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A Socio-metabolic Transition towards Sustainability? Challenges for Another Great Transformation

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ABSTRACT

Over the last two million years, humans have colonized almost the entire biosphere on Earth, thereby creating socio-ecological systems in which fundamental patterns and processes are co-regulated by socio-economic and ecological processes. We postulate that the evolution of coupled socio-ecological systems can be characterized by a sequence of relatively stable configurations, here denoted as 'socio-metabolic regimes', and comparatively rapid transitions between such regimes. We discern three fundamentally different socio-metabolic regimes: hunter-gatherers, agrarian societies and industrial society. Transitions between these regimes fundamentally change socio-ecological interactions, whereas changes and variations within each regime are gradual. Two-thirds of the world population are currently within a rapid transition from the agrarian to the industrial regime. Many current global sustainability problems are a direct consequence of this transition. The central hypothesis discussed in this article is that industrial society is at least as different from a future sustainable society as it is from the agrarian regime. The challenge of sustainability is, therefore, a fundamental re-orientation of society and the economy, not the implementation of some technical fixes. Based on empirical data for global resource use (material and energy flows, land use), this essay questions the notion that the promotion of eco-efficiency is sufficient for achieving sustainability, and outlines the reasons why a transition to a new socio-metabolic regime is now required. Copyright © 2009 John Wiley & Sons, Ltd and ERP Environment.

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Society–Nature Interaction: Gradual *and* Revolutionary Change

THE EMERGENCE OF AGRICULTURE AND ANIMAL HUSBANDRY ROUGHLY 12 000 YEARS AGO ALTERED HUMAN SOCIETIES and their relationship with the natural environment so fundamentally that this transition process is called with great justification the 'Neolithic revolution'. The term 'revolution' is also appropriate given the extent of changes that took place as a consequence of this transition process. Having previously lived in nomadic groups of 20–50 individuals, with an average foraging territory of some 25 km^2 per person, after the transition process humans inhabited permanent settlements. Population density grew by a factor of between 100 and 10 000 (Table 1). Agriculture, animal husbandry and the storage of food and other resources emerged and the time horizon of foresight of human societies increased rapidly. The latter aspect also implied the need to pass on the knowledge and skills required for the successful cultivation of land and for managing natural resources – from the acquisition of essential technologies to the social rules relating to stock husbandry or to those resources that were often used by a community as a whole, such as water, grazing land and woodland (Boyden, 1992; Sieferle, 1997; Winiwarter and Knoll, 2007).

The Neolithic revolution required a fundamental reorganization of the relationship with the natural environment: there are clear reasons why we talk about the preceding period as that of hunter-gatherer societies and the subsequent era as that of agricultural societies (Vasey, 1992). Agrarian ecosystems created by human activity, such as arable land, grazing land and meadows, replaced natural ecosystems, which had provided the habitat for hunters and gatherers; natural landscapes were transformed into cultivated landscapes ('cultural landscapes'). The central innovation, expressed in the terminology of social ecology, was the appearance of a new kind of society–nature interaction, the 'colonization of nature' (Fischer-Kowalski and Haberl, 1997). This concept refers to socially organized activities that alter natural systems in order to increase the benefits to humans obtained from those systems. Land use in the form of agriculture and forestry can be understood as the 'colonization of terrestrial ecosystems', and the cultivation of livestock and useful plants upon which this process depends as the 'colonization of organisms' (Haberl and Zangerl-Weisz, 1997). Domestication of plants and animals may be seen as co-evolution between natural and social systems leading to the emergence and use of different species and varieties in Africa, Asia, Europe and the Americas.

The 'controlled solar energy system' (Sieferle, 1997) of agrarian societies emerged through the development of the knowledge and skills that were required for undertaking and improving colonizing interventions and for socially organizing the required labour processes as well as the tradition of knowledge from one generation to the other. This energy system continues to form the basis for the subsistence of agrarian societies up to the present

	Unit	Hunter-gatherers	Agrarian society*	Industrial society**
Total energy use per capita	[GJ/cap/yr]	10–20	40–70	150–400
Use of materials per capita	[t/cap/yr]	0.5–1	3–6	15–25
Population density	[cap/km^2]	0.025–0.115	<40	<400
Agricultural population	[%]	–	>80%	<10%
Total energy use per unit area	[GJ/ha/yr]	<0.01	<30	<600
Use of materials per unit area	[t/ha/yr]	<0.001	<2	<50
Biomass (share of energy use)	[%]	>99	>95	10–30

Table 1. Metabolic profiles of hunter-gatherers and agrarian and industrial society. Sources: adapted from Krausmann *et al.*, 2008a, based on data from Haberl *et al.*, 2006b; Krausmann and Haberl, 2002; Malanima, 2002; Schandl and Schulz, 2002; Sieferle *et al.*, 2006; Simmons, 1989, 2008; Weisz *et al.*, 2006

*Typical values for an advanced European agrarian socio-metabolic regime (18th century). In agrarian societies based on labour-intensive horticultural production with low significance of livestock, population density might be significantly higher, while the per capita use of materials and energy would be lower.

**Typical values for current fully industrialized economies. In countries with high population densities, per capita values of energy/materials use tend to be in the lower range, while values are high when measured per unit area. The reverse is true for countries with low population densities; in this case values per unit area can be very low.

