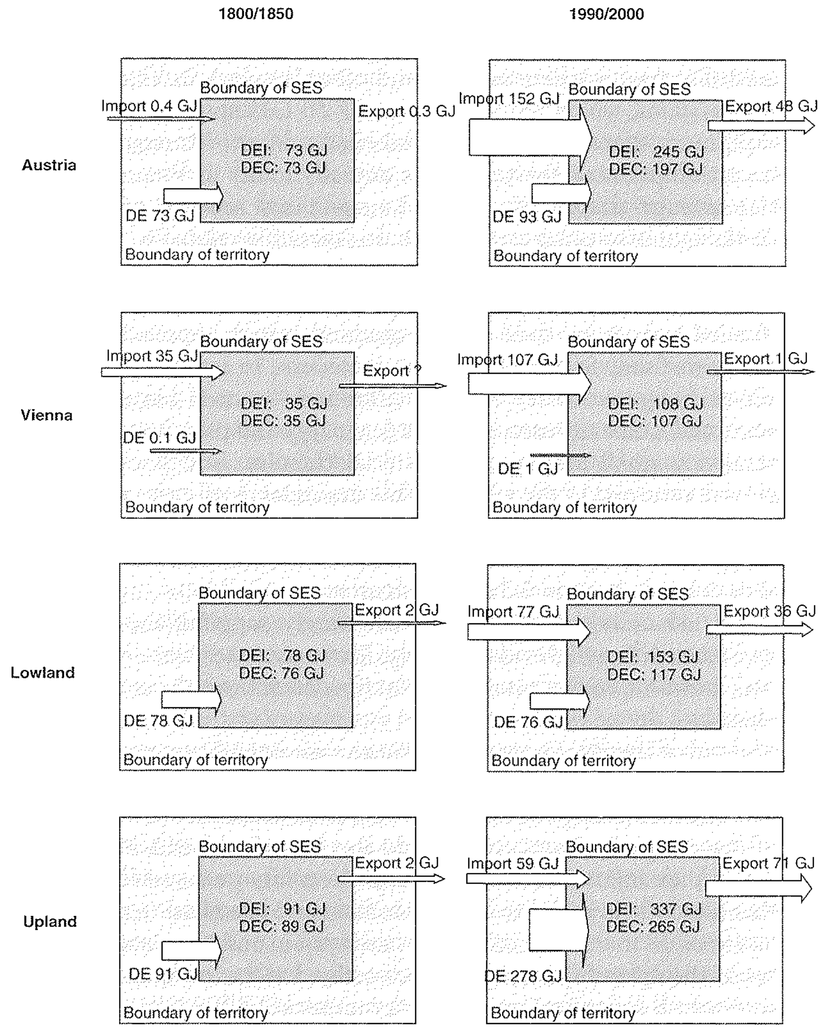
There are, however, meaningful deviations with respect to fuels used. Both rural municipalities, the upland and the lowland systems, use much more biomass (mostly wood) for space and water heating than the Austrian average: in these municipalities, biomass accounts for almost one-third of technical final energy use in the lowland system and about half of technical final energy use in the upland system, and both values are far above the Austrian average of 14 per cent. District heating is not available in both municipalities.[3] Moreover, the upland system was not connected to a natural gas grid in 1991; gas heating systems in the upland system used liquid gas. In the upland system, biomass accounts for almost all (87 per cent) of energy used for space heating.

These figures show that locally available biomass can still play a significant role in technical energy supply in rural areas, while its importance is much lower in urban settings and thus also in the national average, since a large proportion of Austria's population today lives in urban areas. The use of oil products was higher in the Austrian average, due to the higher share of heating oil in space heating compared with the two rural municipalities (upland and lowland), where a high percentage of dwellings used wood as a heating fuel.

Rural–Urban Interrelations: Growing Connectedness and Interdependency

The data contained in Table 5.2 are presented in comprehensive form in Figure 5.1. Quite clearly, in 1800/1830, Austria as a whole resembled the two rural cases while Vienna, as a city, differed completely. Just like Austria as a whole, rural villages were almost self-contained systems, which received little quantifiable inputs from outside (there were a few, but our assessments suggest that these were quantitatively negligible). Unlike Austria, however, both rural systems exported biomass. Even though this export was small in biophysical terms – around 2 GJ/cap/yr for both villages – it was highly valuable and decisive for the functioning of the system: such small net exports from vast areas made up the input needed by urban systems such as Vienna. This export was only about 2–3 per cent of the domestic extraction of energy in both rural cases. By contrast, according to the figures presented here, Vienna depended almost completely on imports, which were mostly in the form of biomass: coal constituted only about 3 per cent of Vienna's energy input in 1800/1830 (Table 5.2).

