# Interdisciplinary perspectives on soil protection in a sustainability context: Using the material and energy flow (MEFA) approach in studying land use

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# Interdisziplinäre Perspektiven zum Bodenschutz im Nachhaltigkeitskontext: Der Nutzen des MEFA-Ansatzes (Material und Energieflussanalyse) für die Landnutzungsforschung

## 1 Sustainability as a problem of interaction between society and nature

In recent years a consensus seems to have emerged to regard sustainability as a problem of society-nature interaction. A "new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society" (KATES et al., 2001). The challenge this concept poses is that it requires interdisciplinary cooperation of scientists from various disciplines across the social/natural sciences divide. On the other hand, conceptualising sustainability as a problem of society-nature interaction offers a new perspective beyond the simplistic idea that sustainability can be achieved by adding a third, "environmental" dimension to the classical policy goals of improving economic performance and social well-being. Such a perspective is indispensable for the integrated analysis of sustainability problems, and thus a prerequisite for the search of solutions that might eventually succeed in reconciling economic, social, and environmental goals.

If sustainability is a problem of society-nature interaction, then observing progress towards sustainability requires us to observe societies, natural systems, and their interaction over time and to ask the following questions: (1) Which changes do socioeconomic activities cause in natural systems? (2) Which socioeconomic forces drive these changes, and what can we do to change them? (3) How do changes in natural systems impact on society? (4) How, if at all, can society cope with the changes it has set in motion? (HABERL et al., 2004).

There is ample evidence that natural systems undergo pervasive changes naturally. Global average temperature,

**Zusammenfassung**

Die Produktions- und Konsummuster in den Industrieländern sind instabil und können nicht weltweit verallgemeinert werden. Ein Übergang zur Nachhaltigkeit wird Veränderungen erfordern, die in ihren Auswirkungen mit der industriellen Revolution vergleichbar sind, also mit dem Übergang von der Agrargesellschaft zur Industriegesellschaft. Nachhaltigkeit ist ein Attribut sozial-ökologischer Systeme, d. h. von Systemen, die durch die Wechselwirkungen zwischen sozio-ökonomischen und ökologischen Prozessen entstehen. Nachhaltigkeitsforschung erfordert daher inter- und transdisziplinäre Kooperationen und muss Lücken schließen zwischen Disziplinen, zwischen der lokalen und der globalen Ebene und zwischen der Integration von Nutzerinteressen und wissenschaftlicher Exzellenz. Dieser Aufsatz diskutiert die Nützlichkeit des Material- und Energieflusskonzepts zur Analyse des „gesellschaftlichen Stoffwechsels" und der „Kolonisierung von terrestrischen Ökosystemen" (z. B. Landnutzung) als ein Ansatz zum Schließen der Lücke zwischen Wirtschafts- und Sozialwissenschaften und Naturwissenschaften wie etwa der Bodenforschung. Am Beispiel Österreich 1830–2000 zeigt der Artikel auf, wie Veränderungen in der Ressourcennutzung und der Technologie fundamentale Veränderungen in der Landnutzung und damit der Beeinflussung von Böden hervorrufen.

**Schlagworte:** Bodenforschung, Gesellschaftlicher Stoffwechsel, Kolonisierung von Natur, Landnutzung, Nachhaltigkeit.

## Summary

The pattern of production and consumption in industrial societies is unstable and cannot be generalised across the whole world. A transition towards sustainability will require changes of a proportion similar to the industrial revolution, i. e. the transition from agrarian society to the present pattern. Sustainability is here conceptualised as an attribute of socio-ecological systems, i. e. of systems that emerge through the interaction of socioeconomic and ecological processes. Sustainability science thus requires inter- and transdisciplinary cooperation and, therefore, needs approaches that bridge the gaps between disciplines, between local and global scales, and between integration of user needs and scientific excellence. The paper discusses the potential usefulness of the material and energy flow (MEFA) approach to quantify socioeconomic metabolism and the colonization of nature (e. g., land use), thus helping to bridge gaps between social sciences, including economics, and natural sciences, such as soil science. Using Austria 1830–2000 as an example it demonstrates how changes in resource utilization and technology resulted in fundamental changes in land use and thus of impacts on soil.


