The transformation of society's natural relations:

from the agrarian to the industrial system

Research strategy for an empirically informed approach towards a European Environmental History

IFF-Social Ecology Programme on Environmental History

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Content

1 Problem definition and current state of knowledge

1-1 Explanation of research question

The research of IFF-Social Ecology in the field of Environmental History investigates two fundamental questions. The first one is that of how systemic change in society-environment-relations occurs and what processes shape the interaction between socio-economic activities and the natural environment, both historically and in the contemporary period. The second question is that of how contemporary transformation processes in society's natural relations are bound to past patterns of society-environment-relations and how this might influence future sustainability.

Concern about global environmental change has stimulated interest in the comprehensive analysis of flows of energy and matter through economies, as well as their social organisation. This comprehensive approach has been termed “industrial metabolism” (Ayres and Simonis 1994). The endeavour to understand the future dynamics of industrial metabolism has stimulated a new interest in gaining deeper insight into its past evolution.

The transformation of economic, social and technological systems in the course of industrialization over the past 250 years has been extensively studied in the field of social and economic history (e.g. Cipolla 1985; Hobsbawm 1968; Maddison 1982; Rostow 1978). In research on global change and sustainable development, the metabolic or, more widely speaking, the biophysical aspects of this transformation are now receiving increasing attention (e.g. Turner et al. 1990), which is reflected in their appearance as an important issue on the international research agenda (e.g. Lambin et al. 1999; Vellinga and Herb 1999). The overarching problem that guides that interest is the following: If it is true, as has been established by previous research (e.g. McNeill 2000; Pfister 1994; Sieferle 1982), that historically the transformation from an agrarian to an industrial society with further industrial growth up to present times was accompanied by an exponential rise in resource consumption and the production of wastes and emissions, then how can industrial development of the less developed majority of the world take place without a further substantial, and possibly fatal, overuse of the environment?

Our research aims at addressing this problem by describing the historical process of industrial transformation quantitatively in biophysical terms, as well as the concomitant changes in society's environmental relations, starting for two specific cases: the United Kingdom and the Austro-Hungarian Monarchy (from 1918 on the succession countries Austria, Czech Republic and Hungary). These two cases differ in very important respects. The UK was the pioneer of industrial transformation while Austria was one of the European latecomers. The UK externalised much of its agriculture to its colonies and transformed its land use early in the nineteenth century, while Austria built much of its industrial development on agricultural revenues. The UK conquered and utilized large parts of the world for the supply of its home industry with cheap resources, while Austria never really owned any colonies overseas and for a long time participated in world trade to a very small extent only. Nevertheless, while these two empires differed widely by the mid-nineteenth century as far as primary energy consumption, material intensity and land-use patterns are concerned, by the early 1970s their developmental trajectories had led to pretty much the same per capita levels both biophysically in terms of resource consumption and economically.

In a first step, we plan to create a multidimensional database on these two cases, containing their energy and material flows as well as their land-use and time-use patterns for the period from the late 18th to the late 20th century. In a second step, we aim to do a comparative analysis of both these cases in the light of two different theoretical approaches:

(1) the historian R. P. Sieferle's broader approach to industrial transformation as a socio-ecological transformation of society's energy base moving away from land-based biomass towards fossil fuels (Sieferle 1982, 1997, 2001a), and

(2) the physicist Robert U. Ayres' somewhat narrower but related attempt to explain long-term economic growth by a "growth engine" driven by energy inputs, namely "useful work" defined as the product of energy (exergy) inputs multiplied by a conversion efficiency (Ayres and Warr 2001; Ayres and Warr 2002a; Ayres and Warr 2002b).

Both theories are 'socio-ecological' in the sense that they base their explanation of socio-economic change on assumptions about the society-environment interaction, particularly on society's energy metabolism. They thereby distinguish themselves from the more common explanations that focus on technological and socio-economic innovations (such as Barro 1996; Barro and Sala-i-Martin 1995; Grübler 1994; Rostow 1978) or on international competition and unequal exchange (such as the World Systems Theory linked to Wallerstein's *oeuvre* (e.g. Wallerstein 2000). Both have important implications concerning the possibility of finding industrial development trajectories for the rest of the world that do or do not fundamentally clash with the preconditions of sustainability.

1-2 Current state of knowledge

The problem we wish to address can be traced back to the "limits to growth" debate of the late 1960s. Authors like Ayres and Kneese (1969), Boulding (1966) or Meadows et al. (1972) were suggesting at the time that in its rapid and continuous growth since the end of World War II the economy was neglecting the limited biophysical carrying capacity of the "spaceship earth" and running the risk of destroying the natural environment it depended upon. These arguments, while stimulating great public attention, were contradicted by most of standard economics.

Thus a new economic sub-discipline evolved out of these approaches, one that named itself "ecological economics." Ecological economics, in contrast to, for example, environmental economics, treats the environment not as an adjunct to socio-economic activities, nor as a medium through which some social activities harm or benefit others. Instead, ecosystems are conceptualised as the fundamental entities within which socio-economic systems are embedded. Thus, environmental problems can be seen in terms of shortfalls in the capacity of economic and ecological systems to function in conjunction with one another (Arrow et al. 1995; Costanza et al. 1998; Daly 1992; Martinez-Alier 1987). In the context of ecological economics, a "biophysical approach" emerged (Cleveland and Ruth 1997; Cleveland et al. 1984; Daniels and Moore 2001; Wackernagel 1999), dealing with the question of natural resources contributing to economic growth. In contrast to the approach of ecological economists, the mainstream view is that energy and other natural resources should be regarded as economic intermediates, as consequences of industrial activity rather than as factors of production. Commonly, long-term economic growth is dealt with as an issue of technological and social innovation, driven by thrusts of human inventiveness (Barro 1996; Barro and Sala-i-Martin 1995; Grübler 1994; Rostow 1978). This perspective is challenged by authors like Robert U. Ayres, who treat the economy as an evolutionary materials processing system; an adequate description of this system must include materials and energy flows as well as money flows (Ayres 2001). These flows and conversion processes are governed by the laws of thermodynamics (Ayres and Warr 2002a; Ayres and Warr 2002b). While Ayres applied his approach, very successfully, to the economic history of the United States 1900-2000 (Ayres and Warr 2001; Ayres and Warr 2002b), we are not aware of any similar comprehensive attempt having been made to apply this approach to the economic development of the United Kingdom – even though, in principle, the socio-economic data base for such an endeavour seems to be sufficient (Maddison 2001; Mitchell 1988; Nef 1966). Nevertheless, some case studies have linked certain aspects of economic development and energy consumption (Adams 1982; Fouquet and Pearson 1998; Humphrey and Stanislaw 1979). Equally, the Austro-Hungarian Monarchy has not yet been a case for such an analysis, although some data have been compiled and attempts have been made to relate energy consumption and economic development (cf., Gross 1990; Sandgruber 1978b; Turetschek 1979).

Another scientific tradition we wish to build upon is environmental history. This sub-discipline of history focuses on the fact that society's relations to the environment change over time and conceives of these historical transformations as affecting both society and nature (cf. Godelier 1984). The significance of a biophysical reading of historical processes and of society's natural relations is explicitly addressed in a number of more recent publications on environmental history, e.g. in McNeill (1998, 2000), Pfister (1994, 1995), Sieferle (1997a, 1997b, 2001a, 2001b), Simmons (1993), Worster (1988, 1993, 1994).

We are not aware of the existence of any comprehensive literature on the environmental history of the UK that would systematically include the energy and material flow aspects. Because of the quality of the data base and because of the UK's role as a pioneer in industrialization, UK data are frequently analysed in the context of global historical development (e.g. by Rostow 1978; Sieferle 1982; Sieferle 2001b; Simmons 2001). This is much less the case, for obvious reasons, for Austrian environmental history, which is practically non-existent – with a few noteworthy exceptions (e.g. Bruckmüller and Winiwarter 2000; Projektgruppe Umweltgeschichte 1999; Sandgruber 1978b; Winiwarter 2001; Winiwarter and Sonnlechner 2001).

Conceptual and empirical studies from a broad variety of scientific traditions have focussed more specifically on the interrelations between the biophysical variables we wish to address. There is an important strand of research from an agro-ecological background linking demographic variables to land use and often to labour and energy use, too (Boserup 1981; Boserup 1988; Boserup 1965; Cohen 1977; Cohen 1989; Netting 1981; Netting 1993). Following this strand of research, some theoretically demanding modelling attempts have recently been made which link energy consumption, land use and time use (Giampietro 2000; Giampietro and Mayumi 2000; Giampietro and Pimentel 1991) and seek to explain economic development on the basis thereof (Pastore et al. 2000).