The amount of energy flowing into the system in 1800/1830 was much lower in Vienna than in all other systems. This discrepancy is mostly a result of the fact that the energy imported to Vienna was different from the energy extracted in the rural systems: while the domestic extraction in the rural systems was biomass containing a lot of feed for livestock required to produce food for domestic consumption and export, Vienna imported 'ready-to-use' biomass that could be directly used as food, feed for draught animals and fuelwood. Fuelwood and charcoal for space/water heating as well as manufacture accounted for about 80 per cent of Vienna's energy



Notes: Values are gigajoules per capita and year (GJ/cap/yr). SES is an abbreviation for 'socioeconomic system' with the same system boundaries as applied on the national scale (see Chapter 2). DE denotes 'domestic extraction', DEI 'direct energy input' and DEC 'domestic energy consumption'.

Source: Table 5.2.

Figure 5.1 Main components of energy flow analyses for Austria, Vienna, the lowland and the upland systems import, food for humans for about 17 per cent and 4 per cent was fed to draught animals (including about 5000 horses). That is, much less energy was needed to feed working animals and other livestock in Vienna than in the rural systems, which required about 40–50 GJ/cap/yr to sustain their livestock, more than half of their total energy input. Moreover, the per-capita consumption of fuelwood was actually lower in Vienna than the Austrian average, despite the fact that a significant amount of wood was used in the manufacturing sector. This was certainly related to the relative scarcity and hence also more efficient use of wood in the city.

Under the conditions of the agrarian regime, urban/industrial centres were fuelled entirely by their rural hinterland, which supplied the urban dwellers with food, firewood and raw materials. In energetic terms, the physical exchange processes between cities and the rural hinterland were unidirectional, cities represented a sink for energy and plant nutrients. Only comparatively small amounts of material (textiles, iron goods) but no energy were returned to the villages. This dependence of cities on biomass and, therefore, the energy surplus of the rural hinterland was a major bottleneck for urban growth and spatial concentration, an issue that is discussed in detail in Section 5.3 of this chapter.

In turn, urban/industrial centres increasingly supplied the hinterland with products with a high value density, for instance textiles or iron tools. This was, however, only a small material flow back from the centres to the hinterland.

By the end of the 20th century, Austria as a whole had become a throughput system in energetic terms, with the energetic value of imports being about three times as large as exports. Fossil fuels accounted for over 80 per cent of these imports. Rural systems had also become dependent on energy imports, as their inflows of fossil fuels and electricity were considerable. On the other hand, their ability to export biomass had increased tremendously, by a factor of 18 in the case of the lowland system and by a factor of 36 in the case of the upland system. It is noteworthy that the lowland system had already become dependent on net energy imports, with a relation between imports and exports of over 2, whereas the upland system still exported slightly more energy than it imported. This shows that rural–urban relations had changed their character fundamentally, as rural systems, thanks to the availability of fossil fuels, they no longer had to fulfil a role as suppliers of net energy to urban systems, a role they had inevitably had in the agrarian regime. Except for systems including fossil-fuel extraction sites, hydropower plants or other similar installations, only predominantly agricultural systems can today be expected to export more energy than they consume. The negative energy balance of the lowland system can be explained on the one hand by its function as a settlement area for people commuting to nearby centres, above all, to the Lower Austrian capital St Pölten, and on the other by the meanwhile significant presence of economic activities outside agriculture, that is, firms in the manufacturing and service sectors.

The changes seem to be smallest for Vienna: its energy throughput per capita had tripled, but it continued to depend completely on energy imports. The fuel mix had changed substantially, however: about 88 per cent of the imports at the end of the 20th century were fossil fuels, the remainder were electricity and biomass, mostly food. Vienna still consumed considerably less energy than the Austrian average, and the reason remains that Vienna mainly imported 'ready-to-use' final energy and most energy conversions required to produce this energy took place outside its boundaries. Moreover, Vienna was dominated by service sectors, a considerable share of the population being engaged in government, education, company headquarters and so on, and had little heavy industry. It may be assumed that Vienna imported large amounts of so-called 'grey energy', that is, energy incorporated in the products it consumed but that were produced elsewhere. To establish how large this amount of energy consumed only indirectly was would require an input–output analysis to be undertaken.