**Key words:** Colonization of nature, land use, socioeconomic metabolism, soil science, sustainability.

precipitation patterns, sea level, atmospheric chemistry and biodiversity have fluctuated drastically, driven by both endogenous (e. g., geological or biotic processes) and exogenous (e. g., meteorite impacts) phenomena (SCHELLNHUBER, 1999; SCHLESINGER, 1997). Natural systems may thus be seen as self-organizing dynamic systems which may be near equilibrium for limited periods, but may as well undergo rapid transitions between different equilibria (HOLLING, 1986; SCHEFFER et al., 2001). The term 'punctuated equilibrium' also seeks to describe stability domains between which rapid change is experienced. It is thus hardly arguable that sustainability should require the maintenance of an equilibrium as such over long time spans.

Sustainability has been defined as meeting the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987). The sustainability discourse stresses the need for a more equitable distribution of resources between regions and within nations (UNEP, 2002), and refers to "creating and maintaining our options for prosperous social and economic development" (FOLKE et al., 2002). Sustainability is an anthropocentric notion: human-induced changes in ecosystems must not threaten the exchange processes between society and its natural environment in ways that affect society's survival or well-being. Observing sustainability, therefore, must include the analysis of society's behaviour towards its natural environment on many spatial and temporal scales.

If equilibrium is an unattainable goal, what else could sustainability mean? Some stress the need to "expect the unexpected" (HOLLING, 1986) and improve society's ability to cope with uncertainty and surprise, defined as a situation in which perceived reality departs qualitatively from expectation (BERKES and FOLKE, 1998). This has led to a definition of sustainability as "the capacity to create, test, and maintain adaptive capability" (HOLLING, 2001) or, in other words, as the resilience of social-ecological systems (CARPENTER et al., 2001).

If we accept the sustainability criterion that societies, in order to be sustainable, should live "within the regenerative capacity of the biosphere" (WACKERNAGEL et al., 2002), then it becomes obvious that a transition towards sustainability requires not just minor changes in current trends, but a radical reorientation of our current trajectory (Figure 1). Even in the current situation where only about one fourth or maybe one third of humanity lives in relative prosperity, humanity consumes each year an amount of natural resources for the regeneration of which the biosphere would need at least 1.2 years (WACKERNAGEL et al., 2002). Expected growth in energy and food consumption would considerably increase the rate of human resource consumption. For example, according to a projection by the "World Energy Council," global fossil fuel consumption may increase until 2050 by around 65% over the amount consumed in the year 2000, i. e. from around 348 EJ/yr to 575 EJ/yr (WEC, 1999).

In addition, expected growth of world population, maybe in combination with diets richer in animal protein and increased use of biomass for energy provision, may result in considerable increases in humanity's consumption of biomass. World population might be around 8 billion in 2030 and between 7 and 11 billion in 2050 (LUTZ et al., 2004). Many energy scenarios also predict strong increases in the amount of biomass used for energy provision. For example, according to the World Energy Assessment (TURKENBURG,

