Chapter 2
Economic History and the Environment: New Questions, Approaches and Methodologies

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Abstract Ecological economics is enabling economic and environmental historians to enhance their understanding of economic growth, by placing it in a broader perspective of biophysical interactions between nature and society. In this chapter, several ongoing researches and historical debates are examined from this standpoint such as the missing role of energy carriers in GDP growth, the socio-metabolic profiles of past and present societies, the pre-industrial 'Smithian' responses to 'Malthusian' traps, the role of efficient land-use in breeding livestock to increase agricultural yields, the reasons why the Industrial Revolution began in a high wage and cheap energy economy, the first globalization as a socio-metabolic watershed, and the question of whether there was a general crisis of biomass energies at the coming of fossil fuels era. Research discussing long-term socio-metabolic transitions may contribute to our understanding of how economic growth actually occurred, and which ecological impacts affected the Earth's life-support systems. Equally, these projects leave room for the institutional settings or ruling actors needed to explain why growth has happened and by whom. Far from naturalising history, the use of ecology in the explanation of human history historialises ecology.

2.1 Introduction

If all the research done in the well-established scientific field of economic history had to be summed up in one word it would be 'growth'. The main subject, if not the single issue, studied by economic historians is when, where, and why economic growth has taken place. In doing so, there has been a greater tendency to rely

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mainly or exclusively on mainstream economics as an analytical foundation. One of the earliest criticisms raised by environmentalists decades ago, and later by environmental historians is that mainstream economists, and some economic historians, have not only set aside the role played by natural resources in past and present economic growth, but have also ignored the increasingly powerful and global environmental impacts of economic growth on the planet's ecological life-support systems.[1]

Yet the misunderstanding between mainstream economics and environmental sciences goes beyond having ignored some "external" inputs and outputs that can simply be reintegrated into current macroeconomic growth analysis. As many specialists have recognized, economists have found profound and persistent problems in the explanation of long-term economic growth. These difficulties originated at the beginning of the neoclassical analytical approach. Ironically, mainstream economists intended to become the analytical physicians of the social sciences precisely as they discarded 'land' and other natural resources as relevant factors within economic theory.[2] Interestingly enough, it was also in this period when history ceased to be a basic background within economics.[3] From then onwards the standard neoclassic growth model assumed that the final value added flows of GDP are directly produced from labour and capital alone, without specifying a role for energy flows, which were only considered to be consumable intermediates.[4]

2.2 The Missing Role of Useful Work from Energy Carriers in Economic Growth

According to these neoclassical analytical assumptions, technological progress becomes exogenous and natural resource consumption is seen as a consequence, not a driver, of economic growth. Perhaps it is not so surprising that the first generation of macroeconomists who accounted for growth by means of a Cobb-Douglass production function using capital and labour as the only relevant factors, couldn't fully explain no more than a small level of growth in GDP, because the results left a large, increasing residual (Fig. 2.1). Labelling this unexplained residual "total factor productivity" (TFP), and considering it to be the contribution of technical progress to economic growth, has become common practice. However as Robert Solow stresses, by calling it "the measure of our ignorance", TFP has become an exogenous factor not taken into account by the standard growth theory.

[1] Debier et al. (1986), Worster (1988), McNeill (2000a), Krech III et al. (2004), Hornborg et al. (2007) and Sing et al. (2013).

[2] Pasinetti (1981).

[3] Hodgson (2007).

[4] Ayres and Warr (2005).

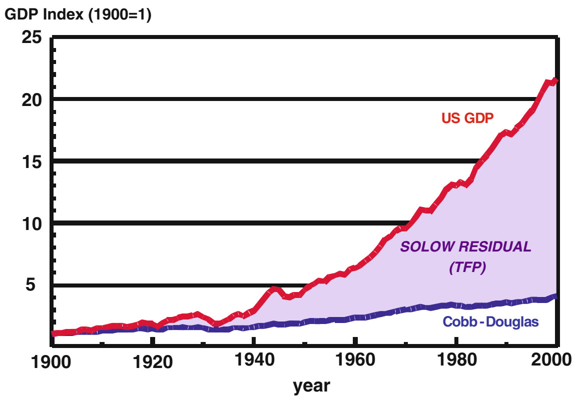

Fig. 2.1 Explained share of the actual GDP growth of the United States economy during the 20th century, and the Solow residual obtained by a conventional Cobb-Douglass production function. *Source* Ayres et al. (2009) during 100 years of economic growth, presented to the Q2 session on Energy, climate change and growth: perspectives from economic history of the 25th World Economic History Congress, Utrecht, The Netherlands. The following three-factor Cobb-Douglas production function has been used: $Y_t = A_t\,(H_t\,K_t)^{\alpha}\,(G_t\,L_t)^{\beta}\,(F_t\,R_t)^{\gamma}$, where Y_t is output at time t, a function of K_t, L_t, R_t as inputs of capital, labour and natural resources; A_t is "total factor productivity" or the "Solow residual"; H_t, G_t, F_t are the coefficients of factor contribution taken from its revenue share in the income distribution of GDP—in this case as 0.70 for L, 0.26 for K, and 0.04 for the rest. According to the constant returns to scale assumption required by this function, $\alpha + \beta + \gamma = 1$

A second wave of "endogenous growth" theories has attempted to overcome this analytical *cul-de-sac*. Nevertheless, instead of reintroducing the material and energy layers that embody and activate capital assets or enhance labour capacities, the endogenous growth theorists came from a different angle.[5] They looked towards increasingly symbolic and immaterial dimensions, such as the role played by 'human capital' endowment in long-term economic growth, and other social and cultural aspects. This approach has inspired a wide range of interesting and valuable historical research on the economic history of education, literacy and numeracy, book printing, skill premiums in the labour markets, the long-term effects of the European Marriage Pattern characterized by late weddings resulting in independent households based on a single nuclear family, and "a million of mutinies" in the everyday life of a large fraction of people which, according to Robert Lucas[6] is needed for income growth to occur in any society. These may range from nutritional standards and height increases, to the rise of contractual arrangements on weddings seen as a direct token of 'girlpower' and an indirect indicator of the habit to negotiate all sorts of business in life.[7]

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[5] Ayres (2001).

[6] Lucas (2002).

[7] van Zanden (2009).

There has also been a renewed interest in studying the role played by income or wealth inequality, social public spending, and socio-institutional settings in the long-term economic performance of nations.[8] When income inequality approached the maximum permitted by available wealth and the need to reproduce the labour force at a subsistence level, societies often get caught in a 'worlds apart' lock-in state: the great majority of people could not change the situation, and the privileged minority did not want to. This explains why the agrarian class structure, the social conflicts that arise within it, and the kind of institutional changes fostered by social and political struggles are so important for historical processes of economic development.[9]

All these socio-institutional settings and human capabilities raise important questions that deserve to be studied in their own right. They have more than likely played a key role, considering them as results as well as crucial factors, that help explain *why* economic growth has taken certain directions in only some places and in only certain periods, and *by whom*. Also, if we apply here the distinction put forward by Amartya Sen and Martha Nussbaum between economic growth and human development, taking into consideration all these important questions may significantly help explain historical human development as an individual and collective increase in freedom of choice and 'empowerment'.[10] Nevertheless, it is doubtful that this can ever fill the Solow residual gap to explain *how* economic growth takes place. After several decades of endogenous growth analyses, the growth engine remains a black box.[11]

Although the historical process of human development has always included many social, institutional and symbolic dimensions, we should wonder if the empowerment of human capabilities, and the enhancement of individual and social choices, could ever be attained without relying on a greater amount of energy power able to move an increasing amounts of physical flows in a wider global scope.[12] According to both qualitative and quantitative historical evidence, physical and energy resource flows have always been a major factor in increasing the aggregated production of goods and services. A recent contribution to a never-ending debate, the Bob Allen book on *The British Industrial Revolution in Global Perspective*, has again stressed the role played by the supply of cheap coal as a driving force for the beginning of modern economic growth in England.[13]

Several economic and environmental historians have studied this link between coal and the British Industrial Revolution, or underlined the role played by the increasing access to fossil fuels for other regions of the world to industrialize and

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[8] Lindert (2004), Acemoglu (2004, 2009), Acemoglu and Robinson (2006) and Aghion and Williamson (1998).

[9] Aston and Philpin (1985), Hoppenbrouwers and van Zanden (2001) and Milanovic (2005).

[10] Sen (1993, 1999).

[11] Easterly (2002) and Helpman (2004).

[12] Ayres and Warr (2005).

[13] Allen (2009).

converge with developed nations. All these studies reaffirm what Nicholas Georgescu-Roegen wrote many years ago in *Energy and Economic Myths*: "Now Economic history confirms a rather elementary fact—the fact that great strides in technological progress have generally been touched off by a discovery of how to use a new kind of accessible energy. On the other hand, a great stride in technological progress cannot materialize unless the corresponding innovation is followed by a great mineralogical expansion. […] This sort of expansion is what has happened during the last one hundred years*"*.[14]

The failure to explain how the growth engine actually works is relevant from an environmental standpoint because the energy flows or material throughputs moved by the economy all over the planet are put aside. The principal ways through which the economy affects the ecosystems are exactly these same energy and material flows. Moreover some recent developments made by Robert Ayres and Benjamin Warr seem to open a promising new way to address the unsolved problem of the long-term growth accounts, without encountering the Solow residual.[15] This approach considers economic growth as an open multi-sector processing system of materials, energy and information, which moves forward in a perpetual disequilibrium, beginning with the extraction of natural resources and ending with the consumption and disposal of wastes. Since the Industrial Revolution, radical innovations in energy conversion technology have been among the most potent drivers of growth and structural change, which have put in motion much positive feedback by means of reducing energy costs. The substitution of increasingly cheap mechanical, thermal and chemical useful work (or 'exergy') for increasingly expensive human labour and capital has played a key role as a driver of economic growth (Fig. 2.2).

Considering that this evidence strongly suggests that 'exergy' (or the useful work actually performed by all energy converters which empower human labour and capital goods at its disposal) should be taken as a factor of production, Ayres et al. have been able to almost fit the empirical GDP historical series of the United States, Japan and other countries during the 20th century by including the useful work performed by all energy converters after discounting energy loses, together with the standard labour and capital factors, either in a conventional Cobb-Douglass or in a linear-exponential (LINEX) production function where all factors become mutually dependent, and where empirical elasticities do not equal cost share (Fig. 2.3).

[14] Georgescu-Roegen (1976).

[15] Ayres and Warr (2005).

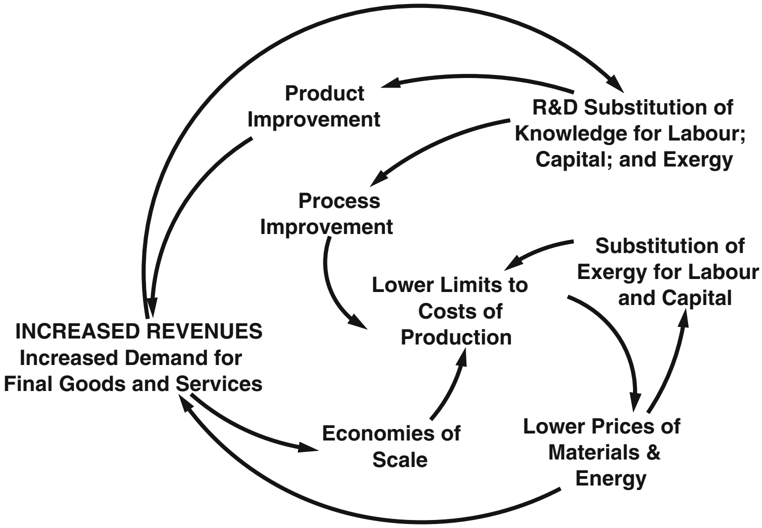

Fig. 2.2 The substitution of exergy for labour and capital seen as the key factor of lowering costs and increasing revenues in the virtuous cycle driving historical economic growth. *Source* Ayres and Warr (2005)