The livestock-intensive agricultural production system of the upland system is reflected in an extremely high per-capita value of domestic extraction: in the upland system the per-capita domestic extraction of biomass was larger than Austria's aggregate per-capita energy input, and about five times higher than the average Austrian per-capita domestic extraction of biomass.[4]

The extent of specialization between different rural systems, which was low in 1800/1830, has, by the end of the 20th century, become striking. In the early 19th century, the per-capita domestic extraction of Austria as a whole and of the lowland as well as the upland system was astonishingly similar. At the end of the 20th century, extreme differences are visible. This specialization process can be traced by looking at the indicators displayed in Table 5.1: in 1800/1830 livestock density was identical in the lowland and the upland systems – in both cases, 24 livestock units (LU) per km^2 – and similar to the Austrian average of 17 livestock units per km^2. Nowadays, livestock has almost disappeared from the lowland system (8 LU/km^2), while the density has almost tripled in the upland system to 61 LU/km^2.

To summarize: we find that the most significant change between agrarian and industrial metabolism, besides the surge in overall throughput and the reliance on new resources such as fossil fuels, is the increasing connectedness and interdependence between different locales. In the agrarian regime, almost all material and energy flows were local, and beyond that there were small, but largely unidirectional flows from rural areas (sources) to urban areas (sinks). A similar flow existed also for population, with rural areas exporting people to urban centres, which, at least during the early stages of the transition, were not able to sustain themselves demographically (Wrigley 1985). The biomass 'exported' consisted partly of tithes and taxes and partly of produce sold on the market. Revenues were mostly used to buy essential goods such as iron tools, salt and other items that could not be produced locally.

In the industrial regime, within a highly developed country, energy flows between urban centres and rural communities become more symmetrical, as they flow in both directions. These exchange processes are fuelled by internationally organized flows of fossil fuels. In the case discussed here, the flows between urban and rural systems grew by a factor about one order of magnitude larger than the growth of the per-capita or national-level flows discussed in Chapter 2. For example, Austria's per-capita DEC grew only by a factor of 2.7, but the outflows from the rural systems grew by factors between 18 and 36. Economically, these often marginal rural systems depend to a large extent on subsidies making up a significant part of the income of agricultural households. Retired people account for a substantial share of the population in many marginal rural communities (among them the lowland system discussed here), their income is obtained from transfers (pensions), as is the income of unemployed people, proportionately more of whom live in rural than in urban regions. Moreover, in many rural communities a significant percentage, sometimes even the majority, of gainfully employed people commute to regional centres for work, which is also a strong factor in the lowland case discussed here.

5.3 SCALE LINKAGES AND THEIR IMPLICATIONS FOR TRANSPORT AND SPATIAL ORGANIZATION

The analyses presented in the previous section have shown that the transition from an agrarian to an industrial society implies enormous increases in the flows of materials and energy between different locales. That is, transport processes of materials as well as people are soaring. In this section we will discuss 1) implications for overall transport intensity and 2) their significance for land use.

Rural–Urban Interrelations and Transport Intensity

Using the data presented above, it is possible to estimate the area demand of urban centres. Vienna's energy import of about 35 GJ/cap/yr or about 8 petajoules per year (PJ/yr) in the early 19th century was equivalent to about 600 000 tons of biomass, above all, wood, grain, meat, milk, feed and so on. Assuming typical yields and conversion efficiencies of the early 19th century, the supply of this amount of materials and energy required about 70–100 times more area than was available within the boundary of the city: Vienna's wood and food demand each directly required about 1500–3000 km^2, and feed for draught animals required about 150 km^2. The supply of an average inhabitant of Vienna required about 1.5–2 hectares (ha) of agricultural or forest land, of which only about 0.02 ha were available within the boundaries of the city.