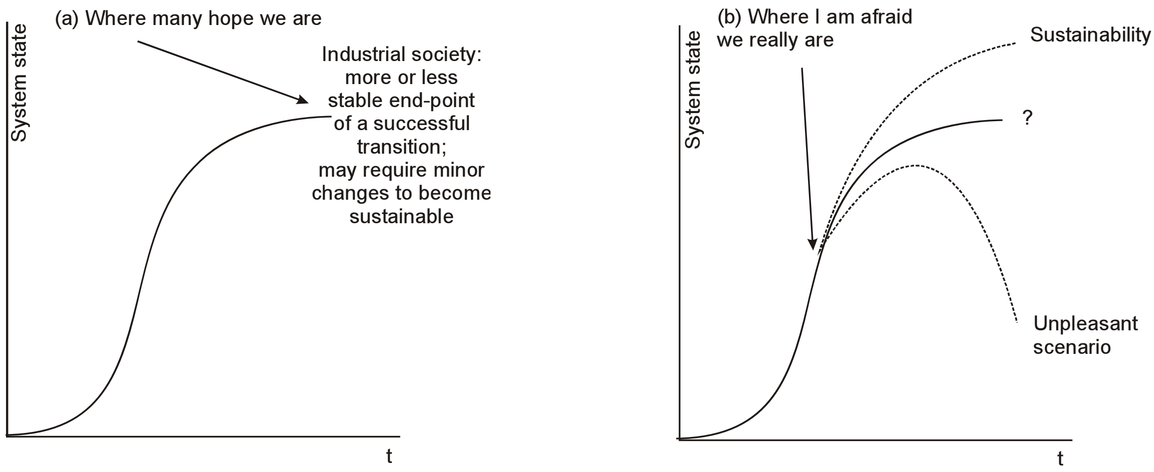


Figure 1: Sustainability: achievable through "minor technical amendments" to the current state (a), or requiring major changes in current trends (b). While many may hope that industrial society is the more or less stable end-point of a successful transition (left graph), I tend to believe that we are still in a rapid transition which might eventually lead to sustainability, if current trajectories can be changed, but might also lead to much more unpleasant scenarios (right graph).

Abbildung 1: Nachhaltigkeit als (a) erreichbar durch kleinere technische Veränderungen im Vergleich zum bestehenden Zustand bzw. als (b) ein Ziel, das nur durch fundamentale Veränderungen erreichbar ist. Während viele zu glauben scheinen, dass die Industriegesellschaft einen mehr oder weniger stabilen Endpunkt eines Übergangsprozesses darstellt (linke Grafik), tendiere ich zu der in der rechten Grafik skizzierten Sichtweise, wonach wir immer noch in einem raschen Übergangsprozess begriffen sind, der möglicherweise in Richtung Nachhaltigkeit umgelenkt werden kann, wenn gegenwärtige Trends verändert werden, der aber auch zu äußerst unerfreulichen Entwicklungen führen kann.

2000), global use of biomass for technical energy generation may more than double over its present value of about 45 EJ/yr to something between 94–280 EJ/yr. The "ecological footprint" of such scenarios is at present unknown (for agriculture see TILMAN et al., 2001), but it seems clear that such a scenario would put heavy pressures on soils and that it will be difficult, if not impossible, to reconcile such increases in resource use with the goal of living "within the regenerative capacity of the biosphere".

## 2 Conceptualizing society-nature interaction

(Un)sustainability is an attribute of a "social-ecological system". Such systems emerge through the interaction of a society with its natural environment. Some have defined social-ecological system as an ecosystem "that does explicitly include humans or, more specifically, the *social system*" (BERKES and FOLKE, 1998). This formulation could be misleading, however, because even though society may be a subsystem of the ecosystem in a biophysical sense, it is also characterized by emergent properties such as culture or communication that can not be fully understood by analysing biophysical patterns or processes (FISCHER-KOWALSKI and WEISZ, 1999). It is thus more useful to "look upon society as a hybrid of the realm of culture, of meaning, of communication, and of the natural world. In our understanding, society comprises a cultural system, as a system of recurrent self-referential communication, and material components, namely, a certain human population as well as a physical infrastructure such as buildings, machines, artefacts in use, and animal livestock," which in their entirety can be denoted as "biophysical structures of society" (WEISZ et al., 2001).

Socio-ecological systems can thus be defined, as shown in Figure 2, as comprising a "natural" or "biophysical" sphere of causation governed by natural laws, and a "cultural" or "symbolic" sphere of causation reproduced by symbolic communication. These two spheres overlap, constituting what is here termed "biophysical structures of society". According to this concept, (un)sustainability refers to the interaction process between nature and culture which can only proceed indirectly, via the biophysical structures of society.