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day. Hunters and gatherers subsist solely on foraging. They take from the ecosystems in their territory (which are otherwise allowed to evolve without deliberate human interventions) those resources needed to satisfy their requirements and do not become actively involved in the reproduction of these resources.[1] In contrast, agrarian societies, often by employing the aid of domesticated animals, invest in ecosystems, e.g. by clearing woodland in order to create fields and grasslands. Slash-and-burn agriculture also creates temporary fields, while it is usually not based on the work of domesticated animals. This not only changes the vegetation cover but also alters the productivity of ecosystems: In most of the temperate zone, where previously woody biomass indigestible to humans had dominated, herbaceous plants become a main part of the environment. They provide leaves, fruits, roots and seeds suitable for direct human consumption, or may be partly or wholly consumed by livestock and thereby provide indirect benefits to human society. In this way, the share of the annual biomass production of ecosystems (that is, their net primary production or NPP) that can be obtained for feeding people and livestock can be markedly increased. This in turn significantly increases the availability of biomass for human use ('social metabolism', Fischer-Kowalski *et al.*, 1997): whereas hunters and gatherers consume roughly one per cent or less of the NPP of the ecosystem which they inhabit, this proportion may rise to over 75 per cent in the case of agrarian societies (Boyden, 1992). This increase is the basis not only for a much larger population density, but also for a new level of material and energy use per capita. Biomass extraction of agricultural societies per unit area exceeds that of hunters and gatherers by up to three orders of magnitude (Table 1). The Neolithic revolution resulted in fundamentally new patterns in social metabolism, altered plant and animal species and transformed terrestrial ecosystems to an extent that warrants a new notion ('agro-ecosystems'). It created entirely new constellations at the landscape level, i.e. cultural landscapes (Berglund, 1991).

The term 'social metabolism' (Ayres and Simonis, 1994; Fischer-Kowalski *et al.*, 1997; Weisz *et al.*, 2001) encompasses the entire flow of materials and energy that are required to sustain all human economic activities. It is not limited to the nourishment of the population within a society. In the case of agrarian societies, social metabolism includes, alongside human nutrition, mainly the feeding of livestock. Raw materials for buildings and other infrastructures (roads, bridges, fences), tools, equipment, indeed all artefacts required by the economy as a whole, are equally relevant parts of the metabolism, although they are of minor quantitative importance in the agrarian regime (Table 1). The development of the ability to colonize natural systems in the course of the Neolithic revolution was the prerequisite for increasing the social metabolism per land unit and per annum by several orders of magnitude. It thereby created the conditions for permanent human settlements and for population growth.

This in turn fundamentally altered the sustainability problems faced by human societies. Before the Neolithic revolution, the primary threat to the socio-ecological viability of societies was the natural variability of the availability of comestibles. The Neolithic revolution provided a solution to this type of scarcity problem. Animal husbandry and agriculture decouple the supply of human societies with raw materials and energy from the natural development of uncontrolled ecosystems and make them accessible for active, socially organized human intervention (Boserup, 1981; Netting, 1993, Sieferle, 1997): through the application of human and often also of animal labour, terrain and vegetation cover are reorganized so that primarily plants that are useful for human society grow. Through the further development of technology, new plant varieties and increases in labour efficiency, it is subsequently possible to increase the productivity of agrarian ecosystems per unit area and per year within certain limitations. Ecological constraints are, for instance, caused by the limited possibilities to increase the availability of plant nutrients or water.

Other limitations are social in origin. The main advantage of agrarian societies, their ability to produce stocks of grains or animals that can be used during periods of lower productivity of the colonized land systems, also bears a disadvantage: grain stores have to be protected from rivalling people, and the erection of granaries (mainly for coping with the natural threat to stores, vermin) is costly also in terms of energy expenditure. A similar problem is incurred in irrigation agriculture. While irrigation allows us to increase yields and to spread agriculture into dry areas, it often results in soil salinization over the long term. Many such environmental legacies can persist for elongated periods of time, degraded soils being a case in point. This phenomenon has been termed a 'risk spiral'

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[1] This is not to say that hunter-gatherers did not have a considerable impact on the ecosystems on which they were foraging. In particular, it has been argued that the systematic use of fire in hunting had an enduring effect at the landscape level (see, e.g., Simmons, 2008) and that Palaeolithic hunting had significant impacts on the diversity of large mammals.

to describe the fact that the successful abatement of one risk often leads to new, different risks (Müller-Herold and Sieferle, 1998). In other words, while ecological constraints can sometimes be overcome through the use of human labour and ingenuity, this is commonly associated with new risks, adverse environmental effects, excessive demand for human labour or a deterioration of the agricultural energy balance (Pimentel *et al.*, 1990).

For agrarian societies, sustainability thus develops into a multi-dimensional socio-ecological problem. In each specific case in which solutions were found throughout history, such diverse processes as soil degradation, the development of new technologies, knowledge transfer, the ability to organize labour processes or the capacity to agree upon and implement workable rules governing the common usage of resources have all played a part.