The area actually used to support Vienna's 230 000 inhabitants was, however, much larger: as shown above, only a small fraction of the production of rural areas could actually be exported to support urban centres. According to the data presented above (see also Fischer-Kowalski, Krausmann and Smetschka 2004), between five and 15 people living in rural communities were required to produce enough food, fuelwood and feed to support one city dweller. Therefore, the total amount of area indirectly needed per capita was probably about 10–30 hectares.

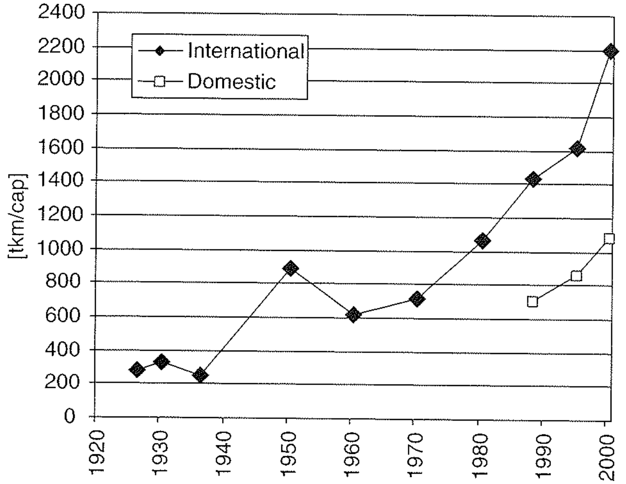
This illustrates the limitations for urban growth under the conditions of the agrarian regime: comparatively low yields and agrarian surplus rates translated urban demand into vast hinterlands required to supply the city with sufficient energy and raw materials. Together with the high energy costs of transport this constituted a major bottleneck for urban/industrial concentration. In particular, overland transport was associated with high costs that were prohibitive for long-distance transport of bulk materials such as firewood or cereals. Waterways provided a much cheaper means of transport and inland cities such as Vienna relied heavily upon rivers and canals for their supply. Hence, not the absolute amount but the location of woodlands in relation to waterways was decisive for urban wood supply. Only about 50 per cent of Vienna's wood demand could be supplied from adjacent forests, but large amounts of wood originated from distant woodlands along the Danube river: some 26 per cent came from Upper Austria, Salzburg and Tirol and about 10 per cent from Bavaria, all of which was transported several hundred kilometres on the Danube and its feeders (Wessely 1882). Grain came partly from regions that today form part of the Czech Republic or Hungary; two-thirds of the oxen consumed as meat came from Hungary and were walked across the Puszta, thereby creating a very specific grassland ecosystem that is all but 'natural' (Mayr 1940; Messing 1899).

In the early 20th century, Vienna's population had risen to 1.6 million. Despite considerable increases in agricultural yields, the direct area required (that is, not counting the support of the agricultural workforce) to provide the food consumed by this roughly five times larger population had risen to about 6000–10 000 km^2. Vienna's 40 000 draught animals required another 1000 km^2. The city's demand for combustible fuel had grown almost tenfold since 1800. Assuming that the 60 PJ of fuel burned annually in Vienna would have had to be supplied from fuelwood alone, this energy demand translates into a hypothetical forest hinterland of 20 000 km^2. This is a vast area, equivalent to about two-thirds of the Austrian woodlands at that time and it is easy to imagine that it would have hardly been possible to manage the fuel supply of Vienna on the basis of wood alone. By 1910, however, 95 per cent of the technical energy was supplied from coal, which increasingly substituted for fuelwood from the 1840s onwards. The actual forest areas needed to supply wood had shrunk to about 1000 km^2, only one-third of the area needed 100 years earlier. Taken together, these figures imply that Vienna's direct area requirement per capita sank to about 0.5–0.75 ha/cap/yr. Both yields and labour efficiency had risen considerably by the early 20th century so that the indirect area requirement per capita must have been reduced considerably too.

Due to the enormous increases in yields, the direct area requirement of Vienna's food supply is today in the same order of magnitude as it was in the early 19th century, that is, about 3000 km^2, despite a considerable rise in the share of meat and other animal-derived food, and despite the population being approximately five times larger. The indirect area requirement of agricultural workers is negligible, due to the more than 300-fold increase in agricultural labour productivity discussed above. Of course, all of this was only made possible by the use of fossil fuels. Today, substituting biomass-derived fuels for fossil fuels consumed in Vienna would require about 25 000–30 000 km^2, roughly one-third of Austria's territory (Krausmann 2005).