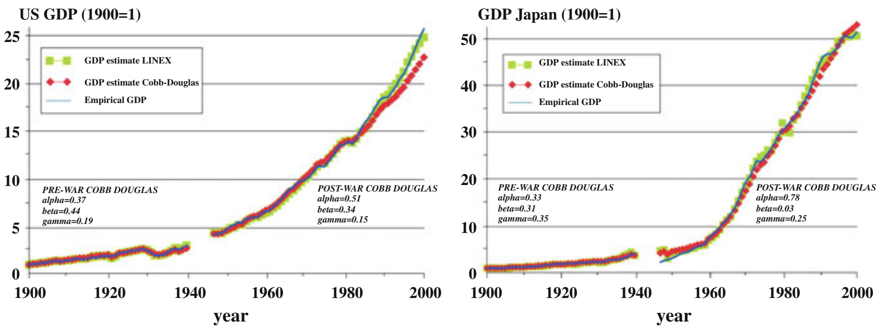

Fig. 2.3 The explanatory capacity of a LINEX or Cobb-Douglass production function which includes useful work together with labour and capital, confronted with the historical GDP series of the United States and Japan (1900–2000). *Source* Ayres (2008). Besides the standard Cobb-Douglass function, the following LINEX production function has also been used: $Y_t = U \exp\left\{a\left(2 - \frac{L+U}{K}\right) + ab\left(\frac{L}{U} - 1\right)\right\}$ which includes capital (K), labour (L) and useful work (U). Considering that there is an apparent inconsistency between very small factor payments directly attributable to physical resources—especially fossil fuels—and the obvious importance of final useful energy (or exergy) as a factor of production, this approach abandons the neoclassical assumption that the productivity of a factor of production must be proportional to the share of that factor in the national income. Alternatively, it considers that available useful work, either mechanical, chemical or thermal, multiplies the joint productivity of any combination of capital and labour throughout all value-added stages of the whole set of production chains (Ayres 2001, pp. 817–838; Ayres and Warr 2005, pp. 181–209 and Ayres et al. 2009). Therefore, the neoclassical identification of marginal productivities with factor shares is here replaced by a statistical assessment of the equation parameters

For the United States and Japan, a = 0.12. For the United States b = 3.4, and for Japan b = 2.7. It corresponds to $Y = K_{0.36}\, L_{0.08}\, U_{0.56}$ (i.e., useful work performed by energy sources could explain as much as 56 % of actual GDP growth experienced during the 20th century, while growth of capital stock would account for 36 and 8 % would come from the increase in labour capabilities).

It is too early to tell if this new way to account for the long-term economic growth, just now being opened from an ecological economics standpoint, will consolidate and gain acceptance among the majority of mainstream economists and economic historians. For the moment, even admitting the increasing relevance of environmental global concerns, mainstream developing economists and economic historians continue to consider primary energy as only another input or intermediate good that can always be substituted in the market. All of this explains why there is a growing suspicion among ecological economists and environmental historians that ignoring the environmental impacts of economic growth comes from the same analytical foundation that has forgotten the role played by natural resources in human economy and ecology, and both seem to be tightly related to the persistent inability by mainstream economists to fully explain how economic growth actually works.

2.3 From Economic History to Social Metabolism and Beyond

The rise of ecological economics is enabling economic and environmental historians alike to share and, at the same time, enhance their respective long-term understanding of economic growth by placing it in a broader perspective of biophysical interactions between human economies and natural systems in the biosphere. This socio-metabolic approach has been summarized by the Institute of Social Ecology in Vienna as follows: "The central theme underlying this research is the notion that most, if not all, global sustainability issues have to do with the fact that about two-thirds, if not three-quarters of the world population are currently in the midst of a rapid transition from agrarian society to the industrial regime. This transition is fundamentally changing societal organization, economic structures, patterns of resource use and so on, thereby probing the limitations of the planet Earth in many ways, among others by using up exhaustible resources, altering global biogeochemical cycles, depleting diversity and degrading Earth's ecosystems".[16] A new set of questions, methods and accounts arise from this, focus on the main socio-ecological transitions experienced in the interplay between nature and societies:

1. Was there a 'characteristic metabolic profile' of agrarian societies? Was such a metabolic profile connected to, and dependent on, certain land-use patterns?

[16] Fischer-Kowalski et al. (2007).

2. What happened when these socio-ecological agrarian regimes started to change? Which were the major drivers of change? Which pressures upon the environment gained momentum with industrialization and urbanization based on burning cheap fossil fuels, and which pressures receded? Which changes within natural systems could be observed during the socio-ecological transitions?
3. How much did the course of the socio-ecological transitions depend on the historical context, either local, regional or worldwide? Do common patterns exist?
4. How does the interplay between different spatial scales and levels of society work and interact with nature? Does globalization matter?

This approach has led to detailed quantitative studies of the energy and biophysical flows that link human economic activities with their ecological foundations, opening new ways of accounting: Material and Energy Flow Analysis (MEFA), the reconstruction of energy balances of economic systems and sectors, the estimation of energy returns on energy inputs (EROI), the study of nutrient and water cycles, the extent of the human appropriation of the ecological net primary production (HANPP) or the historical evolution of ecological footprints. These have established themselves as leading lines in current research.[17] There have also been attempts within the European Union to standardize these methods of ecological-economic accounting in established systems of National Accounts (EUROSTAT 2001).

As Fridolin Krausmann, Heinz Shandl and Rolf Peter Sieferle have written, "In this way, industrialization appears as a process of continuous increases in labour productivity and energy efficiency as well as growing industrial output resulting in continuous economic growth. Besides impelling social change and creating material wealth it has fundamentally changed the human domination of the Earth's ecosystems and brought along a plethora of environmental problems. A major claim of ecological economics is to broaden our understanding of economic processes and how they are embedded in nature by taking a biophysical perspective which conceptualizes economic processes also as natural processes in the sense that they can be seen as biological, physical and chemical processes. […] In this context, a historical understanding of the long-term development of society-nature interactions is of vital importance. […] We understand the industrialization process as a qualitative transition which transforms the agrarian socio-ecological regime into an industrial regime thereby establishing a distinct and fundamentally new pattern of society-nature interaction and material and energy use".[18]

The following scheme (Fig. 2.4) summarizes the key features of the two last main socio-ecological transitions from a solar land-based socio-metabolic regime (a) towards the coal stage of industrialization, combined with a set of 'advanced organic agricultures' which optimised traditional low-input agrarian systems (b); and then to a new stage of the oil and electricity driven technologies of the second Industrial

[17] Martinez-Alier (2011) and Krausmann et al. (2012).

[18] Krausmann et al. (2008), pp. 187–188.

Revolution that fuelled mass production and consumption, together with a reversal in the traditional relationship between the agricultural and non-agricultural sectors (c), by means of massive fossil energy subsidies for all economic activities and transport which fostered a boom in worldwide trade.

Perhaps the most interesting feature of this socio-metabolic approach is that it establishes a clear and accountable link between local and regional environmental problems with regards to the input side of nature-society interaction, based on resource-use together with related land-use changes; and from the output side, with local and global environmental problems derived from polluting emissions along the economic throughput chains. As Krausmann, Schandl and Sieferle have put it, "Taking a biophysical view it becomes evident that it will not be possible to accomplish global industrialization without an alternative pathway for the metabolic transition. Scarcity of oil and gas will increasingly become an issue and declining energy prices, a major precondition for the industrialization of the industrial core, are unlikely to prevail for latecomers. Before energy scarcity and rising energy prices become a major problem, the world is faced with rising greenhouse gases in the atmosphere contributing to global warming and destabilization of the world climatic system to a large and unknown extent. […] In the light of the historical process, the need for a new, sustainable, industrial socio-ecological regime with lower per capita material and energy turnover and a lower share of non-renewable energy and materials becomes a vital need for the global system".[19]

One of the aims of this broader ecological-economic perspective is to explore the connections, on all levels, between value-added flows in the market sphere, and the biophysical and energy flows or climatic suitability that sustain them from their ecological base. Measuring the energy and material dimensions of what GDP growth actually means for natural systems can provide us with new answers to previous questions regarding what triggers economic growth, what growth in fact involves, and what consequences it has for both social and natural environments. This standpoint connects the understanding of economic growth with the new studies on Global Warming and Climate Change which, during the last thirty years, have enhanced the focus on climate history. The IPCC concern about Global Warming has led to a development of new indicators and methodologies that have had a dramatic impact on all areas of knowledge, especially in a long-term historical perspective. Many recent studies have broadened the methodological possibilities open to climate historians, aimed at understanding the evolution of climate and its impacts on past and present times.[20]

Moreover, the analysis of biophysical flows linking economic performance with the carrying capacity of ecosystems necessarily leads to the study of changes in terrestrial land covers by human land-uses. Together with pollution and bio-invasions, this changing face of the Earth by human landscapes is precisely the main origin of the crisis of biodiversity at present. Putting together biophysical flows moved by

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19 Krausmann et al. (2008), p. 199.

20 Brázdil et al. (2005) and Costanza et al. (2007a).

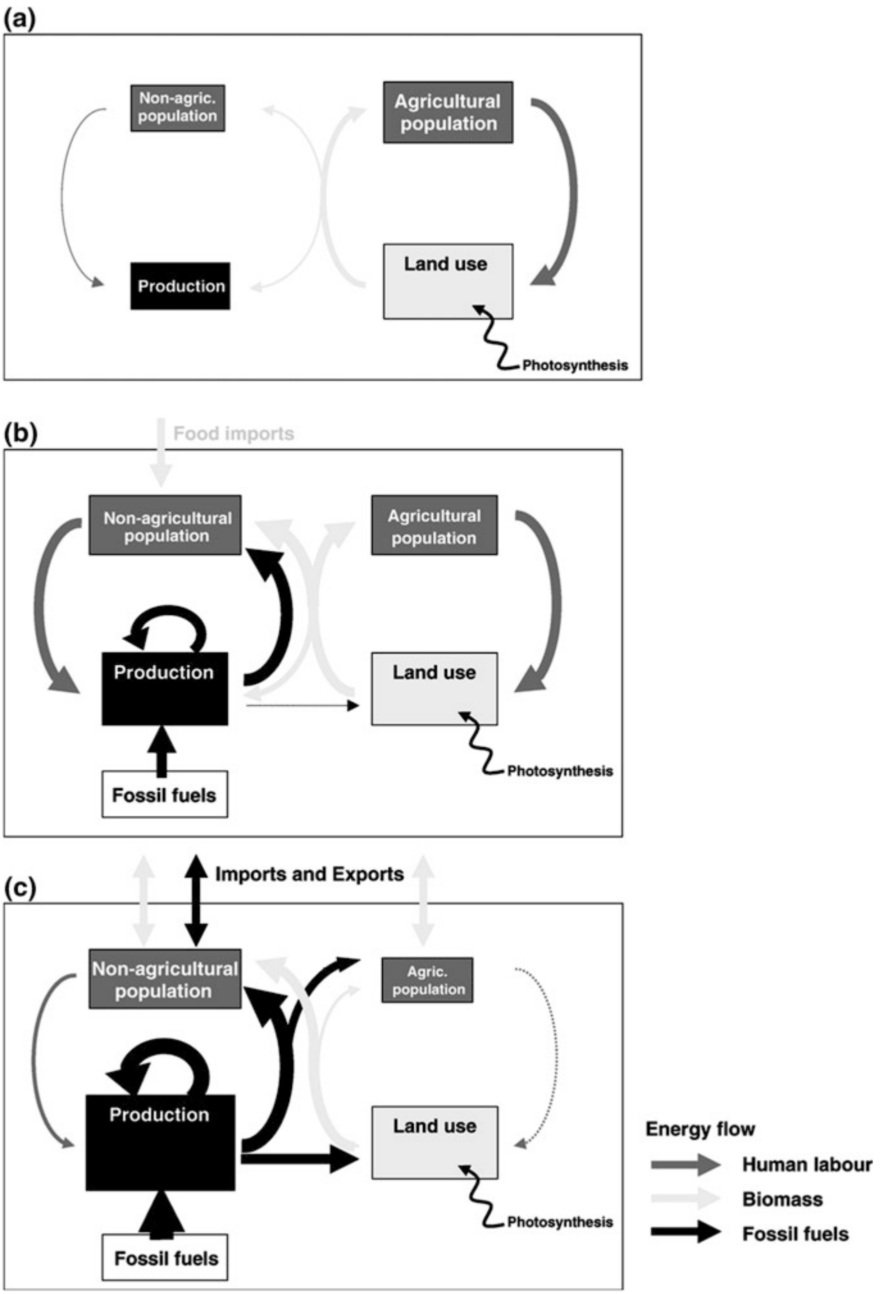

Fig. 2.4 The changing relation of energy, land and labour during the stages of the socio-ecological transitions. *Source* Krausmann et al. (2008)

human societies with the land-use changes made by them leads to the study of Global Change, a crucial meeting point for all scientific disciplines interested in the sustainability of human-nature interaction.[21]

This emerging socio-metabolic perspective does not entail prior assumptions concerning the causal direction in the ecological-economic interaction or phenomena.[22] The common attitude among practitioners of the emerging 'sustainability science' is a cautious, multidimensional and transdisciplinary approach which, from a co-evolutionary background, can admit that sometimes the driving forces originate from within the economic sphere and leave their ecological footprint on the surrounding environment; whereas in other cases researchers highlight the role played by the availability of energy, water, raw materials or climatic conditions and variability, either as a limiting factor or as a source for economic growth. Neither does such an approach entail the making of any deterministic presumptions; rather it is dependent on the type of enquiry being undertaken and on its historical or geographical scope.[23]

When environmental historians seek to discover the ecological impact of economic growth, usually from a short or medium-term perspective, they typically adopt market or state economic forces as the main driving force. But by adopting a long-term, comparative historical perspective, they also raise questions about the role played by the availability of energy, land, water and raw materials in accounting for historical economic growth processes or catching-up paths. On occasion, both approaches can be adopted simultaneously within the same research strategy, as Astrid Kander demonstrates in her study of the long-term relationship between energy, economic growth and greenhouse emissions in Sweden since the beginning of the 19th century—a research strategy that has been adopted within a broader comparative analysis between different countries and regions of the world undertaken by the members of the Energy-Growth and Pollution Network and the Institute of Social Ecology.[24]

Whereas it is true that all these new perspectives and methods provided by ecological economics and environmental history are greatly expanding the toolbox of economic historians, it is no less true than among scholars devoted to the study of past organic economies there was already a long tradition of taking bio-geographic, agro-ecological, energetic and landscape factors into account. However, their explanatory relevance has tended to decrease with the shortening of the time perspective from which economic historians seek to understand the present. The practitioners of prehistory and ancient, medieval or early modern history have never

[21] Cronon (1983, 1991), Crosby (1986), Cuff and Goudie (2009) and Hornborg and Crumley (2007).