A process of gradual change over thousands of years resulted in the emergence of agrarian societies with widely varying socio-ecological characteristics (Fischer-Kowalski and Haberl, 2007). Yet one fundamental barrier to the growth of the agrarian regime could not be broken by gradual change, namely the constraint of an area-related energy system (Sieferle, 1997). The energy supply of agrarian societies depends almost entirely on biomass from agricultural and forestry ecosystems. Energy supply, as we understand it (for details see Haberl, 2001), includes the supply of people and livestock with the requisite food energy to sustain their survival and their capacity to work. Technical energy conversion processes, such as the burning of wood or charcoal, are also important, yet in quantitative terms they play a minor role. Energy sources not based on photosynthesis, for example water and wind power, are significant for important processes such as transportation, the milling of grains or metal-working (Smil, 1991), but the amounts of energy thereby converted are almost negligible in relation to the flow of biomass-related energy (Krausmann *et al.*, 2008a; Malanima, 2001; see Table 1).

As land use (agriculture, animal husbandry and forestry) provides the lion's share of energy supply, land use in an agrarian society must yield a positive energy balance. This means that the amount of energy that can be invested in land use by society in the form of the labour of people and animals must be much lower than the amount of energy yielded. This relation was established as early as 1880 by S. A. Podolinsky using French agricultural statistics, and later rediscovered and quantified by ecological anthropologists (Leach, 1976; Martinez-Alier, 1987; Rappaport, 1968). Expressed in the terminology of modern energy flow analysis (Hall *et al.*, 1986), agriculture must yield a positive *energy return on investment* (*EROI*) of at least 1:5; that is, it must supply society with at least five times as much energy as society invests in land use. Under conditions where increases in agricultural outputs can only be accomplished by investing additional labour at declining marginal returns (Boserup, 1965), this condition limits the potential to increase the productivity of agro-ecosystems, and thereby the amount of resources that could be produced per unit area each year.

These limitations (Sieferle *et al.*, 2006), which are shared by all types of agrarian society, could only be overcome by the emergence of a new type of energy system, the 'fossil energy system' (Krausmann *et al.*, 2008b; Sieferle, 1997). The transition to this socio-metabolic regime is another socio-ecological revolution, which leads to new patterns of material and energy use (Table 1). It was not characterized by gradual change, like the change ongoing in agrarian societies until the beginning of large-scale coal usage. On the contrary, it was a rapid transition that continues today and has enabled humankind for the first time to trigger processes of environmental change on a global scale, having led to calling this era the Anthropocene (Steffen *et al.*, 2007). This introduces qualitatively new conditions in the earth system and will possibly lead to accelerated change such as a runaway loss of species or rapid and far-reaching global climate perturbations.

The Agrarian–Industrial Transition is Still Ongoing

Viewed from the perspective of the inhabitants of a highly developed industrialized country – a global minority to which the majority of scholars belong – the agrarian–industrial transition appears to be solely of historical interest. After all, from such a vantage point, it seems that we have already arrived in a post-industrial society, as a service society seems to have replaced industrial society decades ago (Pfister, 1995). A large part of our gross domestic product is now produced in the tertiary sector, which employs approximately two-thirds of the labour force.

Such a perspective neglects important facts, however. First, the seemingly dematerialized post-industrial society continues to depend on a material-intensive, largely machine-operated and ecologically destructive foundation involving agriculture, mining and the raw materials industry that is increasingly located in developing countries

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(Martinez-Alier, 2002). Second, the economic value added in the tertiary sector in rich countries translates into wages and profits, which are to a large extent spent on the consumption of material-intensive products or services (e.g. long-distance travel, large houses and cars). Third, this is a minority perspective. Currently, only one-third of the world population lives in highly developed industrialized countries or in the industrial archipelagos that have emerged in developing countries, i.e. countries that are otherwise predominantly agrarian in character, like those that preceded the industrialized countries of today (Sieferle, 1997). The majority of the world population today finds itself in the middle of a socio-metabolic transition process from an agrarian to an industrial society, a process that is at different stages in different locations (Fischer-Kowalski and Haberl, 2007; Krausmann *et al*., 2008a).

Meanwhile, it is clear that humankind's use of resources and sinks – a large part of which can be ascribed to the industrialized countries – outstrips the ecological limits of the planet. A case for this has been made by studies looking at the global development of an indicator called the 'ecological footprint'. Studies of humanity's ecological footprint have attracted much attention because they suggest that humanity already consumes more resources than the biosphere can replenish (Sutcliffe *et al*., 2008; Wackernagel *et al*., 2002). Less popular but of greater significance in scientific terms are the large-scale studies known as 'assessments'. This term refers to attempts made by large, internationally connected groups of researchers to synthesize the current state of research on various ecological problem areas. In the case of the IPCC reports on climate change, the greatest efforts have been made in terms of scientific quality assurance and political independence (see, e.g., IPCC, 2007b). In addition, works such as the 'Millennium Ecosystem Assessment' on the state of ecosystems and their ability to provide society with vital ecological services, termed *ecosystem services* (Millennium Ecosystem Assessment, 2005), or the 'Global Biodiversity Assessment' (Heywood and Watson, 1995), have also gathered a large number of prominent experts, who focussed on providing a balanced assessment and a broad coverage of the current state of research.