All of this implies that enormous increases in freight transport were a prerequisite for the emergence of modern consumption patterns. Unfortunately, at present no consistent time series for the transportation volumes required for the supply of Vienna is available. In a recent modelling exercise, Fischer-Kowalski et al. (2004) estimated that about 800 000 people were required to feed an urban centre of 100 000 inhabitants in the 19th century. Freight transport amounted to about 11 ton-kilometres per capita and year (tkm/cap/yr).[5]

Figure 5.2 presents data on the amount of transport required for Austria's biomass supply from 1926, showing that Austria's foreign biomass trade already required about 300 tkm/cap/yr in the 1930s, a number that surged to a staggering 2200 tkm/cap/yr in the year 2000. If we add to these data rough estimates of internal (on-farm) transport and domestic transport derived from the model calculations discussed above (Fischer-Kowalski et al. 2004) we arrive at the result presented in Table 5.3.



Sources: Unpublished calculations based on Erb (2004); Erb (pers. comm).

Figure 5.2 International and domestic transport required for Austria's biomass supply, 1926–2000

Table 5.3 Transport demand of biomass supply in Austria, 1830 and 2000: a first estimate

	1830 [tkm/cap/yr]	2000 [tkm/cap/yr]	Growth Factor
Local (on-farm) transport	4	7	1.8
Domestic commercial	7	1100	160
International commercial	n.d.[a]	2200	4
Total	11	3300	300

Note: [a] Near zero.

Sources: Fischer-Kowalski et al. (2004); Herry (2003); own estimates.

Even though we admit that these are first, rough estimates, we are confident that we have correctly estimated the orders of magnitude at the least. In any case, this analysis shows that changes in transport technology and infrastructure are among the most decisive forces driving transitions from agrarian to industrial society, and with them all their implications for land use, socioeconomic metabolism and other environmentally relevant aspects of society–nature interaction (see also Ciccantell and Bunker 1998; Grübler 1998).

Impacts on Land-use Patterns and Nutrient Flows

As the transition from the agrarian to the industrial regime resulted in spatial specialization between different regions, it had profound impacts on spatial patterns of agriculture in Austria on the national scale (Krausmann et al. 2003). Many of these changes can only be understood by analysing the role of livestock. In the agrarian system, livestock formed an indispensible part of agriculture, not only for food production but above all as working animals and for their function in the nutrient cycle.

Therefore, even in fertile lowlands a mix of cropland, grassland and forest prevailed to guarantee the supply of food, feed and draught power as well as wood for fuel and construction materials. On the other hand, even in mountainous regions, cropland was needed to produce plant food for humans (Krausmann 2001; Netting 1981; Project Group Environmental History 1999; Sieferle 1997; Winiwarter and Sonnlechner 2000).

Fossil fuels and other external energy sources resulted in various concentration processes: intensive cropland farming was concentrated in fertile lowlands and more or less abandoned in mountainous regions. Cattle rearing receded from the intensive cropland regions, which in turn led to a considerable reduction in grassland area there. Manure, formerly an essential source of plant nutrients, was replaced by mineral fertilizer. The use of mineral fertilizer also meant that less area had to be planted with leguminous crops, such as clover, that were used in crop rotation schemes to fix nitrogen and as cattle feed. The fattening of pigs, poultry and cattle for meat production, mostly based on fodder from cropland such as barley, maize and pulses, was concentrated in regions suitable for maize or fodder cereal cultivation but less competitive in wheat and rye production. Mixed agriculture – for example, Simmental cattle farming for combined milk and meat production – retreated to regions not suitable for large wheat and maize monocultures. Such forms of agriculture survived in fertile, hilly, pre-alpine regions and in the ancient granite stock in northern Austria (Böhmische Masse). In the high alpine regions, only grassland agriculture remained, dominated by cattle farming and some sheep rearing.[6]

One important aspect of these changes relates to the growing importance of long-distance transport processes within the agricultural sector, including their significance for nutrient flows. Using factors of species-specific fodder consumption (for example, Hohenecker 1981) and combining them with grassland as well as cropland yield data, we derived feed balances for Austria's municipalities in 1960 and 1995. Feed production and feed demand was still roughly balanced in many municipalities in 1959. Few municipalities existed where either feed demand was much higher than feed production or vice versa. The picture changed completely in 1995: large grain-producing regions emerged, producing considerably more feed than they consumed, for example, the fertile lowlands in the northeast of Austria. On the other hand, large, coherent 'feed deficit' regions emerged in the hilly, pre-alpine regions of Upper and Lower Austria in which cattle and pig densities are high (see Krausmann et al. 2003).