If one accepts these basic ideas on how society-nature interaction works, one useful strategy towards its analysis can then be to focus on material and energy flows between society and nature. In their entirety, these flows have been termed "socioeconomic metabolism" (ADRIAANSE et al., 1997; AYRES and SIMONIS, 1994; FISCHER-KOWALSKI et al.,

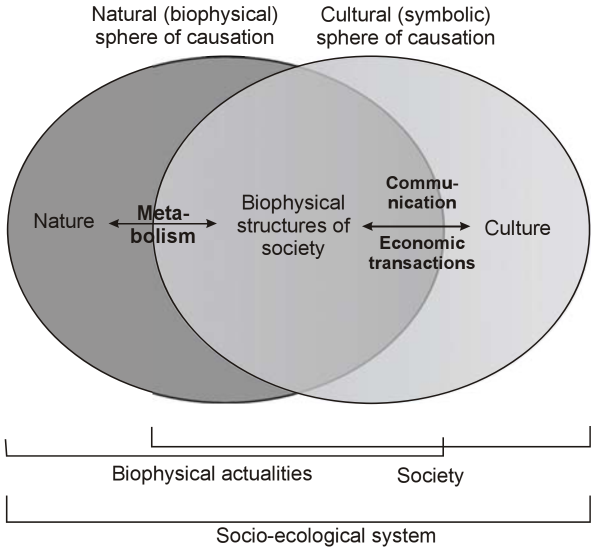


Figure 2: Socio-ecological systems and society-nature interaction: a conceptual framework (based on work by BOYDEN, 1992; SIEFERLE, 1997; FISCHER-KOWALSKI and WEISZ, 1999; HABERL et al., 2004).

Abbildung 2: Sozial-ökologische Systeme und Gesellschaft-Natur-Interaktion: ein konzeptueller Rahmen, basierend auf Arbeiten von BOYDEN, 1992; SIEFERLE, 1997; FISCHER-KOWALSKI and WEISZ, 1999; HABERL et al., 2004.

1997; FISCHER-KOWALSKI and HABERL, 1997; MATTHEWS et al., 2000). This metabolism approach regards society as a physical input-output system drawing material and energy from its environment, maintaining internal physical processes and dissipating wastes, emissions and low-quality energy to the environment. With respect to sustainable development these physical aspects of society are highly important. The analysis of socioeconomic metabolism also has important advantages over the widespread conception among ecologists of "humans causing disturbances in ecosystems", because it allows us to conceptualize society-nature interrelation as a historical process of the interaction between two complex, autopoietic systems, a point of view that offers good starting points for interdisciplinary cooperation of natural and social scientists in sustainability research (FISCHER-KOWALSKI et al., 1997).

Current work on material and energy flows (MEFA) organizes its accounts in a way that is compatible with established tools for societal self-observation, above all, social and economic statistics upon which practically all modeling in economics and the social sciences is based. These tools facilitate the analysis of mutual relations between symbolic (e. g., money flows) and biophysical aspects (e. g., material flows) of society. By means of this "double compatibility" – towards ecological and socioeconomical models and data – the socioeconomic metabolism approach can establish a link between socioeconomic variables and biophysical patterns and processes.

The analysis of material and energy flows related to economic activities, although indispensable to "reintegrate the natural sciences with economics" (HALL et al., 2001), does not capture society-nature interactions in their entirety. One important aspect not adequately grasped by the metabolism approach is land use – one of the most important socioeconomic driving forces of Global Change (MEYER and TURNER, 1994; VITOUSEK, 1992). Land use can be conceptualised as "colonization of nature" (FISCHER-KOWALSKI and HABERL, 1998; HABERL, 1998; HABERL et al., 2001; KRAUSMANN et al., 2003a). An approach to the empirical analysis of the intensity of colonizing interventions is to compare ecosystem patterns and processes observable today with ecosystem patterns and processes that would be expected without human intervention. An example of this approach is the calculation of the "human appropriation of net primary production," or HANPP (VITOUSEK et al., 1986) which is defined as the difference between NPP of potential (i. e. hypothetical, non human-modified) vegetation with the amount of NPP remaining in currently prevailing ecosystems after harvest, i. e. the amount of trophic energy diverted by humans from ecosystems (HABERL, 1997; VITOUSEK et al., 1986).