The message derived from such joint efforts is clear. Humankind is wreaking changes upon the biosphere on a scale and at a speed that gives real cause for concern. This was anticipated by geographers and ecologists who studied humanity's role in changing the face of the Earth (Thomas, 1956). Similarly, the stages in social metabolism in terms of use of energy were described a long time ago by authors such as W. Oswald (1909) and L. White (1943) (for reference see Martinez-Alier, 1987), although they were unable to provide the precise, detailed empirical comparative work that we can accomplish nowadays, using concepts derived from material and energy flow accounting (MEFA) and from studies of HANPP (human appropriation of NPP). They allow us to discern stages and variations in socio-metabolic transitions. For instance, such research can demonstrate that a transition from fossil fuels back to an area-related energy system (with agro-fuels) is not feasible at present population densities because of the low EROI and the increase in the HANPP that it would imply (Haberl and Erb, 2006; Haberl *et al*., 2007).

Climate changes, degradation of ecosystems and biodiversity loss have a common cause: the enormous and continually growing use of natural resources (land, water, materials, energy etc.) to sustain the social metabolism of humankind. The total energy use – that is, the total use of energy, including food energy for people and livestock – is a useful indicator in this context (Haberl, 2001, 2006), since it encompasses both total biomass use (and is thus closely coupled with land use) and the use of fossil energy (coupling it closely with the greenhouse gas problem).

Figure 1 shows the development of the 'energetic metabolism', that is, the total energy use of humankind in the above-mentioned sense, for industrialized countries, developing countries and the formerly planned economies (Central and Eastern Europe and the former Soviet Union), denoted here as FSU. These data clearly show three facts. First, in 2000, the 0.84 billion people living in industrialized countries used roughly the same amount of energy as the 4.7 billion people living in developing countries (the rest of the world population lives in the FSU). Second, Figure 1 makes clear that the per capita energy use of developing countries, at 50 Gigajoules per capita and year (GJ/cap/yr), is in the same range as the typical value for pre-industrial agrarian societies (Table 1). Biomass provides the major part of the total energy requirements of developing countries, while its proportion of the total energy use in industrialized countries has sunk to about 25–30% (although increasing somewhat in per capita terms). Third, it becomes clear that the growth in global energy use in recent decades is occurring primarily in developing countries but has little to do with growing per capita use: it is almost entirely resulting from population growth. By contrast, the growth of energy use in industrial countries has slowed down, mostly due to their low population growth, while energy use per capita is still growing there, although slowly.

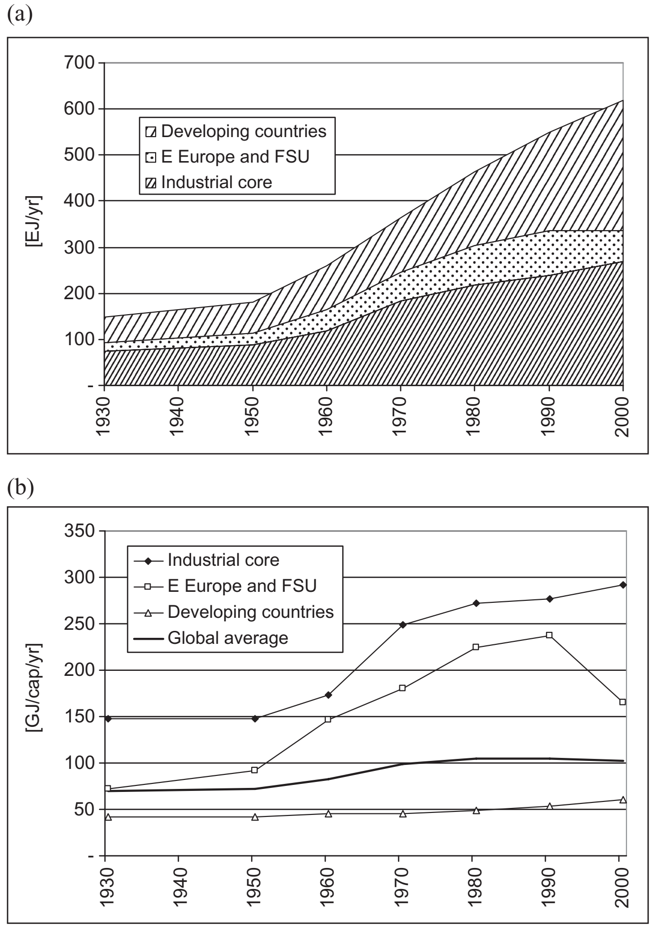

Figure 1. Humanity's energetic metabolism, 1930–2000. (a) Total energy use per year. (b) Energy use per capita and per year. Data source: Haberl *et al.*, 2006a

A Globalization of Our Industrial Metabolism is Impossible

A simple calculation highlights the problems that a global industrialization based on our current pattern would entail. If we assume the world population growth rate that seems most likely (based on current trends), then roughly 8.5 billion people would be inhabiting the Earth by 2050 (Lutz *et al.*, 2004). Assuming that their total energy use would rise in accordance with the mean value of today's industrial societies up to a rate of 250 GJ/cap/yr, the global energy use of humankind – including food energy for people and livestock – would more than triple in this period, from a current figure of roughly 600 Exajoules per year (EJ/yr, 1 EJ = 10^{18} J) to above 2100 EJ/yr. The energy consumption of humankind would then be roughly equal to the entire terrestrial net primary production (NPP), that is, the entire quantity of biomass that green plants produce each year on the earth's surface through photosynthesis.