[22] Costanzaet al. (2007b), pp. 522–527.

[23] Kates et al. (2001) and Haberl et al. (2006).

[24] Kander (2002).

failed to analyze changing environmental conditions as a key dimension to understanding the evolution of any human society.[25] Nevertheless, until recently, their presence has tended to vanish between the historians devoted to modern and contemporary times.

This growing lack of interest cannot be attributed to the loss of relevance of such environmental factors, as it is from mid-twentieth century onwards when the impact of human societies on the face of the Earth has become more intense, global and dangerous. The reason is ideological, and derives from a way of seeing reality that has characterized the two major socio-economic visions of the 20th century.[26] Within the mainstream approach to these two great visions, natural environments were considered as a set of restrictions and limitations that development would overcome. By seeing economic growth as a “liberation” of environmental constraints, the relevance of their study was considered inversely proportional to the degree of technological progress. Hence the explanatory weight of environmental factors was seen to decrease with the time-distance to the present covered by the analysis, in open contradiction with the degree of human degradation of Earth’s ecosystems. Thus, this long-lasting Faustian vision of the modern Unbound Prometheus has paid a learned ignorance to the environmental dimension, until the obvious signs of a global ecological crisis have forced many to rethink.[27]

Since it is impossible to summarize within this text all lines of research which are currently changing the old visions of economic growth that formerly remained disconnected from environmental constraints and effects, we will take only a few relevant issues and ongoing debates as examples to illustrate the new emerging trends.

2.4 The Socio-metabolic Profiles of Past Organic and Present Industrial Economies

Until the mid 1980s a tradition of historical studies of pre-industrial agrarian economies was highly skewed by a pessimistic reading of the classical economists, especially Malthus and Ricardo. The work of B.H. Slicher van Bath, Michael Postan, Wilhelm Abel or David Grigg emphasized the difficulties experienced by traditional societies to increase agricultural output per capita because of the limits imposed by technological backwardness, and the inevitable arrival of diminishing returns spurred by population growth.[28] This tradition has been revisited and

[25] Bloch (1955–1956), Slicher van Bath (1963), Campbell and Overton (1991), Overton (1996) and Allen (2008).

[26] Thompson (1991) and Scott (1998).

[27] Landes (1969) and Landes (1998).

[28] Postan (1973), Abel (1980) and Grigg (1982).

revised by E. Anthony Wrigley by means of a fruitful dialogue with the classical texts which, along with limits, also noted the advances in productivity that could be achieved within the pre-industrial economies—particularly through trade specialization and urbanization.[29] Taking into account the approach of Adam Smith, and the range of changes or adaptations in demographic patterns studied by the Cambridge Group for the History of Population and Social Structure, Wrigley's work has contributed to better identify the actual limits and feasible possibilities to remove them ahead.

While Anthony Wrigley has never been directly interested in the interaction between society and nature as such, his most important contribution has opened a very important bridge between economic and environmental history by placing the emphasis on the characteristics of energy supply based on capturing solar energy through photosynthesis. In order to stress its relevance, he has coined the term 'organic economy' to highlight the fact that when any economic activity had to rely on the tiny fraction of solar energy that is being stored in the form of biomass through photosynthesis: "[…] neither the process of modernization nor the presence of a capitalist economic system was capable of guaranteeing sustained growth […]"; though he adds, "[…] both could help to ensure that the possibilities for growth offered by such economies were exploited effectively".[30]

The results found by reconstructing the long-term historical series of energy intensities of Sweden, Italy, United Kingdom, the Netherlands and Spain,[31] seem to confirm the view forwarded by Anthony Wrigley. From a long-term perspective, and when animal work and human labour are included together with fossil fuels and other modern energy carriers, there is no apparent single inverted-U Kuznets curve in the historical trend of the energy consumption per unit of GDP. What appears is rather something that resembles a downward staircase, or a winding path following an N-shape form (Fig. 2.5). This outcome clearly shows that in earlier pre-industrial times the energy cost per GDP unit was higher than that in the subsequent industrial period. The reason for this seems very simple: before the arrival of large amounts of fossil fuels, considerable amounts of primary energy were needed to obtain a single unit of value added into the market by means of the energy conversion of biomass. This is exactly what Wrigley hypothesised.

Long-term historical series of energy intensity per unit of GDP also show an increasing convergence between countries. While in a biomass-based energy system climatic conditions and natural resource endowment entailed big regional differences in the amount of primary energy consumed, the common adoption of a new set of coal or oil-based converters and technologies led to greater parity. Yet convergence in energy intensities might not be complete, because latecomers do not always use a factor endowment as appropriate as leading countries to the adoption of new technologies deployed. While the initial delay allowed them to adopt more

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29 Wrigley (2010).

30 Wrigley (2004). See also Kander et al. (2013).

31 Kander (2008), Warde (2007) and Gales et al. (2007).

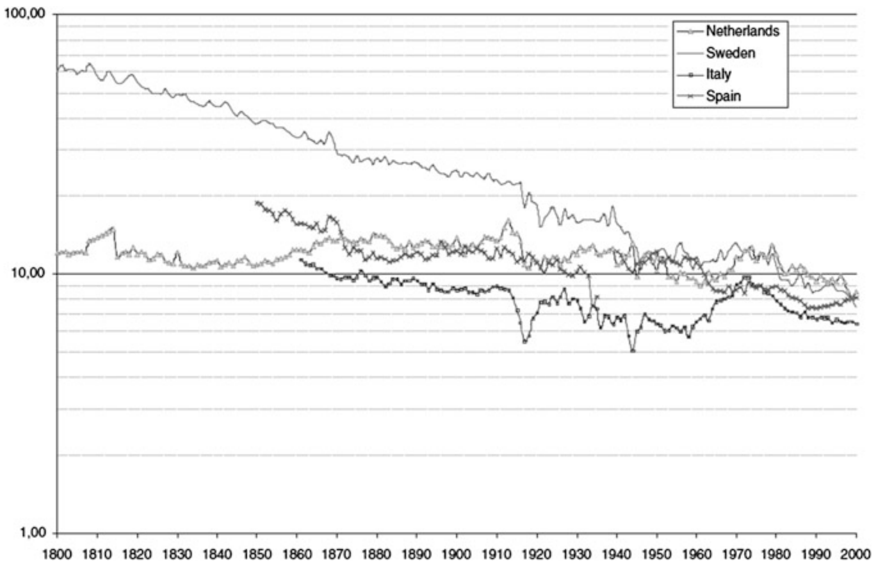

Fig. 2.5 The long-term fall of energy intensity in Sweden, the Netherlands, Italy and Spain from 1800 to 2000, in Mj per dollar (constant 1990 $ at ppp). *Source* Gales et al. (2007, p. 234)

advanced designs of these technologies, this often encouraged a further innovative adaptation that may increase efficiency (see below the comparison between the UK and Austria in Fig. 2.10).

These historical series stress again the role played by mechanical, thermal or chemical useful work provided by increasingly cheaper fossil energy sources in the contemporary increase of labour productivity and capital deepening. As long as the initial high energy costs of production, based on biomass converters, could not be reduced, the capacity of the economy to grow would have been strictly limited. Increasing competition between all lines of production for the same resource base, derived from the solar radiation converted and stored in the soil by vegetal land covers, would lead to a necessary curtailment of growth in a steady state. Wrigley was to draw this asymptotic assumption by studying demographic tendencies in pre-industrial societies, and also through a careful reading of Adam Smith and Thomas Robert Malthus. From an environmental history standpoint, whose foundations were laid by Nicholas Georgescu-Roegen, Rolf Peter Sieferle has adopted a similar perspective of what he calls the 'socio-metabolic regime' based on an indirect agrarian control of solar energy.[32] Wrigley's and Sieferle's approaches do not deny that trade specialization could have greatly helped to optimize the use of available organic resources. Nonetheless, only through the substitution of the renewable solar flow captured in the soil through photosynthesis with the

32 Sieferle (2001).

subterranean stock of fossil fuels, were the energy limits towards modern economic growth finally removed. A structural change in the whole resource base of a pre-industrial organic economy was required.

As Joan Martínez Alier and Marina Fisher-Kowalski have reminded us, the history of these basic ideas on the socio-metabolic foundations of long-term economic growth is quite long,[33] extending back from Georgescu-Roegen through Frederick Soddy, Wilhelm Ostwald, Otto Neurath, Stanley Jevons, Leopold Pfaundler, Edward Sacher and Sergei Podolinski, all the way to Karl Marx who was the first social scientist to coin the term 'social metabolism'.[34] However, until very recently these ecological-economic insights have been ignored by a mainstream approach to either Liberal or Marxian economics which placed all the limits or stimulus for modern economic growth almost exclusively in institutional settings. Backwardness became the standard answer to the question as to why some regions lagged behind the world economic growth race.

The socio-metabolic approach can be very helpful to overcome this backwardness paradigm, and also in understanding why economic historians must deal with three different types of economic growth, labelled by Jan De Vries as 'Malthusian', 'Smithian' and 'Schumpeterian' (in the terminology previously suggested by William Parker).[35] Although Adam Smith shared the same pessimistic outlook as Malthus and Ricardo for long-term economic growth based on an organic resource base, the term 'Smithian' can be used to describe the type of growth that exploited all existing possibilities, stimulating growth through a better allocation of available organic resources, thus temporarily escaping the 'Malthusian fate' and giving rise to different 'advanced organic economies'. What has been called a 'consumer revolution' or an 'industrious revolution' in some European or Asian countries during the 17th and 18th centuries may be understood from this point of view.[36] The term 'advanced organic economy' coined by Wrigley could also be used to characterize the different paths taken by agrarian development in a wider range of European regions and countries during the 18 and 19th centuries, before the full industrialization of agriculture under the so-called 'green revolution' paradigm became widespread from the 1950s onwards.[37]

This approach also seeks to relate 'Schumpeterian' growth with the increasing burning of fossil fuels during the onset of the Industrial Revolution—Sieferle's 'hidden forest'.[38] This entailed the introduction of a completely new socio-metabolic regime, with a different energy and material flow exchange with ecosystems based on other types of land usage. But during this first stage of industrialization, the agricultural sector remained basically organic, at least until what Jan Luiten van

[33] Martínez Alier (1990) and Fisher-Kowalski (1998).

[34] Sacristán (1992) and Foster (2000).

[35] De Vries (2001).

[36] De Vries (2008a) and Sugihara (2003).

[37] Kjaergaard (1994) and Krausmann et al. (2008).

[38] Sieferle (2001).