Land use and land cover have been analysed intensively in the context of global change research (Meyer and Turner 1994; Meyer and Turner 1992). Research in this field is coordinated by the international LUCC program, which explicitly stresses the importance of a long-term perspective on human interference with terrestrial ecosystems (Lambin et al. 1999). Seminal studies that provide a comprehensive perspective on long term changes in land use and land cover include the work done by Turner et al. (1990), Berglund (1991) and Ramankutty and Foley (1999). For Austria, first attempts to analyse the development of land-use patterns during industrialization have been made by Krausmann (2001a), Krausmann et al. (2003a) and Bicik et al. (2001); for similar work on the UK see Chambers and Mingay (1966), Grigg (1989), Mingay (1989), Simmons (2001).

There has long been a tradition of viewing energy as a crucial factor in understanding socio-economic development (Adams 1975; Adams 1982; Ayres and Warr 2001; Cotrell 1955; Giampietro and Mayumi 2000; Lotka 1925; Martinez-Alier 1987; Musson 1978; Sieferle 2001b; Smil 1994). Beyond this conceptual work, empirical studies on long-term developments in socio-economic energy flows have been established for a number of cases (see e.g. Cleveland et al. 1984; Darmstadter 1971; Etemad and Luciani 1991; Humphrey and Stanislaw 1979; Kander 2002; Malanima 2001; Nilsson 1993; Williams 1997).

As a factor in the debate, material flows arrived with delay but then took their place in the discussion on sustainability as a key parameter. There has come to be a rich body of literature on material flow analysis (for reviews see Daniels and Moore (2002), Fischer-Kowalski and Hüttler (1999)). While for reasons of conceptual and methodological consistency it is indeed advisable to rely on this relatively new research tradition, most of the empirical studies reach back only a few decades (Adriaanse et al. 1997; Eurostat 2002; Matthews et al. 2000a) or cover only specific materials or substances (Ayres and Ayres 1994; Lohm et al. 1994; Trömel 1995). Nevertheless, they convey important insights into the interrelation of material flows with population and economic growth. The only attempts to complete long-term studies for the UK and Austria come from the applicant team itself (Krausmann 2001b; Krausmann et al. 2003b; Schandl et al. 2000; Schandl 2000b; Schandl and Schulz 2001; Schandl and Schulz 2002a).

The conceptual idea of linking time use – and labour time in particular –to both economic development and environmental change is certainly not entirely new, but so far there exists to our knowledge no coherent research tradition for this link. Within time-use research, attempts at reconstructing longer historical series have quite a tradition that can be traced back to Robinson and Converse (1972) and seems to be experiencing a revival in the light of environmental concerns (Godbey 1996). For the UK some attempts have already been made at reconstructing historical time use and discussing the results in the context of economic and environmental change (Ausubel and Gruebler 1996).

1-3 Contribution of the IFF-Social Ecology approach towards an empirically informed environmental history to the advancement of science

The research effort of IFF-Social Ecology may be expected to substantially contribute to 'the advancement of science' within two specific contexts:

1) The context of the debate on explaining economic growth within ecological economics. In continuation of Robert U. Ayres' research and in close collaboration with him we are seeking to provide two further empirical case studies against which his theory, which performed very well for the United States, may be tested. Beyond providing additional case studies, there will be the challenge of dealing with energy flows abroad (as in the case of British colonies) and integrating their contribution in a manner consistent with the overall approach.

2) The second context is linked to Rolf Peter Sieferle, who with the help of the Breuninger Foundation has designed a research program on "Europe's Special Course", trying to put his more general theoretical approach to the test of successfully explaining why it was Europe that came to develop the industrial mode (and not, for example, China (Sieferle 2001a)). This research program has, in the meantime, branched out in several directions, of which energy and material flows as well as land use have maintained a focal position from the start; the consideration of time use will represent a new component in this research. Again, there will be close cooperation between this project team and Rolf Peter Sieferle.

Our endeavour's innovative contribution is the establishment of a consistent multidimensional database on 250 years of Austria's and the United Kingdom's environmental and economic history, as well as the analysis and possibly the modelling of these data according to the theoretical assumptions and propositions mentioned above. This will provide an empirical data base serving the assessment of the key research questions and theoretical assumptions of research communities such as ecological economics, environmental history and industrial ecology.

The results obtained will be thoroughly discussed in the context of alternative, more common interpretations of industrial modernization, technological change and economic growth. This is the major reason for inviting Arnulf Grübler to collaborate on the project. Working from an excellent international data and modelling base at IIASA, Arnulf Grübler has been contributing high-profile historical research to the debate on Global Change for a long time. The results of improved knowledge about how socio-economic and biophysical changes have affected each other in the past will contribute, so we hope, to an improved understanding of future pathways for sustainable development.

The existence of a comparative data compendium for two countries might be an incentive for other research institutions to produce compatible data for further countries. Such partner projects would exchange their experience with our project and would be a starting point for a data base on Europe's environmental history.

1-4 Previous work of IFF-Social Ecology in the field of Environmental History

The research effort of IFF-Social Ecology will be based on a close collaboration between the IFF Department of Social Ecology on the one hand and Robert U. Ayres (INSEAD, France), Rolf Peter Sieferle (University of St. Gallen) and Arnulf Grübler (IIASA, Yale University) on the other hand. Since IFF Social Ecology will be the recipient of the research funding, we confine ourselves here to discussing previous work from this institution.

In terms of theory, Marina Fischer-Kowalski and Helmut Haberl (1993) have outlined a concept for assessing society's interactions with nature, namely the concept of society's metabolism and the colonization of natural processes. These theoretical considerations have been further developed in Fischer-Kowalski et al. (1997), Fischer-Kowalski and Weisz (1999) and Weisz et al. (2001). In their more recent work the group conceives of society as a hybrid between the cultural and the material realm, thus offering a framework for analysis which can be linked to the current natural scientific discourse on the earth system and global change as well as to the social science discourses on globalisation and development. The concept bridges the gap between these two scientific traditions and offers an explanation that is neither socially nor naturally reductionist.

Methodology has been developed on the basis of these theoretical assumptions and includes Material Flow Accounting (MFA) and Energy Flow Accounting (EFA). The team has been at the forefront of Material Flow Accounting since the early 1990s and has contributed to developing international methodological standards at the OECD and EUROSTAT (Matthews et al. 2000a; Weisz et al. 2002). The methodology has been outlined , for example, in Fischer-Kowalski (1998), Fischer-Kowalski and Hüttler (1999). For Energy Flow Accounting, a compatible framework has been developed at the IFF by Haberl (2001a, 2001b). Only recently a "Handbook of Physical Accounting" (Schandl et al. 2002) has summarized the MEFA approach. The main features of the methodology are its comprehensiveness, theoretical soundness, compatibility with the system of economic accounting (SNA), the systems perspective and – not least – its feasibility.

Extensive empirical data collection has been carried out for both suggested case studies regarding Austria and the United Kingdom. A data base on the development of land use and primary energy consumption in Austria within its current boundaries from 1830 to present has been compiled by Krausmann (2001b), Krausmann and Haberl (2002) and Krausmann et al. (2003a). These data have been analysed predominantly with respect to the interrelation of land use, the transformation of the energy system and socio-economic development both on the national level (Haberl and Krausmann 2001; Krausmann and Haberl 2002) and on a spatially explicit level (Krausmann et al. 2003a). Furthermore, the impact of the transformation of the energy system on ecosystem properties has been analysed (Krausmann 2001a). Empirical data on the development of land use and energy flows on a local level have been compiled by Krausmann for a number of small villages (Krausmann 2003b) and for the city of Vienna (Krausmann 2003a). Material flow accounts for the time period 1960-1997 have been compiled by Schandl et al. (2000) and Schandl (2000a).

Work done for the United Kingdom includes accounting of material inputs to the United Kingdom's economy 1937-1997 (Schandl and Schulz 2000). This preliminary work was extended in terms of methodology, data sources description and in consideration of the energetic aspect (Schandl and Schulz 2001). The data set has been published in the Handbook for Industrial Ecology (Schandl and Schulz 2002b) as well as in a special section of Ecological Economics (Schandl and Schulz 2002a). These efforts expanded the historical analysis back until 1850. On the basis of this experience a firm knowledge of data availability and data quality as well as a database capable of development for the kind of questions addressed in this project can be guaranteed.

A first comparative analysis of both case studies is offered in Krausmann et al. (2003b). Both empirical case studies have been internationally discussed at several occasions (including the renowned Gordon Conference on Industrial Ecology as well as the conferences of the International Society of Ecological Economics and the European and American Society for Environmental History), and represent an innovative contribution to the fields of ISEE, ISIE and ESEH.