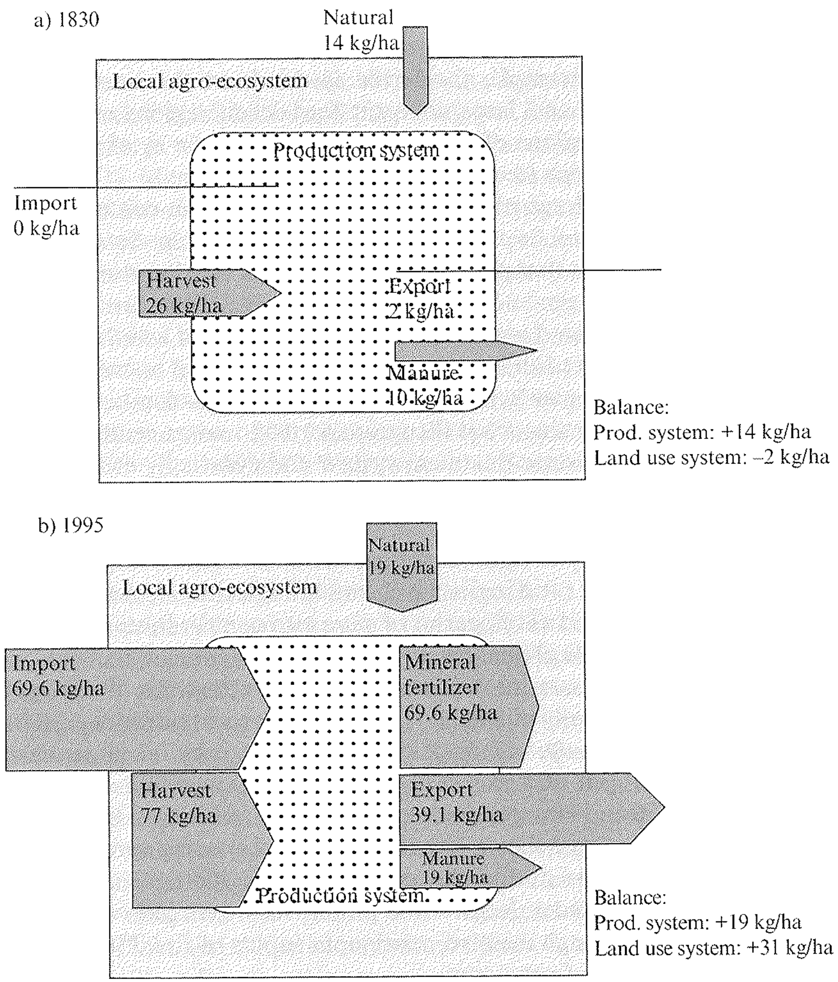
This implies that a large part of the animal feed used in contemporary Austria in 1995 had to be transported over considerable distances. Of course, this also means that previously rather closed, local nutrient cycles, such as that of nitrogen, now extended over large distances: nitrogen entered intensive cropland regions as mineral fertilizer and was then transported as feed to the feed-deficit regions, where nitrogen in manure, by far exceeding local requirements, was then discharged on grasslands. Nitrogen contained in animal products was then transported to urban centres, where it entered the sewage water treatment system and eventually ended up in sewage sludges that are, in Austria, mainly deposited. The once mainly cyclical flow of nitrogen has, thus, been turned into a largely unidirectional flow from air to factory to agro-ecosystem to humans to final repository.

What this means for rural regions is shown in Figure 5.3, which presents nitrogen flows expressed as kilograms of pure nitrogen per hectare of agricultural area per year (kgN/ha/yr) in the lowland system.

According to this assessment (Krausmann 2004), imports of nitrogen increased from practically nil to almost 70 kgN/ha/yr and nitrogen exports increased to 40 kgN/ha/yr – each of these two flows is by far larger than the aggregate nitrogen turnover in 1830. Nitrogen export increased by a factor of about 20 and nitrogen contained in harvested biomass by a factor of about 3.[7] As this figure shows, almost closed local systems were replaced by throughput systems during the transition from the agrarian to the industrial regime. A much larger-scale pattern has emerged, which can only be sustained through massive, continuous inputs of fossil fuels and a large-scale transport infrastructure.