Zanden labelled 'the first green revolution'—which was initially fostered by innovative responses to the European agrarian crisis experienced between 1870 and 1914,[39] when the cheap wheat and corn exported from the United States, Canada, Australia, Argentina or Russia flooded European markets.[40] From then onwards organic manure started to be supplemented by increasing amounts of external inputs of mineral and fossil origin. However, up until the 1950s they remained very small, as long as the diffusion of industrial fertilizers, the adoption of tractors or newly selected seeds and animal varieties served as a complement rather than as a full substitute for organic sources, crop rotations and animal work. Therefore, the radical turnaround in the agrarian sector did not occur until the second half of the 20th century (see the differences between schemes b and c in Fig. 2.4). Before the massive use of fossil fuels within the agrarian system, the main means of increasing agrarian outputs in the various European bioregions still lay in the development of several types of 'advanced organic agricultures'.[41]

2.5 Why the Industrial Revolution Began in a High Wage and Cheap Energy Economy

How did a Schumpeterian-type of modern economic growth began? A long-lasting historiographical tradition has been collecting data on agricultural land usages and yields from medieval times onwards, and has shown two main features: (1) up to 1800, yields and labour productivity remained low but stable in the long run in most European and Asian regions which had experienced comparatively old agrarian colonization and attained high population densities; and (2) only a few regions seem to have been able to overcome the Malthusian-Ricardian constraints, taking advantage of all existing possibilities to optimise traditional low-input organic systems in order to achieve higher agrarian yields per unit area without diminishing agricultural labour productivity at the same time. As far as the ongoing debate on the Great Divergence between Western Europe and Eastern Asia allows to tell for the moment, prior to 1800 these upper outlying cases were the Dutch and English economies, the only ones where wages and standards of living seem to have increased above the rest of the World at the time.[42]

Why did these changes develop in some regions whilst not in others? Why did it take so long to be adopted or emulated by other regions of the World? These questions raise two sets of issues: (1) which kind of land entitlements and institutional settings created an incentive structure that encouraged a long run increase

[39] Van Zanden (1991).

[40] Koning (1994).

[41] Leach (1976) and Naredo (2004).

[42] Pomeranz. (2000) and Allen et al. (2005).

in labour productivity; and (2) how could yields per unit of land be increased, thus overcoming the Ricardian-Malthusian fate of long-term growth in an already organic economy. The first question asks for the agency of change, by looking at those who made them and what they made them for. The second set of questions looks at how they did it, taking into account the available choices offered by their bio-physical and technological context. In order to attain a complete historical answer, both agency and structure must be combined in a single interpretation encompassing natural as well as social environments.

Following the interpretive lines proposed by Bob Allen in *The British Industrial Revolution in Global Perspective* (2009), the outset of the Industrial Revolution in England at the end of the 18th century could be summarized as follows. Within the framework of new institutions that emerged from the defeat of Royalists in the English Civil War (1641–1651) and the Glorious Revolution (1688), together with the agrarian changes towards a highly productive 'advanced agriculture' mainly introduced by the yeomanry at the time, the rise of British colonial hegemony and overseas uncontested power after the defeat of Holland navy in the three wars from 1652 to 1674 enabled the United Kingdom to develop a particularly successful industrious revolution, which turned the country into a textile export economy—during the first half of the 18th century 85 % of the value of English exports were already manufactured goods.[43]

This commercial expansion and industrious revolution spurred urbanization and converted London in the single biggest city at the top of the hierarchy in the urban centre of gravity around the North Sea.[44] Up to a point the English agricultural, commercial, industrious and urban improvements helped to achieve the above mentioned increase in wages and pre-industrial standards of living, well beyond the ones existing at the time in the rest of Europe and Eastern Asia, thus sustaining a distinctive although not exclusive consumer revolution. [45]

At the same time the amount of energy needed to heat the homes of Londoners and other English urbanites in the more and more deforested isle of Great Britain encouraged the replacement of increasingly expensive firewood or charcoal by cheaper coal.[46] As Paul Warde notes, considering that energy embodied in labour, capital and transport services required that coal supply remained mainly 'organic', up to a point its primary difference in price with firewood was probably determined by rents because wood competed for space with other uses: "The changing point at which coal-use became more economic than wood use was probably thus determined by the general level of rents, and these in turn were determined by the necessity of producing by far the least efficient output in energetic terms, food. It is likely that it was not the scarcity of wood but the relative scarcity of food that made

43 Allen (1992, 2009).

44 De Vries (1984) and Wrigley (1987).

45 McKendrick et al. (1983) and De Vries (2008).

46 Wrigley (1987).

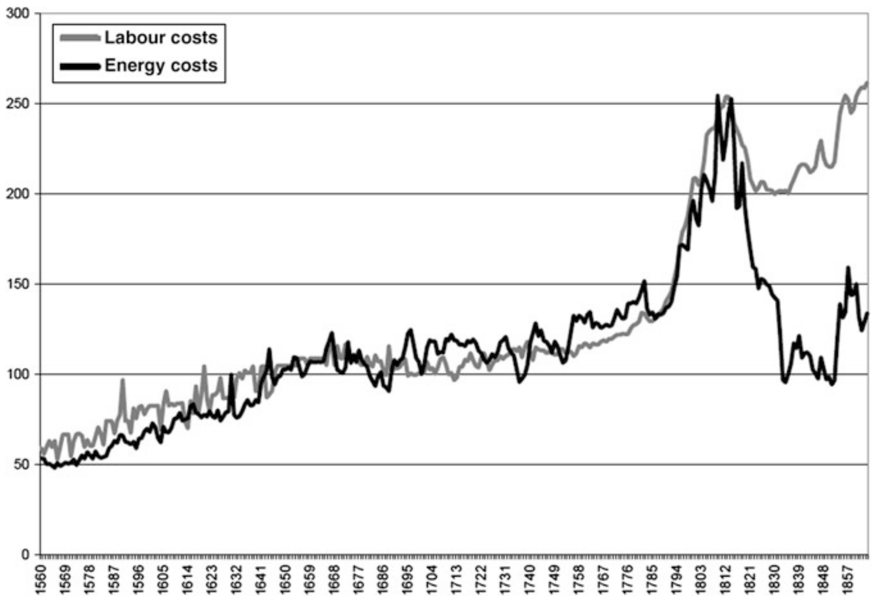

Fig. 2.6 Long-term trends in labour and energy costs at nominal prices in southern England (1560–1860, 1700 = 100). *Source*: Warde (2007, p. 87, 2009). The series has been calculated from the changing mix of energy carriers shown in graph 7, taking into account the labour, capital and land required to get a unit of energy (considering that a single woodcutter could prepare about 1.1 tonnes of firewood a day or 3.3 million Kcal, compared with a coal miner who could extract as much as 2.5 tonnes of coal or 17.5 million Kcal). Until the 1820s, overland travel of firewood as well as coal mainly depended on 'organic' muscle power. This meant that in practice obtaining coal at some distances from the coalfield was largely determined on the prices of human food and animal feed. Therefore, fossil fuel did not enjoy a great advantage over firewood until the use of steam engines, and new transport facilities such as canals or railways become widespread (Warde 2007, pp. 83–86)

coal more attractive fuel".[47] Finally, the combination of higher wages and exceptional availability of cheap fossil fuels created exactly the economic context where relative factor prices led entrepreneurs and financers to invest in the new type of capital goods able to perform thermal, mechanical or chemical useful work that opened the road to a new Schumpeterian-type of economic growth (Fig. 2.6).

After 1800 an unprecedented acceleration of technological change powered by cheap coal ensued, and became a formidable weapon in the hands of new industrial bosses which enabled them to earn and reinvest considerable profits while keeping wages well below the contemporary increase in labour productivity. The new factories powered by steam engines or waterwheels were aimed at centralizing and mechanizing the production processes, in order to replace comparatively expensive human labour with capital goods as well as to control and master the fierce

[47] Warde (2007).

traditional independence of the English labouring people. This may help to explain why the previously high British pre-industrial real wages became stagnant, or even temporarily decreased, during the first phase of the Industrial Revolution. Bob Allen has labelled 'Engels' Pause' (1780–1830/40) this long-lasting gap between wages and productivity growth, which corresponds to the pessimistic outlook about the standards of living during the first phase of British industrialization.[48] The pessimistic view has also been reassessed using new biological and social evidence,[49] like the fall in the heights of military conscripts' and the average life expectancy, or the increase in infant mortality rates, child labour and income inequality.[50]

It is interesting to notice that macroeconomic accounts of economic growth during the British Industrial Revolution have tended to reduce its revolutionary character, by dismissing that growth rates experienced any sudden acceleration compared with previous pre-industrial ones.[51] However, and at the same time, the beginning of the new Schumpeterian-type of industrial economic growth meant a revolutionary turnaround in socio-metabolic terms, as it has been reassessed by the study of the first energy transition from a biomass solar-based energy system towards another, based on burning the underground stock of fossil fuels. Moreover, the historical series on primary energy consumed and the energy intensity per unit of GDP produced in England and Wales (Fig. 2.7), reconstructed from 1560 onwards by Paul Warde, have again shown the outlying character of the English economy which had started substituting coal for biomass energy carriers well before the Industrial Revolution began.

Thus, as Anthony Wrigley pointed out (1988), the continuity of a gradual increase in economic growth rates combined with the chance of having large accessible coal deposits in England and Wales and gave rise to the big energy change of the British Industrial Revolution. Historical comparative analysis has also shown that GDP convergence kept pace with the energy transition to fossil fuels, and this evidence opens up the question whether this relationship was a consequence of economic growth over energy consumption, or rather that the convergence in economic terms would have to wait until each nation or region could find their own path towards the new mineral-based energy system.[52]

While the abovementioned interpretive lines seem to offer an explanation about as to why the first Industrial Revolution was British, they do not offer a full and satisfactory outline as to why it did not also take place in other places throughout Europe and Asia, where convergence with the industrial growth of the United Kingdom encountered numerous obstacles. Bob Allen's interpretive outline stresses

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48 Allen (2009).

49 Hobsbawm (1964) and Thompson (1968).

50 Williamson (1997), Horrell and Humphries (1995), Crafts. (1997), Feinstein (1998) and Komlos (1998).

51 Crafts and Harley (1992).

52 Krausmann et al. (2008).

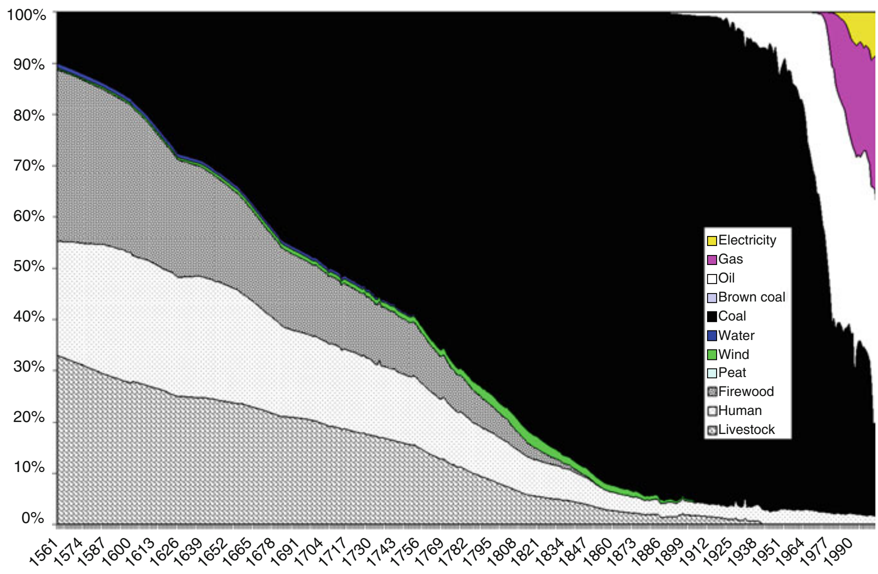


Fig. 2.7 Long-term energy transition in England and Wales, as percentages of each carrier (1560–2000). *Source* Warde (2007, p. 74)

from the beginning the role played by mercantilist policies—under colonialism and imperialism—in fostering British commercial development. Without this commercial empire that followed and undermined the previous Dutch trade expansion, the population of London could not have grown from approximately 50,000 to 200,000 between 1500 and 1600, then doubled in the next century, and reached nearly one million by 1800. In the meantime the fraction of the English population living in settlements of more than 10,000 people increased from 7 to 29 %, whilst the share of the workforce in agriculture dropped from about 75 to 35 %.[53] This, in turn, raises the question to what extent was the new type of Schumpeterian industrial growth started by the British Industrial Revolution an actual possibility for any other nation at the time. Adopting an ecological-economic approach may help to properly address this question by taking into account the environmental load displacement or ecological footprint that the Industrial Revolution entailed.[54]

Following the idea of a 'ghost acreage' won by Europe through the colonization of America, already put forward by Eric Jones and then Kenneth Pomeranz stressed again, we may wonder about the role of environmental endowments and resource availability in the Great Divergence between Europe and Asia before 1800.[55]

[53] Omrod (2003).