An effort to understand the historical development of the interrelation of energy, land and population on a conceptual level, based on empirical data, has been made by Weisz et al. (2001).

2 Objectives for research on environmental history at IFF-Social Ecology

2-1 Data base

One aspect of our research endeavour is to generate a database and it will use this database to test specific socio-ecological interrelations of the industrial transformation process. The multidimensional database will contain core (biophysical) parameters for the time period of the transformation from agrarian to industrial society for the United Kingdom and Austria (i.e. the Austro-Hungarian Monarchy respectively the succession countries Austria, Czech Republic and Hungary). It will encompass data for describing the biophysical interactions between society and nature as well as within society. These biophysical interactions encompass the energy and materials mobilized by the social system, land-use patterns and time-use patterns of the population. Table 1 gives an overview of the general structure and content of the primary data to be compiled in the database. Data on energy and materials throughput is reported in joules and tons, data on land use in km² and time-use data in hours. Where feasible, the data set will be subdivided according to functional and sectoral subcategories. It will be generated in a comparative and consistent manner for the United Kingdom as the forerunner of the industrial revolution and the Austro-Hungarian Monarchy as one of the latecomers (for the latter, data will be from selected succession countries – i.e., Austria, Czechoslovakia/Czech Republic, and Hungary). The time frame of the database will encompass the period from 1750 to the present day.

The set of biophysical data will be complemented by standard economic data (reported in monetary units) and population data (e.g. Maddison 1995; Mitchell 1995). This will allow the linkage of socio-economic and biophysical developments.

The data set will be made available to other scholars via Internet and on CD-Rom (for an example of such a database see the Swiss environmental history database *Bernhist* (histserver.unibe.ch/bernhist)

Table 1 Overview of the general structure and content of the database

Data category	[unit]	Subcategory	Approx. no. of items
and use and land cover	[km²]		
	[km²]	Cropland	15-25
	[km²]	Grassland	3-5
	[km²]	Woodland	1
	[km²]	Built-up land	2
	[km²]	Other land use types	1-5
Material and energy flows	[t] and [GJ]		
	[t] and [GJ]	Extraction biomass	15-25
	[t] and [GJ]	Extraction fossils	5
	[t]	Extraction minerals	10-30

	[GJ]	Extraction hydropower	
	[t] and [GJ]	Imports	50-100
	[t] and [GJ]	Exports	50-100
Livestock	[1000]	y species	5-15
Time Use	[h]	by activity and gender	10-20
Labor force	[capita]	y economic activity and gender	5-15
Population	[capita]	y age group and gender	3-10
GDP	[US $]	y economic sector	3-15

Based on these primary data, data which has been disaggregated by economic sectors and functionally by use will be provided in the data compendium.

2-1 Testing theories

According to Sieferle, the transition from an agrarian to an industrial mode is to be seen mainly as a change in the energy basis of socio-economic activities. Agrarian societies depend on solar energy, captured mainly as chemical energy via agriculture and forestry. The transformation from this agrarian to the industrial pattern started with the increasing use of fossil energy carriers, which allowed the new socio-economic pattern to act on an abundant energy basis independent of land area. Subsequently, fossil fuels were substituted for biomass, thus permitting these societies in transition to the industrial mode to overcome the energy scarcity that had characterized their agrarian socio-ecological regime. It also allowed them to develop new technological solutions. Per capita primary energy input has undergone a quantitative change from 70 GJ/capita in the agricultural mode to 190 GJ/capita in the industrial mode. One objective of the project is to gain a more in-depth understanding of this change in the energy regime with respect to primary energy, useful energy and final energy, including food/feed and human/animal work.

In close relation to changes in the energy system, the use of time was subject to a fundamental transformation. Whereas agrarian society had to allocate a huge fraction of available time to the production of its nutritional base as well as to the provision of other forms of primary energy and raw materials, the industrial system made it possible to “free” the time of its members from these basic relations to nature and allow for socio-economic activities beyond this necessity.

Adjustments between energy and time use were closely related to changes in the land-use system and the quality and quantity of materials use. Under pre-industrial conditions land use provided the energy basis for practically all socio-economic activities (such as food/feed, physical work, transportation, …) and depended on a positive energetic return on investment (Martinez-Alier 1987; Pimentel et al. 1973). In other words, the energy contained in agricultural output had to exceed the energy invested by society in the form of human and animal labour. This vital prerequisite of agricultural production became obsolete with the transformation of the energy system. The relative abundance of fossil fuels allowed land use to be delinked step-by-step from energy provision and agriculture to turn from an energy source to an energy sink (Stanhill 1984; Pimentel et al. 1990).

With regard to materials use, the transformation of the energy system resulted in a tremendous increase in the quantity of material input into economic processes and also an increase by several orders of magnitude in the spatial range of material flows. These increases were triggered by the introduction of fossil-fuel-based systems for the long-distance transport of bulk materials (trains, steamships). This is, in the briefest possible form, Sieferle's schematic account of industrial transformation (see also McNeill 2000; Pfister 1994; Pfister 1995).

Analysing two so different cases as those of the UK and Austria will help to differentiate these general propositions so as to account for much more detail. We expect substantially new insights in particular as regard the role of the territorial "externalisation" of processes (such as agricultural land use in colonies vs. within home territory) and the role of human labour and its having been relieved by fossil energy and technological innovation.

Concerning Robert U. Ayres' theoretical propositions on the "explanation" of economic growth by a combination of increase in primary energy (exergy) input and improved conversion efficiencies, our analysis will play a decisive role in supplying two more "test cases" for this theory, and allowing to test the fit of the functions of Ayres' model. Again the problem of international trade and colonisation will present a methodological and theoretical challenge.

The success (or failure) of these theoretical approaches in explaining the empirical data from the two historical case studies will necessarily be contrasted with the explanatory power of more conventional views and theories on industrial modernization and economic growth.

Beyond these attempts to explain past development, an essential question will be that of whether similar biophysical determinants to growth and development apply to present-day transitions in the developing world. Of course, there is a strong hope that "leapfrogging" is possible. There will be little chance for countries undergoing the industrial transformation now to secure themselves cheap resources from beyond their borders as the UK was able to from its colonies. Austria may well be an interesting example of development based on a country's own territory.

2-3 Expected outcomes (deliverables) of the research of IFF-Social Ecology

Depending on our ability to gain funding the outcomes of our research efforts until 2005 will be:

(a) A comprehensive historical data compendium including a CD-ROM database which will be available to researchers in the fields of economic history, environmental history and ecological economics for further analysis. The compendium will include an extensive technical annex.

(b) A book, in collaboration with the main partners, that uses the historical database established to elaborate on several aspects of the transformation from the agrarian to the industrial system.

(c) A series of publication in peer-reviewed journals, among them the journals of the three communities to be primarily addressed: *Journal of Ecological Economics*, *Journal of Industrial Ecology* and *Environmental History*.

(d) A series of presentations at international meetings of the three communities mentioned above.

(e) Two international workshops.

3 Methods

The primary data source for our research effort are statistical data provided by official statistical institutions. The availability of statistical data dates back to the beginning of industrialisation. In both the United Kingdom and Austria data on domestic extraction, imports and exports of biomass, fossil fuels, minerals and ores as well as industrial production, population and livestock have been available in published statistical reports since the late 19th Century (see Table 2). Significant quantities of relevant biophysical data have been compiled and published in previous research projects undertaken by members of the applicant team (see Section 1.4 of this proposal) or are accessible via contemporary data compilations (see Table 2).

This existing data base will be expanded with regard to a) time frame, b) the reference systems, c) specific new data sets and d) internal consistency. In particular, selected data will be made available as far back as 1750. This data will be extended to the Austro-Hungarian Empire and some of its successor states and will include new data sets (e.g. data on time use, data on material flows for Austria, etc.). Relevant sources include cadastral surveys, agricultural statistics, mining statistics, trade statistics and censuses as well as statistical-topographical publications (see Krausmann 2001b; Krausmann and Haberl 2002; Schandl and Schulz 2001). Table 2 gives an overview of selected statistical sources and edited data sets for Austria and the UK which will be used in compiling the dataset. Although a similar set of statistical sources is available for the successor countries Czechoslovakia and Hungary, a detailed survey of these sources will be done in this research for the first time.

