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The global socioeconomic energetic metabolism as a sustainability problem

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Abstract

This paper discusses sustainability problems related to socioeconomic energy flows based upon the societal metabolism approach. Contrary to conventional energy statistics that only include energy used in technical devices, this approach considers all kinds of energy flows related to human societies, including nutritional energy flows of humans and domesticated animals. Based upon human population data and data on the pro capite energy metabolism of hunter-gatherers and agricultural societies as well as on statistical data on industrial energy flows a time series of the global socioeconomic energetic metabolism for the last 10^6 years and a scenario for the next 50 years is derived. These estimates show that the total energy input of mankind has risen by several orders of magnitude since the Neolithic revolution about 10,000 years ago. Whereas the energy input of agricultural societies prior to the advent of industrial societies about 200–300 years ago did not exceed 5% of global terrestrial net primary productivity (NPP), humanity's energy input currently amounts to about 30% of global terrestrial NPP and is likely to surpass 50% in about 2050. This shows that the sheer magnitude of human-induced flows is historically unprecedented and poses at least two closely interrelated sustainability challenges: (1) a reduction of energy available to ecosystem processes that can be assessed using the concept of 'human appropriation of net primary productivity' and (2) the changes in the global carbon cycle resulting from land-use change and fossil-energy combustion.

1. Introduction

One idea behind the notion of a 'socioeconomic metabolism with nature' [1–5] is that describing human society as an ecosystem component is a useful approach toward analyzing society–nature

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interrelations [6,7]. Basically, the 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. Of course, it would not be valid to reduce the notion of society merely to a physical process, but with respect to sustainable development these physical aspects of society are of high importance.[1] The analysis of physical aspects of human society—e.g. socioeconomic metabolism—also has important advantages over the widespread conception among ecologists of 'humans causing disturbances in ecosystems', because it allows to conceptualize society–nature interrelation as a historical process of the interaction of two complex, autopoietic systems, a point of view that offers good starting points for interdisciplinary cooperation of natural and social scientists in sustainability research [1].

In recent years, there has been a surge of societal metabolism studies; that is, of studies that elaborate on physical exchange processes between societies and their natural environment. This approach can be traced back well into the 19th century (see recent reviews by Martinez-Alier [8] and Fischer-Kowalski [9]). Whereas earlier work focused mostly on energy flows [10–12], recent studies concentrate on material flows [3–5,13]. Meanwhile a vivid international scientific community has emerged that advances the methods and applications of material flow accounting (MFA). Despite the fact that, with respect to sustainable development, energy flows are probably at least as interesting as material flows, most current metabolism research concentrates on material flows [14].

This paper applies MFA standards established in recent years in a collaborative effort [5,13,15] to socioeconomic energy flows, based upon methods proposed in recent work [14,16]. Using these method, a time series of global socioeconomic energy metabolism is derived and the relevance of these results for sustainable development is discussed.

2. Methods for analyzing society's energetic metabolism

One reason for the lacking interest of the MFA community in energy flows might be that the energy use of industrial countries is regularly reported in energy statistics and energy balances. It has been an important goal of MFA research to develop methods for national material balances that can be included in standard environmental and economic reporting systems. This goal has, for example, been achieved in Austria [17] and Germany [18]. Eurostat, the Statistical Office of the EU, has recently developed a methodological guide for national material flow accounts [15] which it endorses for use by the national statistical offices of the EU countries in environmental statistics.

However, there are important methodological differences between national material balances and the energy balances published by national statistical offices or international bodies [19–21]. National material balances account for all materials crossing the boundary of the socioeconomic system under scrutiny, regardless whether the material is used as an energy carrier or as a raw material. The flow of biomass used for human nutrition or as fodder for live-stock is, therefore, included in material flow accounts—just like coal, oil and natural gas that flow through the economy under consideration [13]. In contrast, conventional energy balances and statistics only account for energy carriers used in technical energy conversions as, for example, combustion in furnaces, steam engines or

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[1] For a more elaborated discussion of these issues, see Fischer-Kowalski and Weisz [64].

internal combustion engines, production and use of electricity or district heat, etc. That is, energy statistics neglect, among others, biomass used as a raw material as well as all sorts of human or animal nutrition. These are very important energy conversions in hunter-gatherer and agricultural societies, but are still significant even in industrial society. If accounts of society's energy throughput—the 'energetic metabolism of society'—should be compatible with MFA, it is, therefore, necessary to go beyond the flows accounted for in energy statistics [22] and account for all inputs of energy, including all energy-rich materials [14,16]. Moreover, in order to be compatible with the methods often used in studies of the 'trophic–dynamic' aspect of ecosystem energetics, it is useful to convert all energy-rich materials into energy units on the basis of their gross calorific value (instead of using the net calorific value as most energy statistics do) [14].