[54] Hornborg et al. (2007).

[55] Goody (2004) and Emmer et al. (2006).

Table 2.1 A first rough estimates to some components of ecological footprint entailed by the British Industrial Revolution (1801–1831)

		1801	1811–1815	1827–1831
Coal	Millions of tonnes burnt	13.9	n.a.	22.6
	Equivalent woodland area as total surface of England and Wales[a]	92.7 %	n.a.	150.7 %
Sugar	Footprint hectares (thousand)	436.3	464.6	604.8
	As percentage of contemporary cropland in England and Wales[b]	9.5 %	9.6 %	13.4 %
Cotton	Footprint hectares (million)	n.a.	9	23
	As percentage of contemporary cropland in England and Wales[c]	n.a.	154.4 %	322.8 %
Timber	Footprint hectares (thousand)	666.5	n.a.	n.a.
	As percentage of contemporary cropland in England and Wales[d]	18.5 %	n.a.	n.a.

Source our own, from Sieferle (2001, pp. 14–15), Pomeranz (2000, pp. 313–315) and Grigg (1982, p. 38)

[a] Estimated translating the energy content of coal burnt into cubic meters of firewood, and then assessing the woodland area needed to annually grow this amount of firewood in England and Wales

[b] Estimated assuming that the average caloric intake with sugar imported from the colonies had to be replaced by cereal cultivated in England and Wales

[c] Estimated assuming that average cotton imports had to be replaced from wool produced by sheep bred in the pastureland of England and Wales

[d] Estimated assuming that average timber imports from America and the Baltic had to be replaced by woodlands of England and Wales

Table 2.1 shows the approximate ghost acreage of English consumption of coal, sugar, cotton and timber during the first half of the 19th century:

As can be seen, in spite of the initial tiny amounts of GDP which they might have represented before 1800,[56] the access to these four key natural resources would have immediately outstripped the biological carrying capacity of any 'advanced organic economy'—particularly cotton and coal, which together with iron formed the basic triad of the English Industrial Revolution. The only way out of these land-related constraints was the unique combination enjoyed by the United Kingdom of coal mined from the underground with the 'ghost acreage' provided through an exceptional network of worldwide trade flows nucleated into a single European region. No other nation or region of the world could have had such access to analogous natural resources, until railroads and steam vessels diminished travel costs and opened the way to the first globalization from 1870 onwards.[57] It is worth remembering, as William McNeill pointed out,[58] that this was a very exceptional

[56] Van Zanden (2009).

[57] Williamson (2006).

[58] Mc Neill (1982).

combination of commercial networks and resource availability focused within the British Isles, which allowed for a high wage and cheap energy economy. And this combination was assembled also thanks to a persistent and successful pursuit of military power.

The military aspect of the question leads directly from economic growth towards the contemporary experience of underdevelopment. The 'ghost acreage' of industrialization entailed many different and persistent impacts upon peoples, communities, nations and landscapes of many non-European countries, usually not taken into account within the history of growth of the developed regions of the World. These external impacts of modern economic growth in Western countries deeply affected the subsequent historical path followed for the rest of Humankind. Not only were their lands fissured by mines or plantations that spoiled natural resources and left the burden of heavy pollution everywhere, but their social lives were distorted as their institutions were submitted to foreign colonial or neo-colonial rules.[59] As Ramachandra Guha and Joan Martínez Alier have pointed out, the popular resistance to the exploitation of their natural resources, destruction of their modes of life, and externalization of ecological impacts by the rich, has been the true origin of contemporary environmentalism, often known as the environmentalism of the poor.[60]

2.6 Land-Use and Livestock Breeding as a Crucial Metabolic Hinge for Yield Increase

Precisely because the natural resources required by industrialization in the United Kingdom soon surpassed the bio-capacities of the British Isles, they exercised an increasing series of pressures upon the rest of the World. While in many underdeveloped regions these mainly entailed a set of difficulties and distortions, in other parts of the World a combination of pressures and incentives became apparent which might produce different outcomes, depending on natural and social endowments, institutional settings and public policies, together with the role assigned to the region in the global division of labour established by the British economy.[61] The convergence path followed by the small but growing group of developing nations, and the under-developing divergence of the rest, both ensued the beginning of a Schumpeterian-type of economic growth under British leadership. What were the reasons behind the enduring fortunes of some, and misfortunes of many others? Once again, this brings the research back to the Malthusian-Ricardian constraints that were tightly related to the prevailing land-labour ratios.

[59] Gadgil (2000) and Gadgil and Guha (1993).

[60] Guha and Martínez Alier (1997).

[61] Warde (2009).

Examining one part of the answer within the evolving nature-society interface may help to understand how yield increases can be achieved in some still basically agricultural economies and societies, while not in others. This requires the black-case of the agrarian system to be open in order to look carefully into its agro-ecological engine to understand how matter, water and energy were processed into fertile soil allowing plants to grow. When applied to organic agrarian economies, the quantitative reconstruction of energy and biophysical flows requires that they be located carefully within the territory. It must be noted that almost all energy or biophysical flows mobilized by past agrarian societies were highly dependent on their land-use pattern. Land usage became pivotal, in those organic economies, for any socio-metabolic exchange with nature.

The importance of an integrated management of the three main components of any agrarian system, that is, cropland, woodland, pastureland and the key role played by livestock in linking the three, are readily apparent to all agrarian historians studying pre-industrial societies. However, until recently, very few attempts had been made to connect the energy and material flow analysis with land-use systems. Today the most important research programme seeking to relate socio-metabolic flow analysis with land usages is that being undertaken by the Institute of Social Ecology at the University of Vienna (http://www.iff.ac.at/socec/). Many studies and publications on the changing face of human colonization of terrestrial ecosystems come from the extensive international research programme Land-Use Land-Cover Change (http://www.geo.ucl.be/LUCC/lucc.html). The LUCC examines the transformations undergone by Earth's vegetal cover over the centuries, in order to identify the main driving forces behind global socio-environmental change, and also to assess its socio-ecological impact. Perhaps environmental and economic historians, working together to understand economic growth in past agrarian societies and present industrial ones, can help merge these two approaches, i.e. the accounting of biophysical flows combined with a closer and more analytical examination of the land-use systems in which they take place.

Thanks to the energy balances calculated by many scholars from the mid 1970s onwards, we now know that energy returns on energy inputs were higher in earlier organic agricultures than those attained following the widespread adoption of the 'green revolution' after the Second World War—as wee see in schemes b and c in Fig. 2.4. However, there is an important element to this seemingly paradoxical discovery which should focus our attention on the land-use system: How were these pre-industrial societies able to attain such a high energy performance, while being so heavily dependent on livestock bioconversion which is so inefficient? Why has industrialized agriculture become so inefficient in processing energy and material flows, and thus so pollutant, having at its disposal a wider range of more efficient converters? Some recent results obtained analysing the link between energy-use performance and land-use management in some Mediterranean local case studies suggest that a great deal of the answer lies in the loss of landscape efficiency.[62]

[62] Tello et al. (2006) and Marull et al. (2010).

Many past agrarian societies were able to build up and maintain sound land-use management which enabled them to attain high energy returns on energy inputs (EROI), in spite of the then inevitable losses in available bio-converters.[63] However, this was not for the sake of any positive environmental externality that we might discover now and praise them for. They did so by necessity that is, because of their own energy poverty in available carriers and sources. Thus, there is no contradiction in the lack of primary energy for economic growth in an 'organic economy' and the typically high energy performance attained by pre-industrial agrarian systems, as identified by Anthony Wrigley, Rolf Peter Sieferle, Paolo Malanima or Paul Warde.

We can understand this, following Vaclav Smil, taking into account that under pre-industrial conditions any final output had to be obtained through a set of energy production chains that relied on firewood burnt in highly inefficient fireplaces, animal feed bio-converted inefficiently into power traction and manure, vegetal and small animal human food consumption, and a small amount of raw materials also inefficiently transformed into costly industrial goods, and so on.[64] With only a few alternatives available in order to increase end-use efficiency, i.e., through the adoption of better converters (such as stoves instead of fireplaces), these societies had to rely on the highest primary energy output they could attain if they wanted to achieve even a small increase in the amount or the variety of final consumable goods. The main way of achieving this was to develop and maintain an efficient land-use pattern. Only through the increasing integration of crop production and livestock breeding could past organic agricultures hope to achieve even a modest rise in their agricultural and forestry output, enabling them to diversify and enrich both household and market economies. Herein lies possibly the most important reason explaining why, through sound landscape management, past advanced organic agricultures were more energy efficient than the majority of current agricultural systems (Table 2.2).

The improvement of past organic agricultures became a key condition for any advance in urbanization, as can be seen when looking at cropland needed to provide staple food for any growing city. For example, when only 20 % of agricultural output could be sold and carried to urban centres, a city with 250,000 inhabitants such as 1820 Vienna, required an agricultural hinterland of around 22,000 km^2 (or nearly 88 km^2 of cropland per thousand inhabitants). Thanks to an agrarian surplus that grew by almost 60 %, in 1910 Vienna could be supplied by 24,000 km^2 of cropland when the city already housed two million people.[65] Feeding Paris required a footprint of around 60,000 km^2 with a population of 660,000 in 1784, and a similar area was needed when the population exceeded two million between 1876 and 1881, and even in 1921 when it reached three million.[66] This meant a decrease

63 Agnoletti (2006).

64 Smil (1999, 2001).

65 Krausmann (2013).

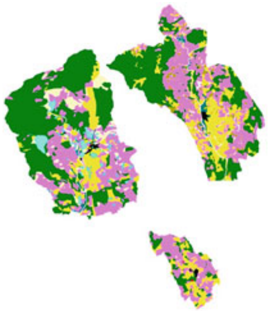
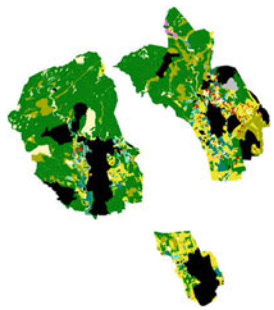
66 Billen et al. (2009).

Table 2.2 Summary of the energy balances of the agrarian system in a Catalan area near Barcelona (Spain) towards 1860 and in 1999–2004, compared with the contemporary agricultural landscapes

		Towards 1860	In 1999–2004
Primary solar energy fixed in the useful agrarian cover (UAC, 1,000GJ, GJ/ha/yr)	Cropland	146.3	187.3
	Pastureland	34.4	–
	Woodland	87.2	211.0
Final output by sector (FO, 1,000GJ, GJ/ha/yr)	Crops	38.6	135.9
	Livestock	2.9	144.5
	Forestry	129.5	69.1
Livestock weight units (LU of 500 kg, Kg/ha)		983 (41)	23.833 (1,021)
Cattle feed (1,000GJ, GJ/ha/yr)		68.7 (5.7)	1,095.7 (103)
Manure or fertilizers applied (1,000GJ, GJ/ha/yr)		23.9 (2)	55.5 (4.7)
Total inputs consumed (TIC, 1,000GJ, GJ/ha/yr)		102.4 (8.5)	1,625.8 (139.1)
External inputs consumed (EIC, 1,000GJ, GJ/ha/yr)		6.6 (0.2)	1,574.4 (134.9)
Total final output (TFO, 1,000GJ, GJ/ha/yr)		171.0 (14.3)	349.5 (29.9)
Energy return on total inputs (EROTI = TFO/TIC, 1,000GJ, GJ/ha/yr)		1.67	0.21
Energy return on external inputs (EROEI = TFO/EIC, 1,000GJ, GJ/ha/yr)		66.6	0.22
TFO/primary solar energy fixed in the AUC (%)		64	88
EIC/primary solar energy fixed in the AUC (%)		1	395

(continued)

Table 2.2 (continued)

Land mosaics towards 1860	Caption	Land covers in 1999–2004
	FOREST LAND RIVERBANK WOODS BRUSHWOODS PASTURE LAND CEREAL LAND CEREAL WITH VINES ALMOND OR HAZEL TREES IRRIGATED LAND VINEYARDS OLIVE TREES URBAN OR DWELLING SOILS	

Source our own, from Cussó et al. (2006b, pp. 471–500) from some 92 m^2 of cropland, pasture and woodland to only 20 for every thousand inhabitants, thus illustrating the role played by the advancement of organic agricultures for urban growth.