Table 2 Selected data sources for Austria and the United Kingdom

International Sources and data compendia: Etemad and Luciani 1991; Maddison 1995; Maddison 2001; Mitchell 1995 FAO (online database and statistical publications) OECD (online database and statistical publications) IEA (online database and statistical publications) UN trade statistics (statistical publications) EUROSTAT trade data base (CD-ROM database)	
Selected data sources for Austria[1] **Data compendia and literature:** Bolognese-Leuchtenmüller 1978; Bundesholzwirtschaftsrat 1980; Butschek 1998; Fillunger 1868; Friese 1870; Friese 1855; Gross 1990; Hain 1852; Handels- und Gewerbekammer in Wien 1867; k.k.Finanz-Ministerium 1858; Kausel 1979; Lorenz 1866; Sandgruber 1978b; Sandgruber 1978a; Springer 1840; Turetschek 1979; Wessely 1853	**Selected data sources for United Kingdom** **Data compendia and case studies:** Mitchell 1988; Mitchell and Deane 1962; Voth 2000; Wittich 1825; Curth 1917; Dodgshon and Butlin 1978; Nef 1966; Riden 1977; Burt 1969; Cullen 1968; Meade 1882; Schmitz 1979; Carus-Wilson and Coleman 1963; Clark 1938; Fouquet and Pearson 1998; Deane and Cole 1967; Hatcher 1993; Jevons 1865 **(Periodical) statistical sources:**

1 Sources for Austria refer to both the Austro-Hungarian Empire and the Republic of Austria.

(Periodical) statistical sources:[2] • Österreichisches Wirtschaftsforschungsinstitut (Online database) • Statistik Austria (Online database) • Tafeln zur Statistik der Monarchie (1821-1871) • Statistisches Jahrbuch für Österreich (1868ff) • Statistische Monatsschrift (1875-1921); Statistische Nachrichten (1923ff) • Wirtschafts- und sozialstatistisches Handbuch (1925-) • Statistisches Jahrbuch des k.k. Ackerbauministeriums (1869-1904); Ergebnisse der landwirtschaftlichen Statistik (1918-); Forstliches Jahrbuch (1880-); • Statistik des Außenhandels (1821-); • Österreichisches Montanhandbuch (1857-) • Industrie und Gewerbestatistik • Häuser- und Wohnungsstatistik (1869- • Ergebnisse der Volkszählung (1869-) • Food balance sheets (1938- • Various cadastral surveys (ca. 1830-) • Energy statistics (1950-)	• Ministry of Agriculture and Forestry, Forestry Commission, Office of National Statistics (ONS) Data Base, Input-Output Table • Statistical abstract for the United Kingdom • The mining and mineral statistics of the United Kingdom and Ireland • Agricultural Statistics, Forestry Statistics, Hunting and Fishing Statistics • Foreign Trade Statistics • Labor Statistics and Labor Gazette • Statistical Digest of the Ministry of Power • Population Census

For certain subsets of parameters – i.e., for certain periods of time (above all 1750-1800) – statistical data are either not available or do not provide information in sufficient detail or to a sufficient degree of accuracy. This is the case for various forms of material and energy input (e.g., biomass uptake due to grazing, and the production of firewood) as well as for flows between socio-economic subsystems (e.g., sectoral data on energy consumption, food and feed balances, and data on labour and time use). For these flows specific modelling strategies will be applied. Conceptual models will be established for the relationship between population, metabolism and land use; these models will be calibrated using the sparse historical data available (see Malanima 2001).

Some of the methodologies used to further organize the historical data set and to calculate the respective biophysical parameters can draw on experiences from environmental accounting. This concerns the following methodologies:

Material Flow Accounting (MFA): In this framework the economic process is portrayed as a process of mobilizing materials from different sources (the domestic environment or other socio-economic units), processing them, adding them to stocks (such as buildings as well as transport and production infrastructures) and, after a time lag, releasing them either to other socio-economies (as exports of

2 Please note that Table 2 does not give the exact bibliographical title for all statistical sources. Most sources were subject to slight alterations in their title during their period of publication. The period of publication does not show interruptions due to changes in the statistical reporting system or the war periods

goods) or to the domestic environment (as emissions and waste to the different gateways of air, water, and landfills) (see Eurostat 2001a; Fischer-Kowalski and Hüttler 1999; Matthews et al. 2000; Schandl et al. 2002). The method explicitly differentiates between flows and stocks of materials, inputs and outputs as well as inter-economy flows. The approach is not only compatible with the system of economic accounting (SNA) but also widens the its scope, mainly with respect to goods which are traditionally not covered by economic accounting but which have a significant relevance in terms of material flow (e.g. livestock grazing). Technically speaking, the data organisation distinguishes between accounts for inputs and outputs and an explicit linking of activities in input-output tables (Duchin 1998; Katterl and Kratena 1990). The MFA approach has achieved broad international acceptance both scientifically and politically. It is a methodological approach that was developed for national economies, but it is also applicable to local socio-economic systems. Numerous material flow case studies have been carried out (including Adriaanse et al. 1997; Eurostat 2001b; Matthews et al. 2000; Weisz et al. 2002) and a harmonized methodology has been agreed upon (Eurostat 2001a).

Energy Flow Accounting (EFA): Energy flow accounts or balances for national economies and local systems have a long tradition and build on internationally well-established methodology. Like material flow accounting, energy flow accounting follows an input/output logic, is compatible with national accounting systems, allows distinctions to be made between domestic extraction and the import and export of energy, and permits energy flows to be followed through socio-economic systems. With respect to the specific physical properties of energy carriers and the technical transformation of energy in socio-economic processes, EFA distinguishes between primary energy, final energy and useful energy. However, currently used methods in energy flow accounting (e.g. IEA 2001) generally consider certain forms of technical energy only and neglect traditional energy carriers. For the tracing of energy flows through pre-industrial societies this may result in significant underestimations of primary energy input for the provision of human and animal work. Hence, in this project we apply a modified accounting approach as proposed by (Haberl 2001a), which explicitly considers all forms of primary energy sources and adapts conventional energy balances in such a way as to render them fully consistent with MFA methodology. EFA aggregates primary energy flows simply by gross or net calorific values. However, when tracing the flow of energy from its primary sources to final energy, measures for conversion efficiency must be introduced; in these cases we will follow the methods utilized by Ayres et al. (2003) and Ayres and Warr (2002b).

Land-use data are available from a number of statistical and remote-sensing sources and are generally disaggregated by land-cover categories, which to a certain extent mirror land use. These data sources operate with different conceptions of the respective land-use categories and show significant consistency gaps. For example, data on woodlands are available from cadastral sources, agricultural statistics and forest inventories and vary in Austria's case by 25% (Umweltbundesamt 1988). To establish consistent time series of land-use and land-cover change, these gaps must be adjusted by in-depth data analysis and by model assumptions. Furthermore, linking land-use data to data on socio-economic material and energy flows necessitates the re-organization of statistical land-use categories by functional categories (e.g., with respect to land used to produce food, feed draught animals, provide firewood and timber, etc.). Functional data aggregation will be based on model assumptions in close relation to detailed material flow analysis. Data on land-use and land-cover change will be analysed according to data availability at specific points in time at spatially explicit levels. For instance, spatially explicit land-use data for Austria are readily available in digital form at the resolution of political municipalities beginning in the 1950s. Changes in spatial patterns of land use will be analysed in GIS software (ArcView and MapInfo).

Time-use Accounting: This approach has had a long standing tradition since the early 1970s (Robinson John and Converse Phillip 1972; Szalai 1972) and has been implemented within the census data sets of a large number of countries. The methodology relies on questionnaires and sample observations, which are established according to a standard which has been internationally agreed upon and which involves 20 or 40 sub-categories of time use (Gershuny 2000). These data sets report on micro-sequential, micro-aggregate and macro-level aspects of how individuals, households and whole national populations use their time. For historical reconstructions we will have to rely on demographic data (population by gender and age-group, life expectancy, number of children, occupational structure) and model assumptions on these demographic aggregates' time use. These model assumptions can be backed by specific "anchor" studies (such as Voth 2001). We will distinguish between time spent on personal recreation, household chores and subsistence production on the one hand, and formal economic activities on the other hand. In an input-output framework we will consider both time supply and time demand of various social systems such as the person system, the household/community system and the formal economy. This approach allows us to estimate particular social systems' activity potentials. Socially available time marks a boundary condition for each society.

4 Researchers involved in the IFF-Social Ecology environmental history programme

Dr. Fridolin Krausmann

PhD in Biology from the University of Vienna, researcher at the Dept. of Social Ecology of the Institute for Interdisciplinary Studies of Austrian Universities since 1995. University teacher at the Dept. of Social Ecology of the IFF and the Institute of Ecology, University of Vienna since 1998. Research foci: land use change, agricultural systems, socio-economic energy systems, long term development of society-nature relations, historical statistics. Academic teaching in human and social ecology, environmental history. Experience in managing interdisciplinary research projects.