The notion of a "MEFA framework" has been proposed (HABERL et al., 2004; KRAUSMANN et al., 2004) to describe an integrated, consistent accounting framework consisting of data on socioeconomic metabolism and on the colonization of nature. Three parts of the MEFA framework have been proposed in considerable detail: (1) Material flow accounting (MFA) has received most attention (e. g., EUROSTAT, 2001; EUROSTAT, 2002; MATTHEWS et al., 2000). (2) Energy flow accounting (EFA) methods consistent with MFA have been proposed and applied (HABERL, 2001a; HABERL, 2001b; KRAUSMANN and HABERL, 2002). (3) The Human Appropriation of Net Primary Production, or HANPP, proposed almost 20 years ago (VITOUSEK et al., 1986), has been further developed in a way that makes it consistent with material and energy flow accounting (HABERL et al., 2001). The MEFA framework is not necessarily complete with these concepts. For example, expressing socioeconomic metabolism not in terms of materials, but as carbon flow, would increase its usefulness for some applications (e. g., for climate issues), as would other, yet undeveloped accounting tools.

The MEFA framework is useful to analyze how we depend on, and use the following three core functions of ecosystems for humans (DUNLAP and CATTON, 2002), all of which strongly depend on soils:

1. "Resource supply": Land serves as a source of inputs for socioeconomic metabolism. It provides renewable and non-renewable resources (e. g., air, water, biomass, fossil fuels, minerals). By definition, stocks of non-renewable are depleted when the resources are extracted. But overuse of ecosystems in order to obtain renewable resources (biomass) may also result in their degradation. In this respect biomass has a special role, because its production depends on NPP which implies that about $10^2$–$10^4$ times more area is needed per unit of material or energy gained than for most non-renewable resources (HABERL and SCHANDL, 1999).
2. "Waste absorption": The biosphere absorbs socioeconomic outputs such as wastes or emissions. While emissions may not require much area directly, absorption of wastes or pollutant does. For example, the area dedicated to absorbing carbon through afforestation could help to stabilize concentrations of atmospheric $CO_2$.
3. "Occupied space for human infrastructure": Humans occupy areas for housing, work space, infrastructure (including transportation), recreation, education, and many other culturally important human activities.

How well ecosystems perform these functions largely depends on their productivity. It is obvious that agriculture and forestry depend on the NPP of agro-ecosystems which is the combined outcome of natural preconditions and present (as well as past) human management. But the "waste absorption" function also may depend on primary production. For example, carbon absorption rates of forests depend on their productivity. While the "infrastructure space" function need not be dependent on ecosystem productivity, relatively few human settlements are situated in unproductive environments because humans predominantly live in areas where environmental conditions like climate and water availability favor human activities. These areas are typically highly productive.

## 3 The agrarian-industrial transition

Given that we may be as far away from sustainability as agrarian societies were from our current industrial patterns, it may be interesting to analyze the changes involved in industrialization with regard to the indicators included in the MEFA framework. As an example, I will use Austria 1830–2000, based on published data (e. g., KRAUSMANN, 2001; KRAUSMANN and HABERL, 2002). Data refer to Austria approximately within its current borders, except the (relatively small) province of Burgenland. For details see KRAUSMANN (2001).

To show how socioeconomic metabolism changes during transitions from agrarian to industrial society, I discuss changes in Austrian energy use (Figure 3). Complementary to conventional energy balances, which only include energy used in technical installations (furnaces, motors, steam engines, etc.), these data also encompass all human-induced biomass flows, including those required to feed humans and livestock.