2.7 Nature-Society Interaction Between a Malthusian Trap and a Smithian Response

To what extent could the development of global market networks have increased opportunities to improve prevailing land-use systems? This question involves, of course, the defining feature in what William Parker and Jan De Vries have labelled a Smithian-type of growth.[67] David Grigg has described the socio-metabolic way of achieving this improvement, characterizing market specialization as a way of taking advantage of the 'ecological optimum' of different soils or regions according to their agronomic aptitudes and limiting factors.[68] Market diversification and specialization meant that these regional 'ecological optimums' could be exploited, while simultaneously other local agro-ecological constraints or 'Liebig minimums' could be overcome through imports. Economic history provides many examples of the link between resource endowment and trade patterns pointed out by the Heckscher-Ohlin model, such as vineyard or olive oil specialization in the Mediterranean regions.[69]

However, if we adopt an ecological-economic perspective we can easily see that market networks might also become a double-edged sword. For example, in the abovementioned local west-Mediterranean case study we found a high energy return on energy inputs of 1.67 attained in mid-19th century Catalonia (Spain); nonetheless, energy efficiency could only have been maintained if agricultural landscapes were kept poly-cultural and combined with some amount of woodland or brushwood. The final energy balance depended on certain key factors, for example a great deal of branches pruned from the vineyards or olive trees were used as fuel, thus serving as a substitute when there was a reduction of firewood supplies, following the loss of woodland due to the growing plantations of wood crops. This was probably the case while the agrarian system remained poly-cultural and vine-growing was a partial specialization that coexisted with many other land usages in a diverse agrarian mosaic. But if increase in demand for wine triggered a complete regional specialization in a single export cash-crop, as was the case during the infestation of the French vines by the *Phylloxera* plague between 1867 and 1890, it would have led to a shortage in livestock and manure. In such circumstances, the pruning of vineyards and other wood crops would have been used as a poor

67 Parker and Jones (1975) and De Vries (2001).

68 Grigg (1982).

69 Pamuk and Williamson (2000), Pinilla and Ayuda (2007) and Badia and Tello (2014).

substitute for manure, by burning them in the so-called Mediterranean *hormigueros* —small charcoal kilns made in fields covered with topsoil.

These Spanish *hormigueros* were traditionally used as a complementary fertilizing method which produced Potassium, and incorporated charcoal into the soil in order to improve its bacterial populations.[70] This was part of the ancient European Mediterranean culture of fire,[71] that took advantage of the summer water stress which meant that large quantities of dead biomass could not fully decompose and tended to accumulate in forests or scrubland until ignited by lightning. This accounts for the fact that Mediterranean woodlands have always coexisted with natural fires.[72] Thus, the removal of this dead biomass from scrub and forests in order to burn it on cropland was a sound human adaptation to natural conditions. In order to provide soil nutrients, however, the thermal process was a less efficient way of decomposing biomass compared to the humid method by means of compost or manure. Furthermore, it was a very labour-intensive fertilizing system. These features would explain why the *hormigueros* were only practised in the most populated and cultivated regions of the Iberian Peninsula. In any case, a complete replacement of the traditional poly-cultural mosaics by a vineyard monoculture would have entailed a serious bottleneck in nutrient availability, together with a rapid reduction in the energy return on energy invested (EROI) up to an index of around one or below. Of course, these local tendencies could have been offset by fertilizer imports, or by substituting tractors for animal traction but, once again, this would have meant a higher amount of external inputs and a further decrease of EROI.[73]

As Martínez Alier reminded us, the theoretical foundations of this double-edged market sword were forwarded as early as 1902 by Leopold Pfaundler, in his attempts to assess Earth's maximum capacity for sustaining human needs. He argued that any estimate would depend on whether we were to aggregate the maximum local capacities of each small territory, where limiting factors vary; or whether we were to consider Earth as one territory, assuming that any local resource would be available globally from any place without transport restrictions. Pfaundler suggested that a reasonable answer would lie somewhere between the two extremes, noting that transport always consumes energy and produces environmental impacts.[74] Looking at the abovementioned Catalan case study, the low energy return on energy inputs of 0.21 that we have found presently, appears to be in keeping with Pfaundler's argument.[75] The most noticeable feature at present is the fact that current energy flows are not in proportion to the land area in which the agricultural systems are placed. The metabolic chains operate in a monoculture pattern or in linear livestock breeding systems that have become virtually unconnected with the surrounding

70 Tello et al. (2012).
71 Pyne (1997).
72 Grove and Rackham (2001).
73 Cussó et al. (2006a).
74 Martínez Alier (1990).
75 Cussó et al. (2006b).

agro-ecosystem.[76] The majority of external inputs–fertilizers, oil, fodder, and the like—merely pass through a territory that operates as an inert platform. Ironically, the massive fodder imports and consumption of cheap fossil fuels have turned most of the woodland area into a derelict space which is increasingly prone to devastating wildfires. Here again, we see a very close link between low energy performance and inefficient land-use, both of which give rise to increasing levels of pollution and landscape degradation—the ecological imprint of what we now know as globalisation.[77]

Thus, any discussion on the relationship between markets and agro-ecological efficiency or environmental impacts cannot be viewed in black and white terms. Depending on the type and extent of the markets under consideration, trade might promote more efficient land usage and biophysical flows, or the contrary. A number of current approaches to the relationship between human development and markets in developing countries seem to draw similar conclusions, considering both the social as well as the natural environments.[78] While a network of local and regional markets was, and still remains, an important tool for sustainable human development, a direct connection to globalized markets is often little more than a trap.[79] To gain a better understanding of this relevant question, more studies on past agrarian economies need to be undertaken from this standpoint.

However, it is already apparent that globalization matters, when considering the relationship between the sort or scope of trade flows and their environmental effects. Therefore, transport must be taken into account as a key component in the ecological side that lies beneath any example of 'Smithian' growth fostered by significant increases in urban population, their consumer baskets, and market development. Marina Fischer-Kowalski, Fridolin Krausmann and Barbara Smetschka tackle this important issue from a socio-metabolic approach, and conclude that "the volume of transport necessarily rises faster than both the size of the society (in terms of population of urban centres and their hinterland) and its material wealth, and this not only constrains but limits the possible size of urban populations. The core mechanism behind these limits is the agrarian energy metabolism: in order to overcome distances, agrarian societies need more land to feed the human and animal labour power required for transportation. So they have to enlarge their territory, thereby again increasing the distances that have to be overcome. Fossil fuels provide a two-edged benefit: they allow to span larger distances, and to manage reproduction within a smaller area. So under industrial conditions, size-constraints for urban centres and for freight transport disappear: transport volumes 'explode'".[80]

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[76] Goodman and Redclift (1991).

[77] Fischer-Kowalski and Amann (2001).

[78] Shiva and Gitanjali (2002).

[79] Aoki and Hayami (2001) and Chang (2002).

[80] Fischer-Kowalski et al. (2004).

In an interesting study of the relationships between ecology, economy and state formation in early modern Germany, Paul Warde has characterized the type of socio-environmental changes brought about by the dual development of wider market networks and the political strength of state rule. According to Warde, a previous 'territorial ecology' sustained by local agrarian communities began to be undermined by a 'transformational ecology' triggered by a new set of merchants, tax-collectors and state-rulers that operated at a wider scale. As Paul Warde says, "The 'territorial ecology' implies a repeatable set of actions happening at a particular place. It is a process that reinforces the 'integrity' of a particular way of doing things. The 'transformational ecology', put bluntly, does not. Eventually it must result in the disturbance of local processes: it is a problem generator".[81] His argument implies that "tracing the 'integrity' of, and 'disturbance' to, systems of resource flows, is one of the most useful tasks historians can undertake. It is precisely because the results of ecological interaction can only be determined empirically that ecology should be historical".[82] Perhaps we could generalize this approach by saying that, when studying the various paths of economic growth taken by early pre-industrial societies, we should adopt the working hypothesis put forward by John McNeill: "In any case, human history since the dawn of agriculture is replete with unsustainable societies, some of which changed not to sustainability but to some new and different kind of unsustainability.[83]"

2.8 From One Unsustainable Path to Another: The First Globalization as a Watershed

Rolf Peter Sieferle, Robert Shiel and other scholars have expressed their suspicions concerning two major forces that perhaps led past organic agrarian societies away from sustainability. The first was the lack of manure to sustain crop yields in a highly intensive organic agriculture, and the second deforestation. According to Shiel, estimates made for the European Atlantic bioregions, with no water stress, practising a three-course crop rotation, and where the livestock grazed on pastures kept separate from cropland, show that the highest level of nitrogen availability would have been achieved when less than 15 % of useful agrarian area was sown with grains.[84] Higher cropland proportions would lead either to diminishing returns–after some decades during which the nitrogen reserves stored in the soil would be exhausted—or to new 'Boserupian' innovative responses aimed at improving seeds or varieties and achieving a closer integration between cropland

[81] Warde (2006a), p. 284.

[82] Warde (2006a), p. 19.

[83] McNeill (2000).

[84] Shiel (1991).

and livestock breeding, as took place in England with the well-known Norfolk four-course rotation.[85]

Here it would be interesting to apply the synthesis proposed by Ronald Lee, of Malthus' and Boserup's approaches.[86] Lee suggests that past technological advances usually occurred within a 'Boserupian space' comprising a limited set of combinations of population densities and technological capacities, as a response to 'Malthusian' tendencies towards diminishing returns. Only from time to time did some historical discontinuities occur that pushed forward technological capacities from one 'Boserupian space' to another.[87] However, this immediately raises the question: What factors induced these large but unusual technological shifts? As Bruce Campbell and Mark Overton have stressed, an important side of that issue lies in knowing how differently pre-industrial societies solved the fertilizing trap, within several historical contexts and natural endowments.[88] Much more research is needed in the historical reconstruction of nutrient cycles, based on the methodological tools that agronomists can offer to historians. This long-term agro-ecological research must be undertaken without forgetting the diverse natural and climatic conditions in which very different kinds of 'advanced organic agricultures' developed. For example, owing to the summer water stress in Mediterranean regions the strongest limiting factor was not the nutrients but the soil water content. [89]

In order to fill the nutrient gap opened up by population growth, or a higher amount in trade and taxes, past 'advanced organic agricultures' had to rely on a more intense land-use which, in turn, required a higher labour intensity and a longer time-span of investment.[90] The Chinese way of solving this problem clearly shows the dilemma usually faced between keeping high yields per unit of land without diminishing labour productivity at the same time.[91] Here again the role played by European colonization of America in abolishing this land constraint can be seen. Any 'ghost acreage' assessment would be very limited without extending the time perspective until the beginning of the 20th century, in order to take into account the American grain exports from the Great Plains where settlers stopped using fertilizer for nearly 60 years up to the 1930s.[92]

The overseas exports of cheap cereal coming from the United States and other 'new Europes', leading to the well-known European agricultural crisis of the late 19th century, were based on large scale soil mining of nutrients stored in the

85 Shiel (2006).

86 Boserup (1965).

87 Lee (1986).

88 Campbell and Overton (1991).

89 Bevilacqua (2001) and Garrabou (2005).

90 Allen (2008).

91 Elvin (2009).

92 Cunfer (2005) and Cunfer and Krausmann (2009).

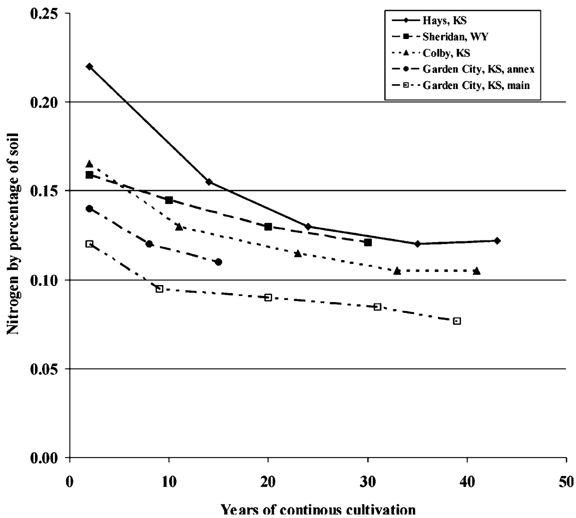

Fig. 2.8 Decline in nitrogen by percentage of soil and years of cropping in several case studies of the Great Plains (United States, 1870–1930). *Source* Cunfer (2004, p. 546)

previously unbroken sod of the Great Plains (Fig. 2.8). In order to compete with these cereal imports embodied with the unpaid 'virtual soil' mined, European farmers were forced to further increase yields per unit of land. Thus, the first globalization linked an unsustainable extensive cropping system on one side of the Atlantic, with an increasingly unsustainable intensive farming on the other.