At present, it is hard to imagine which technologies could be capable of satisfying such global energy requirements without a further massive expansion of the use of fossil energy carriers and without an exorbitant increase in biomass consumption. A nuclear energy expansion programme capable of significantly reducing the surge in fossil energy use at such a scale is barely conceivable. Furthermore, water power, wind power, geothermal or solar energy would be unable to keep pace with such a huge growth of energy requirements. If the current use of

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resources – which largely benefits only one-third of the world's population – is already enough to destabilize the global climate, and if current land use practices in many regions are already creating irreversible soil erosion, loss of biodiversity and degradation of ecosystems, how could such a scenario become reality without catastrophic consequences?

Whether technologies such as carbon capture and storage (CCS) – that is, the separation of CO_2 from flue gases and its environmentally safe storage, for example in underground reservoirs – could help to design a fossil-energy system that would be sustainable for at least one or two centuries, as has been argued (Jaccard, 2005), remains to be seen. The IPCC reports only 'medium agreement, medium evidence' on the prospect that CCS could contribute substantially to CO_2 reduction over the 21st century (IPCC, 2007a, p. 44). The IPCC (2007a, pp. 284ff) also stresses uncertainties about CCS technologies, costs and potentials. Growth in fossil energy use can certainly not rely on conventional oil because of the impending oil peak, first announced some time ago (Hubbert, 1971), and meanwhile expected for the next decades, if not years (Hallock *et al.*, 2004). Because natural gas is expected to peak only few decades after conventional oil, a massive expansion of fossil energy use would have to be based on unconventional oil and gas or on coal. A switch to coal would either further increase greenhouse gas emissions, as coal combustion produces much more CO_2 than that of oil and gas per unit of energy, or amplify the amount of CO_2 to be eliminated through CCS. Moreover, both CCS and a switch to unconventional oil or gas are bound to reduce the EROI of fossil fuel extraction, which has already been falling in the past, and consequently increase the negative environmental impacts of fossil energy use (Hall *et al.*, 2008).

Moreover, there is a feedback loop between the availability of fossil energy and agricultural yields, as modern agriculture relies heavily on energy-intensive products such as fertilizers, pesticides and machines. With global soil degradation as a looming threat and less fertilizer available or economically viable, we should be aware that 'peak oil' might also mean 'peak soil' (Chambers, 2008). The importance of such feedbacks in social metabolism is as yet under-estimated. What does it really mean, for example, that agriculture in the industrialized countries in the mid-20th century changed from a net producer of socially available energy into a conversion system fed by fossil fuels (Sieferle *et al.*, 2006)? What are the full socio-ecological implications of the 'green revolution', the introduction of industrial agriculture in developing countries in the 1970s?

The scenario calculations of the IPCC in the *Special Report on Emission Scenarios* (SRES) do not assume that global industrialization will take place. In the scenarios (which are divided among four 'families', each with numerous sub-types), industrialization is assumed to proceed at different speeds. The technical primary energy use – that is, exclusive of the biomass required for the nutrition of people and livestock – is projected to increase by the year 2050 from 642 to 1611 EJ/yr; typical values are between 813 and 1431 EJ/yr. The CO_2 emissions foreseen in these scenarios rise in relation to 1990 levels (6 Gigatonnes of carbon dioxide per year or Gt C/yr, 1 Gt = 10^9 t) to at least 8.5 Gt C/yr, with the maximum level predicted at 26.8 Gt C/yr, and representative values falling in a range between 11.2 and 23.1 Gt C/yr (Nakicenovic and Swart, 2000). Thus, most scenarios predict that increases in greenhouse gas emissions will occur in the range of two to six times current values.

A number of factors suggest that the energy consumption levels predicted in many of these scenarios might be even too low rather than too high. Since 2000, the growth in CO_2 emissions and hence the CO_2 content in the atmosphere has increased faster than previously assumed. From 1990 to 2000, the CO_2 content in the atmosphere rose by some 1.3% per year. In contrast, emissions between 2000 and 2006 rose annually by 3.3%, largely as a result of rising energy consumption and increased economic activity (Canadell *et al.*, 2007). If these trends continue, the result would be a significant increase in the speed and magnitude of climate change – certainly a very unsustainable trajectory.

Against this trend stands the aim of limiting the global rise in temperature to 2 °C. The European Commission estimates that in order to achieve this target greenhouse gas emissions worldwide will have to be halved by 2050 and reduced in the industrialized countries by 80%. A reduction in emissions on this scale would require a transition to a qualitatively different energy system. A wide spectrum of visions for such a transition has been put forward over many years, from an atomic energy society (Häfele and Manne, 1975; Marchetti, 1979) to a solar low-energy society (Lovins, 1977; Krause *et al.*, 1980; Kohler *et al.*, 1987). What they all have in common is the fact that none has succeeded even in rudimentary form in becoming reality. Although in most industrialized countries the growth of energy use and greenhouse gas emissions has slowed down or in some cases even halted, there is absolutely no sign of an 80% reduction ever becoming viable.