Univ. Prof. Dr. Marina Fischer-Kowalski

Prof. for Social Ecology, PhD in Sociology, head of the Department for Social Ecology of IFF since 1987. Since more than a decade at the forefront of socio-economic environmental research and internationally influential writer and presenter as well as contributor to several international academic and research programmes such as IHDP, SCOPE, MAB, ISIE, ISA.

Dr. Heinz Schandl

PhD in Sociology from the University of Vienna, since 1994 employed at the Institute for Interdisciplinary Studies of Austrian Universities, Department of Social Ecology. Head of and contributor to several interdisciplinary research projects dealing with society's natural relations both with an historical or a policy oriented focus. Thereof, 'Southeast Asia in Transition' funded by the EU commission and a historical case study on integrated environmental accounting for the UK funded by the Breuninger Foundation and the Austrian Ministry of Science. Active in the fields of Environmental Accounting, Social Theory and the Environment and Ecological Economics.

5 International cooperation

The proposed project is part of two larger internationally endorsed research efforts, namely "Transition from the Agrarian to the Industrial Mode" (endorsed focal project of the Industrial Transformation sub-program of the International Human Dimensions of Global Environmental Change Programme [IHDP-IT] and "Land-use Change and Socio-Economic Metabolism" (endorsed by the Land-Use and Land-Cover Change Program [LUCC], a joint program of IHDP and the International Global Biosphere Program [IGBP]).

The proposed project is also closely related to an ongoing research program of the German Breuninger Foundation, namely the program on "Europe's Special Course" (Sieferle 2001a), which assembles environmental historians and various other social scientists to investigate why the "Industrial Revolution" having occurred in Europe first. This "revolution" is conceived of as having been a transformation involving all socio-economic structures and their relationship with nature. Our proposed effort contributes to the program by developing a comprehensive data base and conducting empirical analysis in accord with several of the program's research questions (see Sieferle 2001a).

The Breuninger Foundation will fund one of the international workshops and will offer to publish preliminary results in their working paper series.

Furthermore, the proposed project is part of a international research activity in greater scope, involving partners from France, Sweden, and Japan in investigating new explanations for economic growth by introducing "physical work" as an input factor for the production function. A case study for the United States proved the explanatory capacity of such an undertaking by providing an excellent fit to 100 years of growth for the US economy. The results for the US economy are now to be tested for several other economies, among them France, the United Kingdom, Sweden, Austria and Japan. This effort is headed by Robert U. Ayres; IFF Social Ecology takes part in the form of scientific collaborations endorsed by France and Austria. This endorsement (Amadee) will fund some of the travel activities necessary for the proposed project.

Finally, the cooperation with Arnulf Grübler (IIASA) offers space for in-depth discussions in the light of a more common interpretation of industrial modernization and technological change. This cooperation will take the form of short workshops and might also include data exchange.

6 Funding strategies for the IFF-Social Ecology's research contribution to Europe's environmental history

Since 1999 the Breuninger Foundation's Programme on Europe's Special Course has been funding several case studies for an empirical assessment of sociuety's natural relations which are available in the working paper series of Breuninger Foundation (www.breuninger-stiftung.de).

In 2002 the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, Section for general environmental policy, has provided seed funding for the IFF-Social Ecology group on environmental history to being able to develop this research strategy and furthermore, to apply for national and international funding.

In March 2003 the group has applied for a 3years project at the Austrian Science Foundation. In April 2003 the group has been a partner in an application to the EU FP6-Programme coordinated by Robert U. Ayres (INSEAD).

7 Reference list

Adams, R. N. (1975): *Energy and Structure: A Theory of Social Power*. Austin, London: University of Texas Press

Adams, R. N. (1982): Paradoxical Harvest: Energy and Explanation in Great Britain. 1870-1914. Cambridge: Cambridge University Press

Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenberg, E., Rogich, D., and Schütz, H. (1997): *Resource Flows: The Material Basis of Industrial Economies*. Washington DC: World Resources Institute

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B.-U., Levin, S., Mäler, K.-G., Perrings, C., and Pimentel, D. (1995): Economic Growth, Carrying Capacity, and the Environment. In: *Science* 268(28 April), pp. 520-521

Ausubel, J. H. and Gruebler, A. (1996): Working Less and Living Longer: Long-Term Trends in Working Time and Time Budgets. Laxenburg, Austria: (IIASA Reprint; RR-96-4)

Ayres, R. U. (2001): The minimum complexity of endogenous growth models: . the role of physical resource flows. In: *Energy* 26(9), pp. 817-838

Ayres, R. U., Ayres, L. W., and Warr, B. (2003): Exergy, power and work in the US economy, 1900-1998. In: *Energy* 28(3), pp. 219-273

Ayres, R. U. and Ayres, L. W. (1994): Consumptive uses and losses of toxic heavy metals in the U.S. 1880-1980. In: Ayres, R. U. and Simonis, U. E. (Eds.): *Industrial Metabolism: Restructuring for Sustainable Development*. Tokyo, New York, Paris: United Nations University Press, pp. 259-298

Ayres, R. U. and Kneese, A. V. (1969): Production, Consumption and Externalities. In: *American Economic Review* 59(3), pp. 282-297

Ayres, R. U. and Simonis, U. E. (1994): *Industrial Metabolism: Restructuring for Sustainable Development*. Tokyo, New York, Paris: United Nations University Press

Ayres, R. U. and Warr, B. (2001): Exergy, power and work in the US Economy, 1900-1998. In: *Energy* (submitted)

Ayres, R. U. and Warr, B. (2002a): Economic Growth Models and The Role of Physical Resources. Fontainebleau, France: INSEAD (INSEAD R&D Working Papers; 2002/53/EPS/CMER)

Ayres, R. U. and Warr, B. (2002b): Useful Work and Information as Drivers of Growth. Fontainebleau, France: INSEAD (INSEAD R&D Working Papers; November 2002)

Barro, R. J. (1996): Determinants of Economic Growth: A Cross-Country Empirical Study. Cambridge, Mass.: National Bureau of Economic Research (NBER Working Paper Series; 5698)

Barro, R. J. and Sala-i-Martin, X. (1995): *Economic Growth*. New York: McGraw Hill

Berglund, B. E.(ed.) (1991): *The cultural landscape during 6000 years in southern Sweden - the Ystad Project*. Copenhagen: Munksgaard International Booksellers and Publishers (Ecological Bulletins; 41

Bicik, I., Jelecek, L., and Stepanek, V. (2001): Land-use changes and their social driving-forces in Czechia in the 19th abd 20th centuries. In: *Land Use Policy* 18(1), pp. 65-75

Bolognese-Leuchtenmüller, B. (1978): *Bevölkerungsentwicklung und Berufsstruktur, Gesundheits- und Fürsorgewesen in Österreich 1750-1850*. Wien: Verlag für Geschichte und Politik (Wirtschafts- Sozialstatistik Österreich-Ungarns)

Boserup, E. (1981): *Population and Technology*. Oxford: Basil Blackwell

Boserup, E. (1988): Environment, Population and Technology in Primitive Societies. In: Worster, D. (Ed.): *The Ends of the Earth: Perspectives on Modern Environmental History*. Cambridge, pp. 23-39

Boserup, E. (1965): *The Conditions of Agricultural Growth*. Chicago: Aldine/Earthscan

Boulding, K. (1966): The Economics of the Coming Spaceship Earth. In: Jarrett, H. (Ed.): *Environmental Quality in a Growing Economy. Essays from the Sixth RFF Forum*. Baltimore: John Hopkins Press, pp. 3-14

Bruckmüller, E. and Winiwarter, V. (2000): Umweltgeschichte. Zum historischen Verhältnis von Gesellschaft und Natur. Wien: ÖBV und HPT

Bundesholzwirtschaftsrat (ed.) (1980): Holzbilanzstudie 1926-1978(79) des Bundesholzwirtschaftsrates. In: *Holz-Kurier.5 Jahrzehnte Österreichs Forst- und Holzwirtschaft* 35.Jahrgang(48), pp. 1-55

Burt, R. (1969): Lead production in England and Wales, 1700-1770. In: *Economic History Review* 22(2), pp. 249-267

Butschek, F. (1998): Statistische Reihen zur österreichischen Wirtschaftsgeschichte, Die österreichische Wirtschaft seit der industriellen Revolution. Wien: Österreichisches Institut für Wirtschaftsforschung (WIFO)

Carus-Wilson, E. M. and Coleman, O. (1963): *England's export trade 1275 - 1547*. Oxford:

Chambers, J. D. and Mingay, G. E. (1966): *The Agricultural Revolution: 1750-1880*. London: B.T. Batsford Ltd.