5.4 CONCLUSIONS

The transition from the agrarian to the industrial socioecological regime implies not only the changes in resource use, land use and technology discussed in Chapter 2 but also results in a fundamental reorganization of spatial patterns in socioecological systems. These changes are highly relevant for social organization, including rural–urban relations, spatial patterns in the division of labour and many other aspects of socioeconomic systems. They are equally relevant for ecosystems and cultural landscapes,



Source: Krausmann (2006b).

Figure 5.3 Yearly nitrogen flows in the lowland system in 1830 and 1995

having changed nutrient cycles, spatial patterns in the landscape, spatial organization of different kinds of land use, biodiversity and other factors.

From a socioeconomic point of view, one particularly striking aspect is the enormous growth in transport volumes, measured as ton-kilometres, associated with the spatial reorganization process discussed in this chapter. The 'growth engine' (Ayres and van den Bergh 2005) – that is, the positive feedback loop – behind this seems to be the growing division of labour, which implies longer chains of production, and the utilization of economies of scale in each of the steps of production. These two factors combined clearly mean that more intermediate products have to be transported over ever-longer distances, which is obviously only possible because transport costs are relatively low, due partly to the availability of publicly financed (in other words, subsidized) transport infrastructures.

What a possible substantial rise in transport costs, which might follow a decline in global oil production, could mean for this dynamics is relatively easy to guess, although the entire consequences are difficult to imagine. Global oil production would decline, should the world eventually reach the maximum of global oil production. This event is often termed 'peak oil' and is predicted by some (Campbell 1997, 2004; Hallock et al. 2004)[8] to be likely to occur in the next 15–20 years, perhaps even earlier. From the analysis presented here it is clear that such an event could render much of the current transport infrastructure unsustainable, and would thus call into question current settlement patterns, economic structures and trajectories, the organization of production processes, including agriculture, the distribution of goods and many other fundamental traits characteristic of the organization of modern socioeconomic systems.

From an ecological perspective, the analysis reveals the intricate interrelations between human energy systems, including energy resources used, dominant technologies or even technological clusters (Grübler 1998), and between energy prices (Fouquet and Pearson 1998, 2004) on the one hand and ecosystems on the other. In densely populated countries such as Austria, socioeconomic drivers strongly influence ecological patterns and processes such as primary production (Haberl et al. 2001b), spatial patterns in landscape ecosystems (Wrbka et al. 2004), biodiversity (Erb 2004; Haberl et al. 2004b; Haberl et al. 2005) and many others. How socioeconomic and natural forces interact over long periods of time in shaping cultural landscapes emerging in this interaction process, is an important research question (Haberl, Batterbury and Moran 2001a). Further multi-scale analyses, such as the one presented here, are required if the spatial dimensions of socioecological transitions are to be understood.

APPENDIX 5.1 METHODS USED TO ESTIMATE FOSSIL FUEL USE IN NUSSDORF AND KOTTES

Current fossil fuel energy use in Nussdorf and Kottes was estimated as follows. The estimation was mainly based on the 1991 census, which provided data on household numbers, dwelling size, fuels used for space and water heating, occupation by sector and so on. Final energy use in private households was estimated considering three different kinds of end use: 1) space and water heating, 2) electric appliances including light, and 3) transportation. Final energy used for space and water heating was based on detailed calculations that reflected size and age classes of dwellings, a breakdown of buildings into single family houses and multiple dwelling units, as well as figures on heating systems and fuels used. These indicators were used together with factors on average efficiencies and consumption per unit in the Austrian average taken from the literature (Bertsch et al. 1995). Electricity consumption of electrical appliances was estimated using the average per-capita household electricity consumption in Lower Austria minus the estimated amount of electricity used for space and water heating that resulted from the previous calculation. Fuel use for cars was estimated using data on car stocks per 1000 inhabitants for the respective political districts (St Pölten Land and Krems), assuming an average fuel consumption of 36 GJ/cap/yr (Bertsch et al. 1995).