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So far, we believe, these visions of energy use reduction were too technical in kind to materialize. They failed to take sufficient account of the manifold interconnections between the energy system and society. A radical reorganization of energy systems is simultaneously a radical reorganization of society – for example, towards becoming a nuclear state in the case of atomic energy (Jungk, 1977) or in the direction of a radical reorganization of production and consumption models in favour of greater decentralization and conviviality (Illich, 1973) in the case of solar energy and other renewable energies. A transition cannot be limited to technical corrections to the current economic and social model but will rather be similarly fundamental as the Neolithic and Industrial revolutions. It requires a third Great Transformation.

The 'Gospel of Eco-Efficiency': Good, but Not Good Enough

Our Common Future, the report of the Brundtland Commission (WCED, 1987), might partly have achieved its great success because it pointed the way out of a communicative deadlock. The ecologically motivated critique of growth contained in the report for the Club of Rome entitled *The Limits to Growth* (Meadows *et al*., 1972) proved too indigestible for the public, and even more so for the established political system. It was even too much for the sponsors of the report themselves, Aurelio Peccei and Alexander King, who had launched the Club of Rome in 1968. King remembered that after reading an advance copy of *The Limits to Growth* Sicco Mansholt sent an open letter to the President of the European Economic Commission, explaining that economic growth had to be abandoned as a central economic goal (King, 2006, p. 336): 'Aurelio and I realised we had to react to the Mansholt letter. One thing we agreed was that the Club of Rome must not be linked to zero growth…' (see Winiwarter, 2006).

A world without economic growth was – and is – inconceivable for all but a tiny minority living in industrial societies and was and is not acceptable for the political and industrial elite. The central thesis of the Brundtland Commission brought a new quality to the environmental discourse and continues to shape sustainability discussions today: economic and social development (mostly equated with economic growth) was postulated to be compatible with the preservation of the essential ecological conditions of human existence. Eco-efficiency is the key here, which is also known as 'decoupling'. This refers to the aim of organizing economic growth in such a way as to make it environmentally friendlier, by decoupling economic growth from the growth in the use of resources and sink capacity. The level of monetary value produced – no other aspect defines gross domestic product (GDP), increases of which are currently the dominant indicator for economic growth – is allowed to continue growing because this GDP growth can be made ecologically compatible through increased resource productivity. Improvement in eco-efficiency – measured e.g. in terms of material flow or energy flow per unit of GDP – thus becomes a standard element of practically all strategic plans for sustainable development, the 'gospel of eco-efficiency', as its critics have started to call it (Martinez-Alier, 2002).

There is of course no reason not to pursue eco-efficiency. It is both sensible and necessary to seek ways of living, eating habits and transport patterns that cause minimal ecological damage. It has now become possible, even under the climatic conditions of Central Europe, to design dwellings in such a way that they offer a comfortable room temperature and air quality throughout the year, without requiring any active heating or cooling system. Zero energy houses have now become not only technically feasible, but also economically affordable, or are approaching this status. There is no question that it makes sense to advance such technologies, since they offer benefits in social, economic and ecological terms.

Unfortunately, there is little to suggest that improvements in eco-efficiency will be enough to produce lasting reductions in energy and materials use in absolute terms, that is, to achieve 'absolute dematerialization'. Figure 2 shows that global energy consumption per dollar GDP in the last 70 years has continually decreased, both in the industrialized and in the developing countries. The only exception – and not a desirable example – is the case of the former planned economies of Eastern Europe and the former Soviet Union. Nonetheless, energy consumption in absolute terms continues to grow. As the above-mentioned scenarios demonstrate, it would also increase massively even if it were possible to stabilize the resource use of industrialized countries. In other words, a 'relative dematerialization' has accompanied us throughout our industrialization process, and can perhaps be somewhat fostered through eco-efficiency policies, but it seems unrealistic to assume that eco-efficiency could achieve the reduction in resource use by industrialized countries per capita and per year that sustainable development requires.

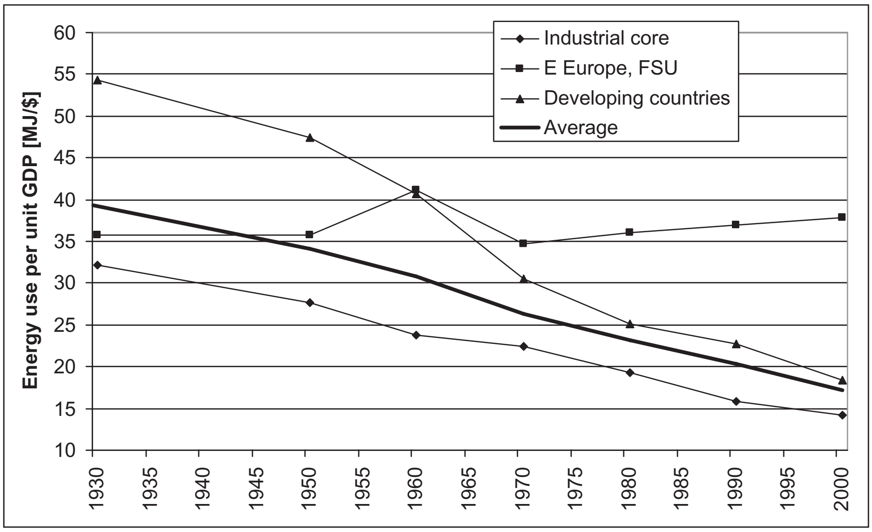

Figure 2. Total energy use per unit of gross domestic product (GDP), the latter measured using constant Geary-Khamis Dollars of 1990 (Maddison, 2001). Data source: Haberl *et al.*, 2006a