Cipolla, C. Ed. (1985): *Die Entwicklung der industriellen Gesellschaften*. Stuttgart, New York: Gustav Fischer Verlag (Europäische Wirtschaftgeschichte; Vol. 4)

Clark, G. N. (1938): Guide to English Commercial Statistics 1696 - 1782. London

Cleveland, C. J. and Ruth, M. (1997): When, Where and by How Much Do Biophysical Limits Constrain the Economic Process? A Survey of Nicholas Georgescu-Roegen's Contribution to Ecological Economics. In: *Ecological Economics* 22(3), pp. 203-224

Cleveland, C. J., Costanza, R., Hall, C. A. S., and Kaufmann, R. (1984): Energy and the U.S. Economy: A Biophysical Perspective. In: *Science* 225, pp. 890-897

Cohen, M. N. (1977): *The Food Crisis in Prehistory*. New Haven, London: Yale University Press

Cohen, M. N. (1989): *Health and the Rise of Civilization*. New Haven, London: Yale University Press

Costanza, R., Cumberland, J., Daly, H., Goodland, R., and Norgaard, R. B. (1998): *An Introduction to Ecological Economics*. Boca Raton: CRC Press

Cotrell, F. (1955): *Energy and Society*. New York, Toronto, London: McGraw-Hill Book Company

Cullen, L. M. (1968): *Anglo - Irish Trade 1660 - 1800*. Manchester: Manchester Universtiy Press

Curth, H. (1917): Der Nahrungsmittel und Rohstoffbedarf Englands. Jena: Gustav Fischer, 1-142

Daly, H. E. (1992): The Steady-State Economy: Alternative to Growthmania. In: *Steady-State Economics*. LondonBd. 9, pp. 180-194

Daniels, P. L. and Moore, S. (2001): Approaches for Quantifying the Metabolism of Physical Economies: A Comparative Survey. Part I - Methodological Overview. In: *Journal of Industrial Ecology* 5(4), pp. 69-93

Daniels, P. L. and Moore, S. (2002): Approaches for Quantifying the Metabolism of Physical Economies: A Comparative Survey. Part II - Review of Individual Approaches. In: *Journal of Industrial Ecology* 6(1), pp. 65-89

Darmstadter, J. (1971): Energy and the world economy. A statistical review of trends in output, trade and consumption since 1925. Baltimore, MD: John Hopkins Univ. Press

Deane, P. and Cole, W. A. (1967): *Britsh Economic Growth 1688-1959*. Cambridge: Cambridge at the University Press (Monographs; Vol. 8)

Dodgshon, R. A. and Butlin, R. A.(eds.) (1978): *An Historical Geography of England and Wales*. London: Academic Press inc.

Duchin, F. (1998): Structural Economics: Measuring Change in Technology, Lifestyles, and the Environment. Washington: Island Press

Etemad, B. and Luciani, J. (1991): *World Energy Production 1800-1985*. Geneve: Librairie Droz

Eurostat (2001a): Economy-wide Material Flow Accounts and Derived Indicators. A methodological guide. Luxenbourg: Eurostat

Eurostat (2001b): Material use indicators for the European Union, 1980-1997. Economy-wide material flow accounts and balances and derived indicators of resource use. Working Paper No. 2/2001/B/2. Luxemburg: European Commission/Eurostat, prepared by Bringezu, S. and Schütz, H.

Eurostat (2002): Material Use in the European Union 1980-2000. Luxembourg: (Eurostat Working Papers and Studies)

Fillunger, J. (1868): Vergleichende Statistik über Real- und Productionswerte im österreichischen Kaiserstaate. Wien:

Fischer-Kowalski, M. (1998): Society's Metabolism. The Intellectual History of Material Flow Analysis, Part I, 1860 - 1970. In: *Journal of Industrial Ecology* 2(1), pp. 61-78

Fischer-Kowalski, M. and Haberl, H. (1993): Metabolism and Colonization. Modes of Production and the Physical Exchange between Societies and Nature. In: *Innovation - The European Journal of Social Sciences* 6(4), pp. 415-442

Fischer-Kowalski, M., Haberl, H., Hüttler, W., Payer, H., Schandl, H., Winiwarter, V., and Zangerl-Weisz, H. (1997): *Gesellschaftlicher Stoffwechsel und Kolonisierung von Natur. Ein Versuch in Sozialer Ökologie*. Amsterdam: Gordon & Breach Fakultas

Fischer-Kowalski, M. and Hüttler, W. (1999): Society's Metabolism. The Intellectual History of Material Flow Analysis, Part II: 1970-1998. In: *Journal of Industrial Ecology* 2(4), pp. 107-137

Fischer-Kowalski, M. and Weisz, H. (1999): Society as hybrid between material and symbolic realms: Towards a theoretical framework of society-nature interaction. In: *Advances in Human Ecology* 8, pp. 215-251

Fouquet, R. and Pearson, P. J. G. (1998): A Thousand Years of Energy Use in the United Kingdom. In: *The Energy Journal* 19(4), pp. 1-41

Friese, F. M. (1870): Übersicht der Roheisen-Produktion der oesterreichisch-ungarischen Monarchie. Wien: Waldheim

Friese, F. (1855): Übersicht über die österreichische Bergwerks-Produktion in den Jahren 1823-1854. Wien: Friedrich Manz

Gershuny, J. (2000): Time Use Research Methods. In: Baltes, P. B. and Smelser, N. J. (Eds.): *International Encyclopedia of the Social & Behavioral Sciences*. Oxford: Elsevier Science Limited, pp. 15752-15756

Giampietro, M. (2000): *Jevon's Paradox, Scaling in Societal Metabolism and the Fairy Tale of Kuznets Curves.* Proceedings of the 3rd Biennial Conference of the European Society for Ecological Economics - ESEE, Vienna, 3-6 May 2000; CD-Rom or Website: http://www.wu-wien.ac.at/esee2000,

Giampietro, M. and Mayumi, K. (2000): Multiple-Scale Integrated Assessment of Societal Metabolism: Integrating Biophysical and Economic Representation. In: *Population and Environment* 22(2), pp. 155-210

Giampietro, M. and Pimentel, D. (1991): Energy Efficiency: Assessing the Interaction between Humans and their Environment. In: *Ecological Economics* 4, pp. 117-144

Godbey, G. (1996): No Time to Waste: Time Use and the Generation of Residential Solid Waste. New Haven: Yale School of Forestry and Environmental Studies

Godelier, M. (1984): L'idéel et le matériel. Pensée, économies, societés. Paris: Fayard

Grigg, D. (1989): *English Agriculture - an historical perspective*. Oxford, New York, Blackwell

Gross, N. T. (1990): Economic Growth and the Consumption of Coal in Austria and Hungary 1831-1913. In: Komlos, J. (Ed.): *Economic Development in the Habsburg Monarchy and the Successor States*. New York: Columbia University Press, pp. 185-201

Grübler, A. (1994): Industrialization as a Historical Phenomenon. In: Socolow, R. and others (Eds.): *Industrial Ecology and Global Change*. Cambridge, Mass.: Cambridge University Press, pp. 43-67

Haberl, H. (2001a): The Energetic Metabolism of Societies, Part I: Accounting Concepts. In: *Journal of Industrial Ecology* 5(1), pp. 11-33

Haberl, H. (2001b): The Energetic Metabolism of Societies, Part II: Empirical Examples. In: *Journal of Industrial Ecology* 5(2), pp. 71-88

Haberl, H. and Krausmann, F. (2001): Changes in Population, Affluence and Environmental Pressures During Industrialization. The Case of Austria 1830-1995. In: *Population and Environment* 23(1), pp. 49-69

Hain, J. (1852): Handbuch der Statistik des österreichischen Kaiserstaates. Wien: Tendler und Compagnie

Handels- und Gewerbekammer in Wien (ed.) (1867): *Statistik der Volkswirtschaft in Nieder-Oesterreich 1855-1866*. Wien: Leopold Sommer2

Hatcher, J. (1993): The History of The British Coal Industry. Volume 1: Before 1700: Towards the Age of Coal. Oxford: Clarendon Press

Hobsbawm, E. (1968): *Industry and Empire*. London:

Humphrey, W. S. and Stanislaw, J. (1979): Economic growth and energy consumption in the UK, 1700-1975. In: *Energy Policy* 7(1), pp. 29-43

IEA (2001): Energy Statistics of OECD Countries 1998-1999. Paris: International Energy Agency (IEA), Organisation for Economic Co-Operation and Development (OECD)

Jevons, W. S. (1865): *The Coal Question - An Inquiry Concerning the Progress of the Nation, and the Probable Exaustion of our Coal-mines*. Houndsmills, Basingstroke, Hampshire: Palgrave (The Palgrave Edition of The Writings on Economics of W.S. Jevons; Vol. 9)

k.k.Finanz-Ministerium (ed.) (1858): Tafeln zur Statistik des Steuerwesens im österreichischen Kaiserstaate mit besonderer Berücksichtigung der directen Steuern und des Grundsteuerkatasters. Wien.