In analogy to indicators commonly used in national material flow accounts [5], it is then possible to calculate, among others, indicators like the 'direct energy input' (DEI) and the 'domestic energy consumption' (DEC). DEI is defined as the sum of all energy entering the socioeconomic metabolism of the society under consideration; that is, DEI = domestic extraction of energy + energy imports. DEC = DEI − energy exports (see Ref. [14] for more detail). Using these concepts, it is possible to establish accounts of the energetic metabolism of industrial societies based upon conventional energy statistics, agricultural statistics, forestry statistics, and various other statistical sources.

Of course it could be rewarding to complement the analysis presented in this article using methods such as extended exergy accounting (EEA) [23], emergy analysis [24] or life-cycle analysis (LCA) [25]. Such analyses would, however, be much more demanding. For example, an EEA requires data on many inputs not considered here (materials, labor, etc.), and detailed information on all relevant energy conversion processes [23]. An emergy analysis would require a host of (sometimes questionable) assumptions on transformities. LCA could offer more detailed information on environmental impacts, but would require a lot of additional data. Moreover, LCA is usually used to evaluate the production process of products or technical systems; extending LCA to the level of whole socioeconomic systems results in difficult problems of double-counting and aggregation [26]. While it is acknowledged that these or other methods could result in additional insights, it is beyond the scope of this paper to actually carry out such analyses. Nevertheless, it will be shown that even the simple approach used here can yield relevant insights.

3. The global socioeconomic energy input in the last 10^6 years

Based upon differences in social organization, in society–nature interrelations and, above all, in their energy system it is possible to distinguish between three 'modes of subsistence', or different kinds of socioeconomic organization: (1) hunter-gatherers, (2) agricultural societies, and (3) industrial society [2,27–29].

Hunter-gatherer societies can be characterized as having an 'uncontrolled solar energy system' [29]: as energy source they use solely biomass, and they use it in much the same way as any other heterotrophic species: they extract resources from their environment without caring for their reproduction. According to an estimate by Boyden [30], the energy input of hunter-gatherers is in the order of magnitude of about 10 GJ/(cap.yr). The energy input of hunter-gatherers is limited by the amount of digestible or otherwise useful biomass that can be extracted from the environment.

Table 1
Biomass input and direct energy input of agricultural and industrial societies

	Biomass input [GJ/(cap.yr)]	Direct energy input [GJ/(cap.yr)]	'Non-biomass' fraction [%]
Trinket Island, Nicobars, India, 2000	31	39	20
Sang Saeng/NE Thailand, 1998	48	53	9
Törbel, Switzerland, 1875	65	65	n.a.
Austria, 1830	72	72	<1
Austria, 1927	53	85	38
Austria, 1950	55	124	56
Austria, 1995	76	219	65

Sources: Austrian data: [31]. Sang Saeng is a small village in northeast Thailand analyzed in a field study by Grünbühel [61] evaluated by the author [16]. Törbel refers to a Swiss alpine village investigated by Netting [62]; the author used Netting's data for energy flow calculations [2]. Trinket Island is part of the Nicobars, a group of islands between India and Indonesia that politically belongs to India and was analyzed by Singh [63]. The low biomass throughput of Trinket can be explained by the fact that in Trinket most animal protein is consumed as fish (i.e. the conversion from plant to animal biomass takes place outside society's boundary), whereas the importance of animal husbandry for human nutrition is low [63].

Agricultural societies, by contrast, actively manage—or 'colonize' [2]—ecological systems in a way that allows them to utilize a much higher percentage of the productivity of the regions they inhabit. They create agro-ecosystems in which a large part of the net primary productivity (NPP) can be used for human purposes, either as human food, as animal fodder, or for other socioeconomic uses (timber, firewood, etc.). Although agricultural societies use other kinds of energy than just biomass—for example, wind power for sailing boats or windmills, hydropower in mills, etc.—biomass is still the quantitatively dominating energy source of agricultural societies. Studies carried out in different regions and on different levels of aggregation suggest that the DEI of agricultural societies is in the order of magnitude of 40–80 GJ/(cap.yr) (Table 1).

The metabolism of industrial societies relies heavily on the use of fossil fuels and other area-independent sources of energy such as nuclear energy and hydropower. Even in countries with a high share of nuclear power in electricity generation the share of nuclear energy in total primary energy use is limited because electricity in most countries amounts to about only 20% of total final energy use. Hydropower and 'new renewable' energy sources (wind power, solar energy, etc.) usually account for only a small percentage of total primary energy use in industrial countries. Whereas biomass ceases to be an important energy carrier with respect to technical energy conversions—and is, therefore, only to a small part accounted for in conventional energy balances—industrial societies do not use less biomass energy than agricultural societies do. For example, Austria's biomass input in 1995 was nearly 80 GJ/(cap.yr). The fossil-energy consumption of most industrial countries is between 100 and 200 GJ/(cap.yr) [31,32].