Different interpretations have been provided for these findings, which have also received confirmation on the national level (Ayres *et al.*, submitted; Eurostat, 2002; Gales *et al.*, 2007; Weisz *et al.*, 2006). One extreme is the belief that the growth of resource use would have been significantly higher without the efficiency improvements that have undoubtedly been made. This suggests that efficiency improvements make it possible to reduce the rate at which resource use is increasing, given a certain rate of GDP growth. This view is countered mainly by those economists who have pointed out that achieving greater efficiency in provision of services might lead to increases in demand for such services. The reason for this lies with the so-called 'rebound' effect, also known as 'Jevons' Paradox'. As early as 1865, W. S. Jevons wrote in his book *The Coal Question* that an improvement in the efficiency of steam-powered machines would produce an increase instead of a reduction in coal consumption (cited after Martinez-Alier, 1987). Jevons explained that improvements in efficiency would lead to lower costs and thus to increased demand. Many factors play a part in determining just how great a proportion of the efficiency benefit is equalized by this effect (see, e.g., Dimitropoulos, 2007; Herring and Roy, 2007; Schipper, 2000; Sorrell, 2007).

Another perspective is offered by newer, unorthodox approaches in growth theory. If one assumes that economic growth is dependent not only on the classical production factors of labour and capital but also on energy inputs or, more precisely, on the physical work that can be gained from using primary energy, then it is possible to provide excellent statistical explanations for historical economic growth, with no need to use the so-called Solow residual to exogenously account for technological change (Ayres *et al.*, 2003; Ayres, 2008). At the same time, the interpretation of the significance of efficiency improvements changes: they appear as a driving force of economic growth, not as a means to reduce resource use (Ayres and van den Bergh, 2005). Economic growth hence is not independent from the efficiency of resource use – increasing efficiency is more likely to stimulate economic growth. Efficiency is good, but not good enough. Encouraging eco-efficiency is not enough to usher in sustainable development, although it is an indispensable element of efforts to this end.

Looking Beyond 'Too Poor to Be Green': a Third Transition Required

A lead article published in October 1999 in the influential British political and economic magazine *The Economist* expressed the hopes of all those who have placed their faith in the currently dominant development model of the

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current era: 'All this makes it doubly important to explain why trade generally benefits the environment. The reason is that it boosts economic growth. As people get richer, they want a cleaner environment – and they acquire the means to pay for it' (The Economist, 1999, p. 17). Scientific support for this theory was provided in the hypothesis of the so-called 'environmental Kuznets curves', abbreviated as EKCs. This approach is named after Simon S. Kuznets, who won the Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel in 1971. Kuznets noted that income distribution was unequal at early stages of economic growth, and then became more equal – at that time the Scandinavian countries had the highest per capita incomes. So, his theory was that growth first increases inequality, but would decrease it at a later stage of development. Kuznets himself did not focus on environmental questions, so he is not responsible for the EKCs. His ideas were later adapted by environmental economists. According to them, growth in the early stages of industrialization is dirty, but with the increase of per capita income the preference for a clean environment leads to increasing use of environmentally friendly technologies, thus reducing damage to the environment (see, e.g., Stern, 2001). If this were true, there would be no contradiction between economic growth and sustaining the essential ecological conditions for human life, on the contrary: the poor would simply be too poor to care about the environment ('too poor to be green'). Indeed, what would be needed is a higher rate of economic growth. The environmental problems of today would resolve themselves economically.

The empirical evidence, however, yields a different picture. It is possible to find some environmental indicators that fit the inverse U-shape of the EKCs, such as SO_2 emissions or water pollution through faecal matter – both problems that can be largely solved by 'end of pipe' technologies. Yet in the case of sustainability problems related to the massive use of limited natural resources such as fossil energy, the discharge of greenhouse gases or the increasing damage to vital ecosystem services no relationship that corresponds to this model can be found (Fischer-Kowalski and Amann, 2001; Seppälä *et al.*, 2001; Tisdell, 2001). Moreover, international surveys have so far failed to corroborate the hypothesis that environmental concern would increase with rising income (Dunlap and Mertig, 1996; Dunlap and York, 2008). This is in line with authors who criticize the notion of sustainable development as a 'construct of Western hegemony' (Morse, 2008, p. 341) that would basically result in a slightly modified continuation of current trends in the industrial core and voice the need for a new model of post-sustainable development that includes an explicit consideration of power relations, public participation and scepticism towards expert knowledge.