Kander, A. (2002): *Economic growth, energy consumption and CO2 emissions in Sweden 1800-2000*. Lund: Lund University (Lund Studies in Economic History Vol. 19)

Katterl, A. and Kratena, K. (1990): *Reale Input-Output Tabelle und ökologischer Kreislauf.* Heidelberg: Physica

Kausel, A. (1979): Österreichs Volkseinkommen 1830 bis 1913. In: Österreichisches statistisches Zentralamt (Ed.): *Geschichte und Ergebnisse der zentralen amtlichen Statistik in Österreich 1829-1979*. Wien, Beiträge zur Österreichischen Statistik , pp. 689-720

Krausmann, F. (2001a): Land Use and Industrial Modernisation: an empirical analysis of human influence on the functioning of ecosystems in Austria 1830 - 1995. In: *Land Use Policy* 18(1), pp. 17-26

Krausmann, F. (2001b): Rekonstruktion der Entwicklung von Materialflüssen im Zuge der Industrialisierung: Biomasse Materialflüsse in Österreich von 1830 bis 1998. Stuttgart: Breuninger Stiftung (der europäische sonderweg, Vol. 3)

Krausmann, F. (2003a): Das Energiesystem von Wien im 19. und 20. Jahrhundert. In: Borsdorf, A. and others (Eds.): *Umweltgeschichte der Stadt Wien*. Wien: Böhler Verlag (in print).

Krausmann, F. (2003b): Land Use and Socio-economic Metabolism in Pre-industrial Agricultural Systems: Four 19th Century Austrian Villages in Comparison. In: *Collegium Anthropologicum* (in print)

Krausmann, F. and Haberl, H. (2002): The Process of industrialization from the perspecitve of energetic metabolism, Socioeconomic energy flows in Austria 1830-1995. In: *Ecological Economics* 41(2), pp. 177-201

Krausmann, F., Haberl, H., Schulz, N. B., Erb, K.-H., Darge, E., and Gaube, V. (2003a): Land-Use Change and Socio-Economic Metabolism in Austria, Part I: Socio-Economic Driving Forces of Land-Use Change 1950-1995. In: *Land Use Policy* 20(1), pp. 1-20

Krausmann, F., Schandl, H., and Schulz, N. B. (2003b): Vergleichende Untersuchung zur langfristigen Entwicklung von gesellschaftlichem Stoffwechsel und Landnutzung in Österreich und dem Vereinigten Königreich. Stuttgart: Breuninger Stiftung (der europäische sonderweg; Vol. 11)

Lambin, E., Baulies, X., Bockstael, N., Fischer, G., Krug, T., Leemans, R., Moran, E. F., Rindfuss, R. R., Sato, Y., Skole, D. L., Turner II, B. L., and Vogel, C. (1999): *Land-Use and Land-Cover Change (LUCC). Implementation Stragtegy*. Stockholm, Bonn: IGBP and IHDPIGBP Report 48; IHDP report 10

Lohm, U., Anderberg, S., and Bergbäck, B. (1994): Industrial metabolism at the national level: A case-study on chromium and lead pollution in Sweden, 1880-1980. In: Ayres, R. U. and Simonis, U. E. (Eds.): *Industrial Metabolism: Restructuring for Sustainable Development*. Tokyo, New York, Paris, pp. 103-118

Lorenz, J. R. (1866): Die Bodencultur-Verhältnisse des österreichischen Staates. Wien: Seidel&Sohn

Lotka, A. J. (1925): *Elements of Physical Biology*. Baltimore: Williams & Wilkins

Maddison, A. (1982): *Phases of Capitalist Development*. Oxford: Oxford University Press

Maddison, A. (1995): *Monitoring the World Economy 1820-1992*. Paris: OECD (OECD Development Centre Studies

Maddison, A. (2001): *The World Economy. A millenial perspective*. Paris: OECD (Development Centre Studies

Malanima, P. (2001): The energy basis for early modern growth, 1650-1820. In: Prak, M. (Ed.): *Early Modern Capitalism. Economic and social change in Europe, 1400-1800*. London-New York: Routledge, pp. 51-69

Martinez-Alier, J. (1987): Ecological Economics. Energy, Environment and Society. Oxford: Blackwell

Matthews, E., Amann, C., Fischer-Kowalski, M., Bringezu, S., Hüttler, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., Schütz, H., van der Voet, E., and Weisz, H. (2000): *The Weight of Nations: Material Outflows from Industrial Economies*. Washington: World Resources Institute

McNeill, J. R. (1998): China's Environmental History in World Perspective. In: Elvin, M. and Ts'ui-Jung, L. (Eds.): *Sediments of Time*. Cambridge: Cambridge University PressBd. 2, pp. 31-49

McNeill, J. (2000): Something new under the sun. An environmental history of the twentieth century. London: Allen Lane

Meade, R. (1882): The coal and iron industries of the United Kingdom.

Meadows, D. L., Meadows, D. H., and Randers, J. (1972): *The Limits to Growth*. New York: Universe Books

Meyer, W. B. and Turner, B. L. (1994): *Changes in Land Use and Land Cover, A Global Perspective*. Cambridge: Cambridge University Press

Meyer, W. B. and Turner, I. I. (1992): Human population growth and global land-use/cover change. In: *Annual Review of Ecological Systems* 23, pp. 39-61

Mingay, G. E. (1989): *The Agrarian History of England and Wales: 1750-1850*. Cambridge: Cambridge University Press (The Agrarian History of England and Wales; Vol. 6)

Mitchell, B. R. (1988): *British Historical Statistics*. Cambridge: Cambridge University Press

Mitchell, B. R. (1995): International Historical Statistics Europe 1750-1988. New York: Stockton press

Mitchell, B. R. and Deane, P. (1962): *Abstract of British Historical Statistics*. Cambridge: University Press

Musson, A. E. (1978): *The Growth of British Industry*. London: B.T. Batsford Ltd

Nef, J. U. (1966): *The rise of the British coal industry*. Hamden: Archon Books

Netting, R. M. (1981): *Balancing on an Alp. Ecological change and continuity in a Swiss mountain community*. London, New York, New Rochelle, Melbourne, Sydney: Cambridge University Press

Netting, R. M. (1993): Smallholders, Householders. Farm Families and the Ecology of Intensive, Sustainable Agriculture. Stanford: Stanford University Press

Nilsson, L. J. (1993): Energy intensity trends in 31 industrial and developing countries 1950-1988. In: *Energy* 18(4), pp. 309-322

Pastore, G., Giampietro, M., and Mayumi, K. (2000): Societal Metabolism and Multiple-Scale Integrated Assessment: Empirical Validation and Examples of Application. In: *Population and Environment* 22(2), pp. 211-254

Pfister, C. (1994): Das 1950er Syndrom. Die Epochenschwelle der Mensch-Umwelt-Beziehung zwischen Industriegesellschaft und Konsumgesellschaft. In: *GAIA* 3(2), pp. 71-88

Pfister, C. (1995): Im Strom der Modernisierung. Bevölkerung, Wirtschaft und Umwelt im Kanton Bern 1700-1914. In: *Geschichte des Kantons Bern seit 1798, Band IV*. Bern, Stuttgart, Wien, Archiv des historischen Vereins des Kantons Bern

Pimentel, D., Hurd, L. E., Bellotti, A. C., Forster, M. J., Oka, I. N., Sholes, O. D., and Whitman, R. J. (1973): Food production and the energy crisis. In: *Science* 182, pp. 443-449

Pimentel, D., Dazhong, W., and Giampietro, M. (1990): Technological Changes in Energy Use in U.S. Agricultural Production. In: Gliessmann, S. R. (Ed.): *Agroecology, Researching the Ecological Basis for Sustainable Agriculture*. New York: Springer, Ecological Studies Bd. 18, pp. 305-321

Projektgruppe Umweltgeschichte (1999): Kulturlandschaftsforschung: Historische Entwicklung von Wechselwirkungen zwischen Gesellschaft und Natur. Wien: CD-Rom, Bundesministerium für Wissenschaft und Verkehr

Ramankutty, N. and Foley, J. (1999): Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992. In: *Global Biogeochemical Cycles* 13, pp. 997-1028

Riden, P. (1977): The Output of the British Iron Industry before 1870. In: *Economic History Review* 30(3), pp. 442-459