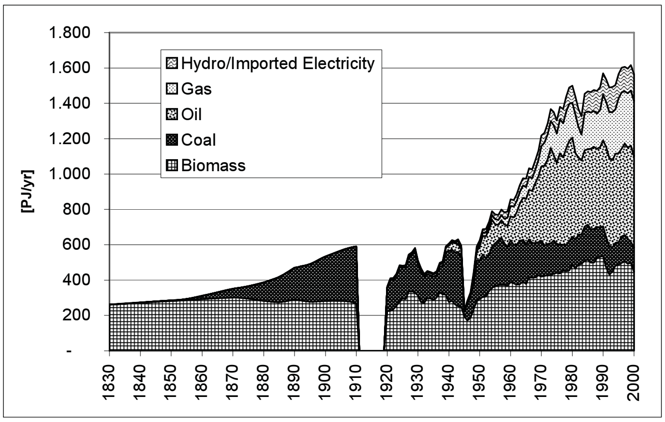


Figure 3: Austria's "energetic metabolism" (domestic energy consumption) from 1830–2000. Contrary to conventional energy balances, these energy flow accounts also include all socio-economic biomass flows, among them those required to feed humans and domesticated animals. Source: KRAUSMANN et al., 2003b.

Abbildung 3: Österreichs „energetischer Stoffwechsel" (inländischer Energieeinsatz) von 1830–2000. Im Unterschied zu konventionellen Energiebilanzen enthält diese Grafik auch alle gesellschaftlichen Biomasseflüsse, darunter jene, die notwendig sind, um Menschen und Nutztiere zu ernähren. Quelle: KRAUSMANN et al., 2003b.

As Figure 3 shows, Austria's overall domestic energy consumption (DEC) increased by a factor of 6.0 from 1830 to 2000. As Austria's population grew in this period from about 3.6 to 8 million, per-capita DEC rose considerably less, i. e. by a factor of 2.7. Most of the increase in DEC was made possible by the increased use of fossil fuels. The mix of fossil fuels used was similar to the general pattern in most industrial countries: In a first phase industrialization was powered by coal which substituted wood. The use of oil began gradually around 1900 and increased quickly after

World War II. Natural gas – the large-scale use of which requires a widespread grid of pipelines – started to gain considerable importance after the 1970s.

Hydropower development had already begun in the early 20$^{th}$ century. At present about two thirds of Austria's techno-economically feasible hydropower potential are used, contributing some 65–70 % to Austria's electricity generation or about 13 % of Austria's technical primary energy consumption. Note, however, that hydropower is more important for Austria's energy system than this modest figure suggests: Producing the same amount of electricity in fossil-fuel fired power plants – which are considerably less efficient than hydropower plants for thermodynamic reasons – would require 2–3 times more primary energy (coal, oil or gas) than the amount of hydropower used.

Total biomass consumption increased by a factor of 1.7 from 1830 to 2000, while per-capita biomass DEC decreased by about one quarter. Whereas biomass consumption remained more or less constant (per-capita use declined significantly) until 1950, it rose again considerably after World War II, but did not reach the 1830 value again. This increase in socioeconomic biomass flows was achieved through agricultural intensification. Areas used for agriculture declined considerably, whereas forests increased by about one quarter since 1830.

Overall commercial yields (e. g., grain harvests per hectare) increased by factors between 5–8 during this period, depending on cultivars used. This increase was partly a result of a rise in the aboveground NPP of agro-ecosystems, brought about by increased fertilization, irrigation, and other new, fossil-fuel dependent agricultural technologies. In addition, harvest indices i. e., the percentage of standing biomass at the time of harvest (of cereals and other cultivars) could be raised considerably through plant breeding. For example, the commercially useful product (i. e. grain) accounts for around 50 %, if not more, of total aboveground biomass for most "modern" cereal varieties (KRAUSMANN, 2001).