The social historian Ramachandra Guha and one of the authors (Guha and Martinez-Alier, 1997) introduced the notion of an 'environmentalism of the poor'. They held that the livelihoods of people who live in subsistence economies directly depend on ecosystem services. Thus, the degradation of ecosystems poses a far more immediate threat to them than it does to people living in industrial societies (Martinez-Alier, 2002). Many examples show that the ecological conditions of marginalized people – often in developing countries – are endangered by the extraction of raw materials to supply the apparently clean, eco-efficient city dwellers of the industrial regions and countries. Hence the many movements of resistance to dispossession, of which the best known are perhaps the Chipko movement in Kumaun and Garwhal in India in the 1970s, the Chico Mendes movement of the rubber tappers in Acre, Brazil, in the 1980s and the struggle against oil companies by the Ogoni and the Ijaw in the Niger Delta, who, after Ken Saro-Wiwa's death in 1995, continue to fight to this day. There are thousands of similar movements around the world (Martinez-Alier, 2002). Such movements sometimes succeed in increasing their socio-ecological resource potential for the future, thus representing encouraging local-level examples for strong sustainability (Devkota, 2005).

As these examples show, sustainability, understood as an exchange between natural systems and society, which, as society taps solely into flows, can potentially be kept up indefinitely (save natural changes), is impossible under socially and economically unsustainable conditions. But what would such a system look like? As the anthropologist Robert McC Netting has argued, four attributes characterize sustainable agro-ecosystems (Netting, 1993, pp. 136f). (1) Relatively stable production per unit of land, no declining yields and a system that is resilient to short-term or seasonal perturbations. (2) Predictable and relatively stable inputs of energy. (3) Economically favourable rates of return between inputs and outputs, both in energy and in monetary terms as well as a diversity of crops and agricultural operations, which limits risk and strengthens stability. (4) Returns to labour and other energy inputs that are sufficient to provide an acceptable livelihood to the producers. Sufficient income also includes sufficient savings to meet contingencies and to be able to make the investments required to maintain

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long-term productivity. Netting argues that, in addition to the resource demands, the economic demands of the producers need to be met in order to make a system sustainable. This is a valid observation. It should not lead to the wrong conclusion that economic stability is necessarily coupled with ecological sustainability. Moreover, social unrest, often coupled with extreme economic inequality, or with unstable political circumstances (e.g. warfare), is not consistent with sustainability. Economic, social and ecological aspects of sustainability cannot be separated from one another.

In other words, another development model is needed. From today's perspective, it is extremely hard to say what this third transition should look like. It is probably as difficult for us to imagine a sustainable society as it was for people in the 16th century to imagine the industrial society of today. Socio-ecological tax reforms that can reduce the burden on labour use and increase the burden on resource use would most probably constitute an effective strategy to stimulate developments in this direction, not only for their immediately positive environmental impact through resultant price changes but also because they would send a strong communicative signal steering creativity and innovations in another direction.

The way in which we spend human lifetime is another element of possible strategies towards sustainability that is (still) overlooked today. Greater quality of life at the cost of lower material consumption could possibly be achieved through a reduction in working lifetime – an area of human life upon which political intervention can have an impact (Schor, 1993, 2005). Finally, it is necessary to reflect upon societal institutions. The institutions of industrialized societies are nowadays based upon the concept of economic growth – without growth, industrialized societies fall into crisis (Vatn, 2005). Yet institutions are capable of change, however slowly this change may progress. Even if this is perhaps a vague hope – and certainly also a perspective that calls for a significant degree of radicalism in rethinking current social relations and the transformation they require – institutional change is a necessary part of the transition. Earth system governance research has helped to outline the challenges and the likely benefits that might be derived from such institutional change (Biermann, 2007).

Twenty years after the proclamation of 'sustainable development' (often understood as economic growth that would be ecologically sustainable), there are signs of a new doctrine or at least a new slogan in the rich countries, 'sustainable de-growth', meaning economic de-growth that would be socially sustainable (Latouche, 2007). This term, *décroissance*, was introduced by Jacques Grinevald and Ivo Rens in 1979 as the title of a collection of Georgescu-Roegen's writings (Georgescu-Roegen, 1979) with the approval of the author of *The Entropy Law and the Economic Process* (Georgescu-Roegen, 1971). 'De-growth' needs to be operationalized. It is similar to our notion of a third transition in the socio-ecological regime of industrial economies, which we base on empirical data on global resource use (material and energy flows, land use). The first international conference on de-growth took place in Paris in April 2008. It clearly stated that economic de-growth, a voluntary reduction of capacities to exploit resources, could actually open a path for sustainability and equity. The economic crisis has given a new resonance to the conference, as the growth paradigm is questioned more and more. The proceedings of the conference are available on the web (http://events.it-sudparis.eu/degrowthconference/en/), and a publication taking into account the recent events is forthcoming (Schneider *et al.*, 2009).

We are convinced, and have provided ample empirical evidence from a long-term perspective (see Fischer-Kowalski and Haberl, 2007; Krausmann *et al.*, 2008a; Sieferle *et al.*, 2006), that fundamental and not only gradual changes in our interaction with natural systems are necessary for human survival. Social metabolism, that is, the amount of energy and matter used, has to decrease markedly, and land use has to be re-organized into a net energy producing system. While we have no clear vision of the make-up of the resulting society, we can infer from historical data how fundamentally different from the present pattern it would have to be as result of the third Great Transformation.

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