Robinson J. P. and Converse P. E. (1972): Social Change Reflected in the Use of Time. In: Robinson John, P. and Converse Phillip, E. (Eds.): *The Human Meaning of Social Change*. New York: Russel Sage Foundation, pp. 17-86

Rostow, W. W. (1978): *The World Economy. History and Prospect*. Austin & London: University of Texas Press

Sandgruber, R. (1978a): *Österreichische Agrarstatistik 1750 - 1918*. Verlag für Geschichte und Politik, Wien (Wirtschafts- und Sozialstatistik Österreich-Ungarns; Vol. 2)

Sandgruber, R. (1978b): Wirtschaftswachstum und Energie in Österreich 1840-1913. In: Kellenbenz, H. (Ed.): *Wirtschaftswachstum, Energie und Verkehr vom Mittelalter bis ins 19. Jahrhundert*. Stuttgart, New York: Fischer Verlag, Forschungen zur Sozial- und Wirtschaftsgeschichte , pp. 67-95

Schandl, H. (2000a): 50 Jahre Umgang mit Natur, Die biophysischen Dimensionen von Modernisierung in Österreich. In: Bruckmüller, E. and Winiwarter, V. (Eds.): *Umweltgeschichte, Vom historischen Verhältnis von Gesellschaft und Natur*. Wien: Österreichischer Bundesverlag, Hölder-Pichler-Tempsky, pp. 167-190

Schandl, H. (2000b): 50 Jahre Umgang mit Natur. Die biophysischen Dimensionen von Modernisierung in Österreich. In: Bruckmüller, E. and Winiwarter, V. (Eds.): *Umweltgeschichte. Zum historischen Verhältnis von Gesellschaft und Natur*. Wien: ÖBV und HPT, pp. 167-190

Schandl, H., Grünbühel, C. M., Haberl, H., and Weisz, H. (2002): Handbook of Physical Accounting. Measuring bio-physical dimensions of socio-ecomonic activities. MFA - EFA - HANPP.

Vienna: Federal Ministry of Agriculture and Forestry, Environment and Water Management, 1-75

Schandl, H. and Schulz, N. (2000): Using Material Flow Accounting to Operationalize the Concept of Society´s Metabolism. A Preliminary MFA for the United Kingdom for the Period of 1937 - 1997. Essex: Institute for Social & Economic Research (ISER) working paper Number 2000-3, University of Essex

Schandl, H. and Schulz, N. B. (2001): Eine historische Analyse des materiellen und energetischen Hintergrundes der britischen Ökonomie seit dem frühen 19. Jahrhundert. Stuttgart: Breuninger Stiftung (der europäische sonderweg; Vol. 4)

Schandl, H. and Schulz, N. B. (2002a): Changes in United Kingdom´s natural relations in terms of society's metabolism and land use from 1850 to the present day. In: *Ecological Economics* 41(2), pp. 203-221

Schandl, H. and Schulz, N. B. (2002b): Industrial Ecology: United Kingdom. In: Ayres, R. U. and Ayres, L. W. (Eds.): *Handbook for Industrial Ecology*. Cheltenham: Edward Elgar, pp. 323-333

Schandl, H., Weisz, H., and Petrovic, B. (2000): Materialflussrechnung für Österreich 1960 bis 1997. In: *Statistische Nachrichten* 55 (NF)(2), pp. 128-137

Schmitz, J. (1979): World Non-Ferrous Metal Production and Prices, 1700 - 1976. London:

Sieferle, R. P. (1982): Der unterirdische Wald. Energiekrise und Industrielle Revolution. München: C.H.Beck

Sieferle, R. P. (1997a): Kulturelle Evolution des Gesellschaft-Natur-Verhältnisses. In: Fischer-Kowalski, M. and others (Eds.): *Gesellschaftlicher Stoffwechsel und Kolonisierung von Natur. Ein Versuch in Sozialer Ökologie*. Amsterdam: Gordon & Breach Fakultas, pp. 37-53

Sieferle, R. P. (1997b): Rückblick auf die Natur: Eine Geschichte des Menschen und seiner Umwelt. München: Luchterhand

Sieferle, R. P. (2001a): *Europe's Special Course: Outline of a research program*. Stuttgart: Breuninger Stiftung (der europäische sonderweg; Vol. 1)

Sieferle, R. P. (2001b): The Subterranean Forest. Energy Systems and the Industrial Revolution. Cambridge: The White Horse Press

Simmons, I. G. (2001): An Environmental History of Great Britain. From 10,000 years ago to the present. Edinburgh: Edinburgh University Press

Simmons, I. G. (1993): *Environmental History. A Concise Introduction*. Oxford, Cambridge: Balckwell (New Perspectives on the Past;

Smil, V. (1994): *Energy in World History*. Boulder, San Francisco, Oxford: Westview Press

Springer, J. (1840): Statistik des österreichischen Kaiserstaates. Wien: Beck

Stanhill, G. (1984): Agricultural Labour: From Energy Source to Sink. In: Stanhill, G. (Ed.): *Energy and Agriculture*. Berlin, Heidelberg, New York, Tokyo: Springer Vol. 6, pp. 113-131

Szalai, A. (1972): *The use of Time*. The Hague: Mouton

Trömel, M. (1995): Quantitative Analyse technischer Wachstumsprozesse: Drei Entwicklungsphasen der Industriegesellschaft im 20. Jahrhundert. In: Sieglerschmidt, J. (Ed.): *Der Aufbruch ins Schlaraffenland. Stellen die Fünfziger Jahre eine Epochenschwelle im Mensch-Umwelt-Verhältnis dar?* Mannheim: European Association for Environmental History, pp. 9-27

Turetschek, K. (1979): Die Entwicklung der österreichischen Primärenergieproduktion. In: ÖSTAT (Ed.): *Geschichte und Ergebnisse der zentralen amtlichen Statistik in Österreich 1829-1979*. Wien: Kommissionsverlag, Beiträge zur österreichischen Statistik , pp. 603-648

Turner, B. L., Clark, W. C., Kates, R. W., Richards, J. F., Mathews, J. T., and Meyer, W. B. (1990): *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years*. Cambridge: Cambridge University Press

Umweltbundesamt (ed.) (1988): Bodenschutz: Probleme und Ziele. Wien: BMUJF

Vellinga, P. and Herb, N. (1999): *Industrial Transformation IT Science Plan*. Bonn: IHDP (IHDP Report No.12)

Voth, H.-J. (2001): *Time and Work in England 1750-1830*. Oxford: Clarendon Press

Voth, H. J. (2000): *Time and Work in England 1750-1830*. Oxford: Oxford University Press

Wackernagel, M. (1999): Ecological Economics Forum: Why sustainability analysis must include biophysical assessments. In: *Ecological Economics* 29, pp. 13-15

Wallerstein, I. (2000): Globalisation or the Age of Transition. A Long-Term View of the Trajectory of the World System. In: *International Sociology* 15(2), pp. 249-265

Weisz, H., Amann, C., Eisenmenger, N., Erb, K.-H., Hubacek, K., Krausmann, F., and Schulz, N. B. (2002): Economy-wide Material Flow Accounts and Indicators of Resource Use for the EU. Eurostat Tender 2001/S 125 - 084782/EN. Final Report. Luxembourg: Eurostat Working Papers

Weisz, H., Fischer-Kowalski, M., Grünbühel, C. M., Haberl, H., Krausmann, F., and Winiwarter, V. (2001): Global Environmental Change and Historical Transitions. In: *Innovation - The European Journal of Social Science Research* 14(2), pp. 117-142

Wessely, J. (1853): Die oesterreichischen Alpenlaender und ihre Forste. Wien:

Williams, J. C. (1997): *Energy and the Making of Modern California*. Akron: The University of Akron Press

Winiwarter, V. (2001): Landwirtschaft, Natur und ländliche Gesellschaft im Umbruch. Eine umwelthistorische Perspektive zur Agrarmodernisierung. In: Gudermann, R. and others (Eds.): *Landwirtschaft und Umwelt in Westfalen 18.-20.Jh.* Paderborn, pp. 733-767

Winiwarter, V. and Sonnlechner, C. (2001): *Der soziale Metabolismus der vorindustriellen Landwirtschaft in Europa*. Stuttgart: Breuninger Stiftung (der europäische sonderweg; Vol. 2).

Wittich, F. W. (1825): *Statistik Englands*. Berlin: Dümmler

Worster, D. (1988): The Ends of the Earth: Perspectives on Modern Environmental History. Cambridge: Cambridge University Press

Worster, D. (1993): The Wealth of Nature. Environmental history and the ecological imagination. New York, Oxford: Oxford University Press

Worster, D. (1994): Nature and the Disorder of History. In: *Environmental History Review* 18(2), pp. 1-16