Industrialization of agriculture had a plethora of effects (see KRAUSMANN et al., 2003a, KRAUSMANN, 2004 for more details):

- It allowed for considerably increased harvests on smaller areas. Agriculture retreated from marginal areas; both cropland (-20 %) and permanent grassland (-34 %) areas contracted considerably. Even though urban and infrastructure areas grew by a factor around 5, forests increased by about 22 % from 1830–2000.
- Both the increase in forest areas, and the increases in the productivity of agro-ecosystems brought about by fertilization and intensification in general, resulted in a considerable increase in aboveground NPP. As a result, the "human appropriation of NPP" (HANPP) fell from around 60 % in 1830 to around 50 % in 1995, despite a significant (+ 70 %) increase in harvests (KRAUSMANN, 2001).
- In addition, as fossil fuels replaced firewood for many industrial purposes, and grazing of livestock in forests could be abandoned due to the availability of mineral fertilizer, forests recovered and wood harvests were considerably lower than wood increments. This together with the increases in forest areas resulted in the emergence of a considerable carbon sink in Austria's vegetation (ERB, 2004). As this phenomenon entirely depends on the fossil-fuel based industrialization of agriculture, and the transition to a fossil-fuel based industrial energy system in general, it is justified to regard it as a "fossil-fuel powered carbon sink".
- The availability of mineral fertilizers and efficient, far-reaching means of transport (FISCHER-KOWALSKI et al., 2004) allowed a fundamental re-arrangement of spatial patterns in agriculture. In pre-industrial agriculture, livestock and cropland were inextricably linked. Even in mountainous regions, peasants cultivated crops for human nutrition, and even in the most fertile lowlands, a mixture of cropland, grassland and forests was required to guarantee a supply of fuelwood, fodder for animals, and food for humans. Under industrial conditions, however, cropland, grassland/livestock rearing and forestry tend to be spatially segregated along a gradient of soil fertility and usability (determined by slope), with the most fertile soils being used for intensive, mineral-fertilizer based cropland, regions with intermediate productivity specializing in livestock rearing, and the least fertile soils being devoted to forestry. This results in a fossil-fuel powered, large-scale distribution process of nutrients from factories to cropland, and from cropland to livestock-rearing regions (as fodder) where they are deposited in excessive amounts. A small amount of the nutrients is then transported to urban areas (in animal products), where it is consumed and ends up in sewage sludge (KRAUSMANN et al., 2003a).

## 4 Why bother about soils?

The above-discussed trends are obviously highly important for soils, as they define the socioeconomic framework within which socioeconomic utilization of soils, including its spatial patterns, takes place. Soil scientists are concerned about the maintenance of resilient, healthy soils (EEA, 2000). Important threats to soils have been identified in the EU Communication "Towards a Thematic Strategy of Soil Protection" (CEC, 2002) including erosion, contamination, loss of organic matter, loss of biodiversity, compaction and other physical deterioration, salinisation, floods and landslides, and sealing.

Although these threats have meanwhile been officially recognized, and impressive global and regional assessments of potential and actual soil degradation have been published (e. g., OLDEMAN et al., 1990), recognition of these problems seems to be hampered by the fact that global (and in most cases also national or regional) yields, and thus agricultural harvests, continue to rise, since the late 1980s even despite declining global inputs of N fertilizer (see Figure 4).

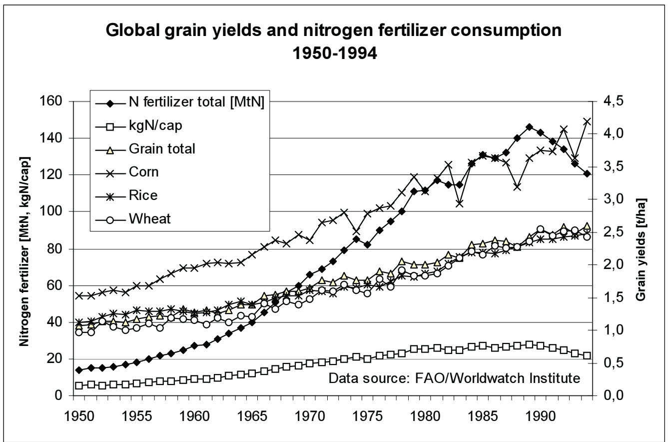


Figure 4: Global yields of many crops are continuing to rise, despite declining inputs of total and per-capita N fertilizer. Data sources: FAO, Worldwatch Institute.

Abbildung 4: Globale Erträge vieler Kulturarten steigen immer noch an, obwohl der Input an Stickstoffdünger sowohl pro Kopf als auch in absoluten Werten zurückgeht. Datenquelle: FAO, Worldwatch Institute.