Eventually, this double-sided process led to an agro-ecological and an economic final crisis of the two sorts of 'advanced organic agricultures'. As Geoff Cunfer has explained, referring to the case of Rooks County in Kansas: "By the late nineteenth century, farmers had pushed into the upper Midwest, the Great Plains, and the Pacific Northwest. In the early twentieth century, only California remained to be tapped for agriculture. The slow wave of westward plowing left behind a secondary wave of abandoned farms. Farmers adopted the old Indian system of swidden agriculture to solve the fertility dilemma. Traditional American farming relied on the existence of an ever-new frontier. Played-out fields eventually grew back to forest or became low-intensity pasturage. Thus, it is no surprise that when the latest wave of American farmers rolled into western Kansas in the 1870s, they implemented a farm system that mined soil nutrients. They applied manure as it was available and occasionally rotated legume crops when convenient, but they had no strategy to sustain cropping for the long term. By the 1930s, Rooks County's fields had been planted, cultivated, and harvested 60 times without rest. Soil nitrogen was about half what it had been at sod breaking, and crop yields were declining steadily. Moreover, the western frontier had disappeared. All of the arable land in Rooks

County—and in the nation for that matter—had been identified and plowed. Soil nitrogen and organic carbon drifted steadily downward, and with it yields and profits. Faced with this problem, farmers implemented a dramatic innovation in soil-nutrient management. Rather than revisiting ancient strategies, farmers (and the industrial nation behind them) appropriated cheap fossil-fuel energy to import enormous amounts of synthetically manufactured nitrogen into their fields".[93]

Being a non-renewable resource, dependence on these chemical fertilizers synthesized from fossil fuels already entailed problems of sustainability. Besides this, they became aggravated later on by the impacts of pollution resulting from excessive and inefficient use of new industrialized cropping systems, that became territorially disjointed from livestock breeding and forestry.[94] Yet before the 1950s the difficulties found in the acceleration of the nutrient throughput remained a major issue for European and American farmers, who kept applying manure as a basic resource and used mineral or chemical fertilizers as a complement.[95] During the spectacular economic growth in the second half of the 20th century, on the contrary, the application to the soil of higher doses of synthetic fertilizers was not only aimed at maintaining acceptable levels of yields, but also to continually increase them up to what was proved feasible. The complete substitution of manure by synthetic fertilizers put an end to the old integrated management of cropland, livestock breeding and forestry, thus entirely upsetting the agrarian social metabolism, and turning farms into an extended network of diffuse pollution and landscape degradation.[96]

Once again we found that economic growth and ecological degradation became the two faces of the same coin. As John McNeill has written, "Environmental change of the scale, intensity and variety witnessed in the twentieth century required multiple, mutually reinforcing causes. The most important immediate cause was the enormous surge of economic activity. Behind that lay the long booms in energy use and population. The reasons economic growth had the environmental implications that it had lay in the technological, ideological and political histories of the twentieth century".[97] The spread of the so-called green revolution added to the diffusion of electrification and forest industrial mass-production and transport, thus allowing a further range of Southern and Central European countries to quickly converge with the United Kingdom and the United States. As the example of Austria shows, catching up in terms of GDP per capita went hand in hand with the convergence in energy consumption and global pollution (Fig. 2.9):

93 Cunfer (2004).

94 Galloway et al. (2004).

95 Tisdale and Nelson (1956).

96 Marull et al. (2008).

97 McNeill (2000).

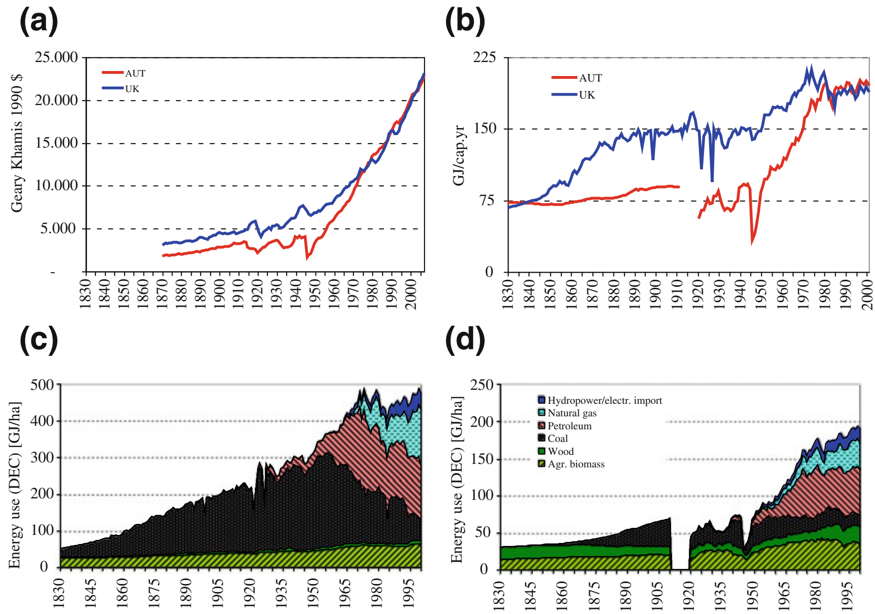

Fig. 2.9 Historical divergence and convergence paths followed by the United Kingdom and Austria in per capita GDP and energy consumption (1830–2000) **a** GDP per capita in real terms **b** Primary energy consumed per capita **c** Energy transition in the UK (per hectare domestic energy consumed by sources) **d** Energy transition in Austria (per hectare domestic energy consumed by sources). *Source* Krausmann et al. (2008, p. 191)

2.9 Was There a General Crisis of Biomass Energy Carriers in Europe?

Looking at deforestation, the second factor that, we can presume, led pre-industrial societies towards greater unsustainability, Rolf Peter Sieferle is in little doubt that Europe did suffer an increasing shortage of wood. He claims that "the historically decisive escape from the wood crisis of the 18th century was the substitution of wood by coal. In the end this process resulted in such an enormous breakthrough in energy supply that any other attempts to substitute and conserve appear marginal by comparison. But for contemporaries it was only one way out among others—they were unaware of its epoch-making importance".[98] This is a controversial issue that deserves to be studied further to clarify whether there was a true widespread wood crisis in Europe or not before the large-scale resort to fossil fuels; and if so, what the main factors were that brought this about.

Landscape photographs taken between the 1870s and 1920s, and the first aerial photos made shortly afterwards, show an apparent deforestation and rejuvenation of

[98] Sieferle (2001).

the surviving forests throughout Europe. Subsequently, and in parallel with the massive consumption of fossil fuels, the forests started to grow again during the second half of the 20th century and today cover a surface area that is perhaps greater than at any other period in the last millennium. The current research on LUCC, applying GIS to historical cadastral maps and aerial photographs, might help historians to confirm the general trend towards a new forest transition.[99] The study on the human appropriation of aboveground net primary production of biomass (HANPP) has demonstrated that in Austria “HANPP decreased continuously from 60 % in 1830 to 48 % in 1970 and then started to increase again slightly, up to 51 % in 1995. This means that today about 23 % more biomass (i.e., 129 PJ/yr or 7 Mt of biomass) remains in terrestrial ecosystems than in 1830”.[100] A more recent study shows there was, in the United Kingdom, a HANPP decline from 74 % in 1800 down to a level of around 65 % in the late 19th and early 20th centuries, followed by an increase up to the late 1950s and a new decline to a value of 67 % in the year 2000.[101] Although much more research is needed on this issue, it seems clear that up to a point past ‘advanced organic economies’ could have exerted a greater direct pressure on European forests than in more recent times, when fossil fuels consumption has globalized ecological footprints and displaced environmental load onto the rest of the world or the atmosphere, subject to global warming emissions.[102]

Here again the question of which driving forces underlay this trend arises. Clearly, increasing population densities must have represented a challenge for any ‘organic-based’ economy. Nevertheless, deforestation must also be linked with market networks and urbanisation, in spite of the fact that many scholars have paid no direct attention to this. To obtain a final energy unit of charcoal, five times more firewood had to be burnt in a charcoal-burner with an energy loss of nearly 60 %. Taking into account that fuel wood extracted from forests could have been consumed either as firewood or charcoal, any switching in consumption from the latter to the former would have had considerable impact on the primary energy needed. What then would have been the use of transforming firewood into charcoal? The main reason was to allow available terrestrial means of transporting heavy goods to travel greater distances, without consuming more energy carrying the fuel than the energy actually carried.[103] The rural population could easily obtain enough firewood from neighbouring forests, coppices, brushwood or wood crops and orchards. Despite the heavy water content of wood, they could easily carry it home for short distances. But cities needed to be provided with much greater quantities of fuel wood coming from quite distant locations. Even the slightest increase in urbanization would have meant

99 Kovář (1999) and Agnoletti (2006).

100 Krausmann (2001).

101 Musel (2008).

102 Haberl et al. (2001).

103 Sieferle (2001).

a rapid growing of fuel weights, and of the distances needed to be covered, thus fostering the shift from firewood to charcoal provision.

We have already seen the close connection that existed between the growth of London and other British industrial cities, and coal extraction in England and Wales.[104] But how did other European cities cope, since they could not expect to be supplied with coal in the same way at the time? We know, for example, that in order to provide Madrid with charcoal during the 18th century the annual output of almost all woods in an area of 70,000 km^2 was required, which represents nearly 15 % of the total area of Spain.[105] More than 17,000 tons were transported every year within a range of 100 km to supply a population of 164,000 inhabitants in Madrid in 1787, with an average of 154 kg of charcoal per inhabitant a year (0.4 kg/inhabitant/day). Assuming the usual efficiency in a charcoal burner, this meant 2 kg of primary firewood per inhabitant a day mainly for domestic purposes. Adding another half a kilo burnt for different industrial activities, we would reach 2.5 kg/inhabitant/day in the pre-industrial city of Madrid. This figure would have been 66 % higher than the average consumption of fuel wood estimated by Paolo Malanima in the pre-industrial Mediterranean Europe, and more than double the minimum supply recorded in Sicily.[106]

We must bear in mind, however, that up to a point charcoal, as well as firewood, could have been kept exploited as a sustainable renewable source, as long as they were made out of small logs shredded, pollarded or cut from coppice-woods in the North-Atlantic regions, and lopped from *dehesa*-types of open forests turned into wood pastures in the Mediterranean South.[107] Even the pruning of vines and olive or almond tress could have been used that way.[108] According to Rolf Peter Sieferle, "at first sight there was no shortage of fuel. It was always possible, and with little effort, to produce firewood […] by establishing coppices. In general, it can be said that the fuel aspect was only part of the wood crisis, and that part most easily open to a traditional solution". He concludes that "the wood crisis of the eighteenth century was in the first place a timber crisis. The enormous consumption of firewood in combination with agricultural uses of woodlands made it increasingly difficult to find old tree stands that were suitable for construction".[109]

The cautious scepticism of A.T. Grove and Oliver Rackham goes even further when they oppose the 'Ruined Landscape' myth with the hypothesis that, instead of a true deforestation, human impacts over Southern Europe mainly altered different types of the ever dynamic forest and shrub covers that characterize the Mediterranean environment (open-tall *dehesa*-type of savannah instead of a thick-short

[104] Allen (2009).
[105] Bravo (1993).
[106] Malanima (2001).
[107] Clément (2008).
[108] Grove and Rackham (2001).
[109] Sieferle (2001).