To calculate energy use in agriculture we used data of diesel fuel use per hectare of cropland, permanent cultures and forest (Haberl et al. 2002). These estimates were derived from official data on the costs of agricultural inputs per hectare and crop published by the Austrian Ministry of Agriculture (BMLF 1992). Using data on cropped area in Kottes and Nussdorf, these data could be used to calculate the use of diesel fuel. Diesel fuel use amounts to 60 per cent of total final energy use in Austria's agriculture (Alder 1999). Total agricultural final energy use was extrapolated from diesel fuel use, that is, we assumed that the distribution of fuels in the lowland and the upland systems is similar in Austria as a whole. For this extrapolation, we used data from an in-depth appraisal of energy use in agriculture and forestry produced by Statistics Austria (Alder 1999).

An estimate of final energy use in other sectors (manufacture, commercial/services and so on) was based on the number of workers. Numbers of workers were taken from the so-called workplace count (*Arbeitsstättenzählung*), which is available with a breakdown into about 65 economic sectors. Final energy use per worker was determined by using Austria's official sectoral energy balance (Alder and Kvapil 1994). Because the sectoral energy balance distinguishes considerably fewer economic sectors (42) than the workplace count, some sectors had to be aggregated in order for these calculations to be performed.

ACKNOWLEDGEMENTS

This chapter builds on material from a number of empirical studies on the relation of land use and social metabolism in Austrian villages in the 19th and the 20th century. The research was funded under the research programme 'Austrian Landscape Research' (http://www.klf.at/) of the Austrian Ministry of Education, Science and Culture and by the Austrian Science Fund within the project 'The Transformation of Society's Natural Relations' (Project No. P16759).

Methodological aspects and detailed analysis of the data used in this chapter have been published in a number of books and journal articles, above all, Krausmann (2004, 2006a, 2006c); Projektgruppe Umweltgeschichte (1997, 1999); Sieferle et al. (2006); and Winiwarter and Sonnlechner (2001).

The authors are grateful to Verena Winiwarter, Christoph Sonnlechner, Ortrun Veichtlbauer and Klaus Ecker for providing us with empirical material and their cooperation and to Marina Fischer-Kowalski, Rolf Peter Sieferle, Enric Tello, Geoff Cunfer, Karl-Heinz Erb and Simone Gingrich for their useful comments at various stages of the project.

NOTES

1. Note that we refer here to a notion of energy throughput that includes not only technical energy – that is, energy transformed in machinery – but also nutritive energy consumed by humans and livestock. In other words, we are concerned with the whole 'energetic metabolism' of society, as analysed in energy flow accounts (EFA) described in more detail in Chapter 2 and the literature (Haberl 2001a; 2001b).
2. Flows not recorded by statistics were modelled: the domestic extraction of biomass was calculated based on data for agricultural land within the administrative boundary of the city and assumptions on typical yields. Imports of food and feed for draught animals were calculated by applying figures for per-capita consumption from statistical sources and secondary literature and data on population and on urban stocks of draught animals. Methods for estimating current fossil fuel use are discussed in Appendix 5.1 at the end of the chapter.
3. According to the statistical data, one single family house in each, the lowland and the upland systems, uses district heating. However, since district heating requires a grid, which is obviously present in neither of the two communities, we assumed that these were statistical flaws and that both houses are actually using heating oil.
4. Of course this depends on the form of standardization: as there are few people and many animals, values calculated per capita of humans will necessarily be high. A standardization by area would give different results.
5. For example, 1 ton could have been transported over a distance of 11 km, or 11 tons could have been transported over a distance of 1 km to arrive at this value.
6. These processes are analysed and mapped in detail in a recent paper (Krausmann et al. 2003), which, among others, presents maps of cattle and pig density in 1960 and 1995 as well as changes in the grassland/cropland ratio during this period.
7. Similar analyses of human-induced changes in nitrogen flows have, among others, been conducted by Robert Ayres and colleagues (Ayres, Schlesinger and Socolow 1994; Domene and Ayres 2002).
8. We note that this issue is controversial and we are by no means experts in this field. The likelihood or otherwise of peak oil happening in the next two decades is beyond the scope of our judgement. However, that oil reserves are finite, for practical purposes, and that the world therefore must eventually reach a maximum of oil production during the next couple of decades, is contested only by a few analysts (for example, Odell 2004).

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