Improving the understanding of policy makers and the general public of the importance of the imminent and serious threats of soil degradation will require explanation of the discrepancy between these current increases in yields (and future projections, see FAO, 2003; HARRIS and KENNEDY, 1999) and reportedly widespread soil degradation risks. Failing to clarify this seeming contradiction may result in poorly qualified, but highly influential public statements (e. g., LOMBORG, 2001).

## 5 Conclusions: Some thoughts on sustainability science

Envisaging sustainability as a problem of society-nature interaction, as suggested by the considerations outlined above (for more comprehensive discussions see HABERL et al., 2004; KRAUSMANN et al., 2004; WEISZ et al., 2001), suggests new directions of sustainability science. Above all, it reveals that the analysis of biophysical processes which are on the one hand subject to the laws of nature, on the other hand driven by socioeconomic activities can generate important concepts for bridging gaps between social and natural sciences. Two such concepts, socioeconomic metabolism and colonization of nature, have been elaborated above. Such concepts present crucial tools for novel, integrated analyses of sustainability.

Sustainability science has to deal with sufficiently long periods of time for realistic evaluation. If we recognize that sustainability will require a major reshaping of society-nature interaction, probably of similar proportion as the transition from agrarian to industrial society, then we have to focus on time spans of several hundred years. As a minimum, I would argue that we have to go back in time to the pre-fossil-fuel age. Among other things, sustainability science will therefore have to establish links to Long-Term Ecological Research (LTER). At present LTER is mostly focused on natural science research, which as such – although highly relevant to sustainability science – is shown to be insufficient. In order to be useful for sustainability science, LTER will have to be transformed into a new, interdisciplinary "long-term socio-ecological research" or LTSER that succeeds in integrating socioeconomic dimensions. Such an endeavor will require a major paradigm shift (REDMAN et al., 2004, HABERL et al., 2006) and will, among other things, also include a transition from a site-based research approach to a multi-scale approach which also recognizes interactions between sites as well as the regional, national or even global context in which an intensively researched place is situated. Of course, strengthening the interaction with environmental historians (e. g., MCNEILL and WINIWARTER, 2004), anthropologists and archaeologists (e. g., VAN DER LEEUW and REDMAN, 2004) will also be important in this respect.

A third conclusion is that soil scientists could greatly profit from strengthening their cooperation with scholars concerned with aboveground processes, above all with those concerned with land use and land cover change. For example, at least as far as I can judge, there seems to be relatively little interaction between the soil science community and the researchers organized around the LUCC (Land Use- and Cover-Change) project jointly hosted by IHDP (International Human Dimensions of Global Environmental Change Programme) and IGBP (International Geosphere-Biosphere Programme) as well as with the emerging Global Land Project hosted by the same two organizations (GLP, 2005). Moreover, improved cooperation with ecological economists could yield important insights, for example on ecosystem services provided by soils (COSTANZA et al., 1997; COSTANZA and FARBER, 2002).

A fourth issue worth mentioning seems to be that considerable advances in modeling are required. At present, most models used to forecast changes in natural (e. g., climate, vegetation) or socioeconomic (e. g., GDP growth) domains originate from single scientific disciplines. Even though more integrated models exist, e. g. the so-called E3 models (Energy-Economy-Environment models; e. g., BEAVER and HUNTINGTON, 1992; JACCARD et al., 2004) or integrated assessment models such as IMAGE (LEEMANS et al., 1996), they are still based on insufficient or unduly simplified ideas of the interaction processes between societies and their natural environment. For example, coupled ecological/economic models that could assess the combined impacts of global environmental change and changes in consumption on food, fibre, wood and bio-energy production, prices of these commodities, maintenance or endangerment of ecosystem services, resilience or biodiversity, soil quality and cycles of C, N, water, etc. could greatly help to shape more sustainable strategies for future supplies of food and energy. The development of such models would greatly help in determining, among others, research priorities that would inform policy-makers in 2010 (BLUM et al., 2004).

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