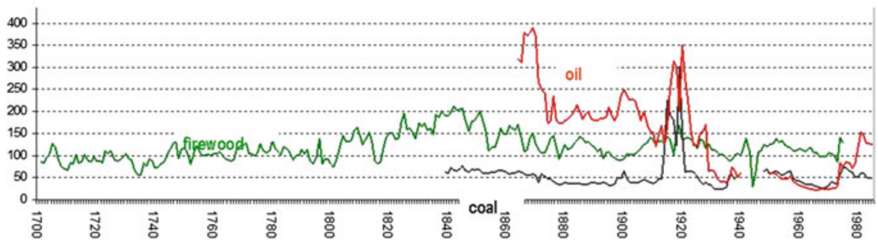

Fig. 2.10 Long-run trends in real prices of firewood, coal and oil in Italy (1700–1985 in 1911 ITL per TOE). *Source* Malanima (2006, pp. 70–71)

forest, *maquis*, etc.).[110] In his overview on world-wide deforestation Michael Williams suggests that, in Europe, before the coming of the fossil fuel era, timber and firewood shortages were more of a local or regional feature than a general one, and he discards charcoal consumption in industrial uses as a relevant factor.[111] On the opposite side, Paolo Malanima bears no doubts when he states that "from the mid-eighteenth century onward, while Europe's population was growing faster, energy availability was decreasing. The result was a sharp per capita decline in energy consumption".[112] This included both food intake and fuel wood availability, which seems to fit well with the anthropometric height decrease of Europeans born between 1770 and 1820. "The decline of forest is borne out—according to Malanima—by the quick rise of the price of firewood, which was usually faster than the overall growth of agricultural prices. In Western European cities, between 1700 and 1800, firewood prices increased by more than three times".[113] The long-term evolution in Italian prices of firewood, compared with prices of coal and oil, clearly fits with the 'exergetic' economic growth theory proposed by Bob Ayres and Benjamin Warr (Fig. 2.10; see also Fig. 2.2):

In a nuanced and detailed overview of the wood shortage debate in pre-industrial Europe, Paul Warde assesses that "if the European population in 1500 was around half that in 1800, and if there were general scarcities in 1500, survival could only have been possible in 1800 as a consequence either of a radical alteration in the domestic fuel economy, or a greatly increased woodland area or productivity. As there is very little evidence for any of these things we must be suspicious of any claims for a general scarcity at any time before the late eighteenth century. Western Europe had a population of around 122 millions by 1820, and if annual domestic demand is set at about three cubic meters per hectare, a coppiced area of 407,700 km^2 would have been required for a sustainable supply. This approximates to the area of modern Germany and Switzerland combined, something under a fifth of western Europe (excluding

110 Grove and Rackham (2001).

111 Williams (2003).

112 Malanima (2006), pp. 101–121.

113 Malanima (2006), pp. 116–118.

Scandinavia). As it is doubtful that many areas of Europe were this well wooded at any point in the period, the case for a general wood shortage by 1820 appears quite plausible, but is hardly plausible for any period before 1750".[114]

At the same time, however, this plausible wood shortage at the end of the 18th or the beginning of the 19th century brought about a wide development of 'scientific forestry', aimed at increasing wood yields and its predictability across time. This shift in woodland management entailed many conflicts between forest engineers, state-rules and peasant communities, and the apparent landscape changes it brought about raised deep social unrest all over Europe as well as in colonial regions such as India under British rule.[115] Yet, as Paul Warde concludes, "in dealing with general scarcity, forestry was fairly successful. […] The nineteenth century augmentation of wood yields demonstrated that there was plenty of scope for productivity increase within the economy after the Napoleonic age, but equally, that the ability to raise consumption per head and indeed income levels was limited. […] When Jevons in 1865 turned to the question of the exhaustion of coal reserves […], most of Europe still looked to wood as its primary source of thermal energy. That this could still be the case after a period of enormous population growth is a tribute to the capacities of the preindustrial ancient regime, and an indicator that Europe, for all its late eighteenth-century problems, remained distant from any ecological frontier". [116] It must be added immediately, though, that it was precisely during the late 19th century when written sources and the first landscape photographs provided direct and indirect evidence of a peak in deforestation all over Europe, just before the start of a fast reforestation wave fostered by rural abandonment.

Was there or was there not a general biomass energy crisis at the beginning of the fossil fuel era? This remains a significant, open historical question that deserves to be extensively looked into in the future by reconstructing land-use statistics or surveys, and making GIS analysis of land-cover changes from aerial photographs and cadastral maps. The aim should be to extend the land accounts that the EEA have started to assemble for the last decade of the 20th century as far back in time as possible,[117] similar to the historical series of main land uses in the United Kingdom and Austria reconstructed from 1830 onwards by Fridolin Krausmann, Heinz Schandl and Rolf Peter Sieferle (Fig. 2.11):

In the meantime, the available evidence suggests that timber, firewood or charcoal scarcity might have been more of a regional situation than a general continental phenomenon. As Paul Warde has suggested for the English case, it is likely that scarcities became a true economic problem when, together with fuel, they increased food or feed prices and land rents as well.[118] It would have been enough, however, that these regional scarcities affected general trends of energy prices to become a

[114] Warde (2006b), pp. 38–39.

[115] Guha (1991).

[116] Warde (2006b), p. 52.

[117] European Environment Agency (2006).

[118] Warde (2007).

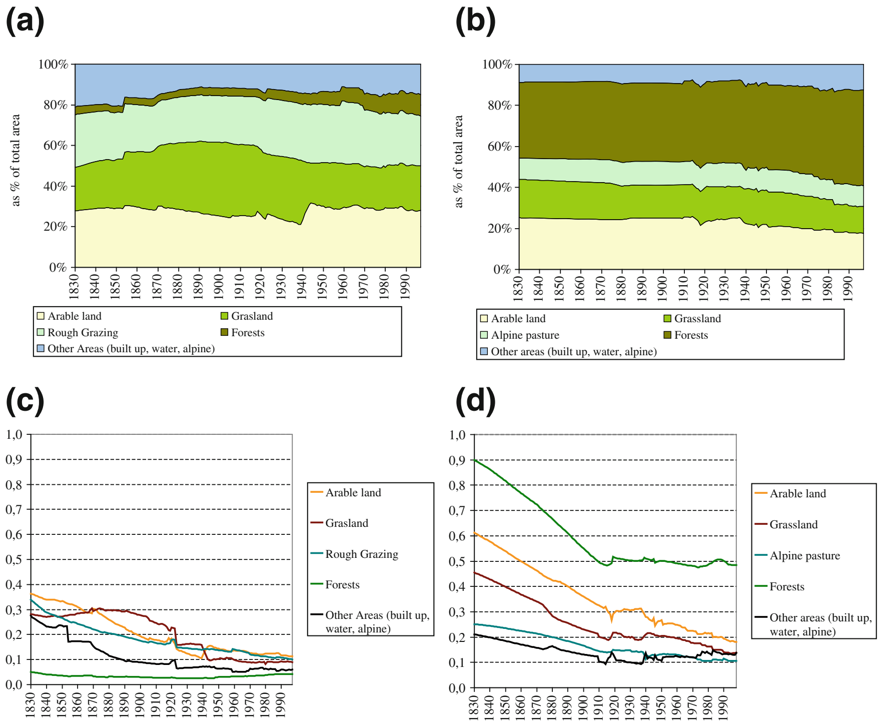

Fig. 2.11 Land-use changes in The United Kingdom and Austria (1830–2000 as % of total area) **a** As % of total area in the United Kingdom **b** As % of total area in Austria **c** Per capita land-uses in the United Kingdom **d** Per capita land-uses in Austria. *Source* Krausmann et al. (2008, pp. 187–201)

driving force that urged the energy transition from land-based biomass energy carriers to mineral-based fossil fuels (see Figs. 2.6 and 2.2). The same way the Stone Age did not end because of a shortage of stones, the way out of a biomass-based energy system had no reason to wait for a devastating deforestation.

Almost all known energy transitions have required a long of time to attain an overall turnaround of the preceding mix of energy sources (see graphs 7, 11.3 and 11.4 as examples). Over a period of time all energy sources, old and new, can continue to grow at different and sometimes similar rates. This was the case of many woodland products whose consumption increased during the 19th and the first third of the 20th century, despite the contemporary growth in coal burning. This happened not only in Nordic countries such as Finland, but also in Mediterranean ones such as Spain, due to the maintenance of many traditional uses, together with the appearance of new applications related to industrialization and urbanization—railway sleepers, mine roof supports, posts for telegraph and power lines, furniture, packages of fruit and wood pulp to make paper.[119] In several

[119] Myllyntaus and Mattila (2002) and Iriarte-Goñi and Ayuda (2008).

developed nations a true “liberation” of forests from fuel wood extraction had to wait for the massive diffusion of gas cylinders during the 1950s, which put a sudden end to the last boom in charcoal burning for cooking stoves.

The fate of European woodlands may have been closely linked to urbanization. However, while charcoal production has been mainly studied in relation to traditional iron smelting, little attention has been paid to this role in relation to the substitution of fireplaces by stoves in growing towns and cities. Some oral memory and other anthropological sources suggest that until the 1950s, in many regions located far away from a cheap coal supply, stoves were usually burnt with charcoal. Charcoal production seems to have grown hand in hand with the increasing use of stoves in urban areas, and peaked just before the arrival of gas cylinders. A historical geography of coal-supplied and charcoal-provided cities, and their respective evolution during the 19th and first half of the 20th century, would help to trace the changes in woodlands in Europe, so as to identify the main turning points and their major drivers. Taking into account that developing nations are experiencing a fast urbanization at present, while simultaneously providing the highest share of wooden raw materials consumed in developed countries, being better informed of past European energy and landscape transitions could greatly help to redress the huge World deforestation.[120]

A careful accounting of biophysical urban socio-metabolic flows would thus help a lot in assessing this long-running link between forest landscapes, urbanization and energy transitions. The wood issue seems only to have been one part of the ever-expanding ‘ecological footprint’ generated by changing consumption patterns as industrialization and urbanisation processes got underway. In addition to firewood, charcoal and timber, the historical approach to urban social metabolism includes the consumption of cereals, meat, milk and other food products, together with the excretion of wastes, which constitutes another interesting field of research for human ecology, ecological economics and environmental history.[121]

2.10 Concluding Remarks

Despite being neither complete nor exhaustive, the examples presented in ongoing debates and current research show a great interest of a further dialogue and interdisciplinary collaboration between environmental and economic history. These examples also show, however, that the strongest barrier lies in the mainstream approach to economic growth and macroeconomic theories which neglect the role of energy and other natural resources. Yet, adopting a common bio-physical and socio-metabolic approach, linked to land-use and global environmental changes,

[120] Williams (2003).

[121] Stanhill (1984), Schmid Neset (2005) and Billen et al. (2009).

would help achieve a greater understanding of how economic growth actually occurs, and the role ecological impacts entail on life-support systems of the Earth.

Neither traditional mistrust nor the suspicion of biased ecological or economic determinism should prevent the necessary rapprochement between economic and environmental history, which is being opened up by the development of ecological economics. In order to put aside any suspicion about causal primacy, it is worth distinguishing from the beginning those explanations that tell us what growth is or how it happens from those that explain why growth occurs.[122] The socio-metabolic research on long-term transitions in the interaction between nature and society may significantly contribute to enhance the understanding of what economic growth is, and how it takes place. Nevertheless, this would leave space for other dimensions, such as institutional settings or ruling actors needed to explain why growth happens, by whom, and for what purpose. Thus, the development of this new biophysical standpoint does not mean that we can afford to neglect institutional, social, cultural and political factors.[123] On the contrary, as Joan Martinez Alier has written, "far from naturalising history, the introduction of ecology into the explanation of human history historialises ecology. This is because human ecology, that is, the relationship between human societies and nature, cannot be comprehended without an understanding of the history of human beings and their conflicts".[124]

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Glossary

EROI	Energy returns on energy inputs
MEFA	Material and Energy Flow Analysis
HANPP	Human Appropriation of the ecological Net Primary Production
EUROSTAT	The Statistical Office of the European Communities located in Luxembourg. Its main responsibilities are to provide statistical information to the institutions of the European Union (EU) and to promote the harmonisation of statistical methods across its member states

[122] North (1999).

[123] Teich et al. (1997) and Sörlin and Warde (2009).

[124] Martínez Alier (1998).

Production function	It is a function that relates the output to the inputs or factors of production used in a production process. The Cobb-Douglass is the most standard in which the output (Y) is produced with two factors, labour (L) and capital (K), and the remaining growth share not explained by the variation of both is explained with the Total Factor Productivity (A). That is, $Y = AL^{\beta}K^{\propto}$ where $\beta + \propto = 1$ and account for the output elasticities of capital and labour, respectively
TFP	The Total Factor Productivity measures the fraction of economic growth that cannot be explained by the contribution assigned to the increases in capital, labour and land. As it is commonly considered that it grasps the efficiency gains obtained through the combination of factors that participate in a production process taken together, and it is taken as a measure of an economy's long-term technological change
Exergy	The useful work actually performed by all energy converters which empower human labour and capital goods at its disposal
IPCC	The World Meteorological Organization (WMO) and the United Nations Organization (UNO) created the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC summarizes the technical, biophysical, socio-economical information to understanding and measure the risk of climate change
LUCC	Land-Use Land-Cover Change programme (http://www.geo.ucl.be/LUCC/lucc.html) examines the transformations undergone by Earth's vegetal cover over the centuries, in order to identify the main driving forces behind global socio-environmental change, and also to assess its socio-ecological impact

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