If we combine these data with world population data [33] and data on 'technical' energy conversion from Ref. [34] it is possible to construct a time series of the global socioeconomic energetic metabolism which is presented in Fig. 1. Of course, this method can be expected to yield only approximate results, but at least the order of magnitude should be correct. Both axes of Fig. 1 are logarithmic.

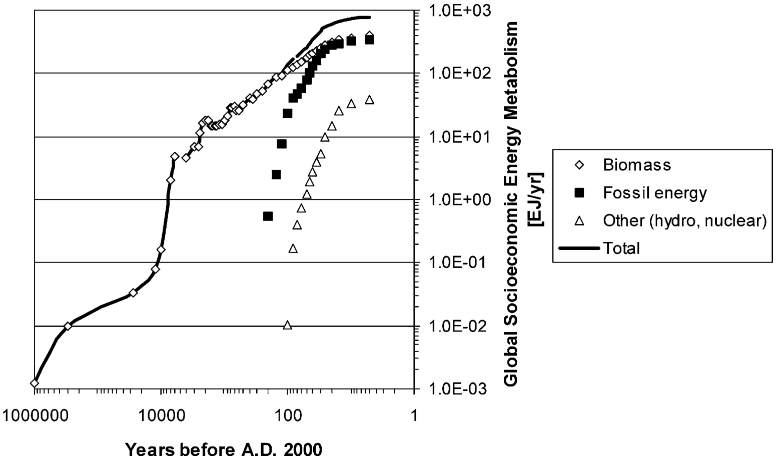

Fig. 1. Global socioeconomic energy metabolism in the last 1 Mio.years. Sources: see text.

The increase in socioeconomic energy flows encompasses six orders of magnitude, from 10^{-3} Exajoule per year (EJ/yr) about 1 million years ago to nearly 10^3 EJ/yr today [32].[2]

4. Socioeconomic and ecological energy flows

Prior to the Neolithic revolution the global socioeconomic energy metabolism was about 0.01–0.1 EJ/yr—an amount of energy that is negligible compared to ecological energy flows: the NPP of global terrestrial ecosystems is about 2400 EJ/yr and would amount to about 2800 EJ/yr if human interference were absent [35]. The energy flows of hunter-gatherers were, thus, 5–6 orders of magnitude lower than terrestrial NPP.

Agricultural society, by contrast, fundamentally alters a host of attributes of terrestrial ecosystems. In effect, agricultural societies transform natural ecosystems into agro-ecosystems in which many processes are regulated and controlled by society—a kind of society–nature interrelation that has been termed ‘colonization of natural processes’ [2]. Colonization allows agricultural societies to use a large percentage of the NPP of the regions they inhabit: on a regional level, a large percentage (maybe up to 80% or so) of the aboveground NPP of terrestrial ecosystems (and some edible belowground organs of plants; e.g. roots and tubers) can be used for socioeconomic purposes by agricultural societies. However, agricultural societies mostly reduce the NPP of the region they inhabit, because their agro-ecosystem are often less productive than the natural ecosystems they replace. Nevertheless, the total energy throughput of human societies grew to about 100 EJ/yr at the beginning of the industrial revolution. While this was 3–4 orders of magnitude more than the energy throughput of hunter-gatherers prior to the Neolithic revolution, it was still only about 4% of the NPP of global terrestrial potential vegetation [32].

Regionally, socioeconomic energy flows were more important. For example, total socioeconomic energy flows in Austria 1830 amounted to about 260 PJ/yr which is about 18% of Austria’s potential

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[2] 1 EJ = 10^{18} J.

aboveground NPP [31,36]. As in the case of hunter-gatherers biomass is by far the quantitatively most important energy source of agricultural societies,[3] although other kinds of energy can provide essential support, above all by supplying drivepower (e.g. wind power in sailing boats and windmills, hydropower in water mills, etc.).

Nevertheless, the energy surplus which agricultural societies can gain by colonizing ecosystems is limited by the amount of area available and by its productivity. One main sustainability problems of agricultural societies is to maintain the often fragile balance between the productivity of agro-ecosystems and the demand for biomass necessary for the nutrition of animals and livestock, for fuel, and for other purposes. While it is obvious that demand depends on population density, it is also essential to note that the productivity of agro-ecosystems vitally depends on the amount of labor invested into colonization; e.g. for managing nutrient cycles, controlling pests, etc. [37]. The amount of labor also depends upon population; therefore, it would be flawed to simply equate population growth in agricultural societies with unsustainability. However, according to Netting's [37] results, increases in the productivity of agro-ecosystems seem to be associated with an increasing pro capite demand for labor. This increase in labor demand ultimately limits the productivity gains that can be achieved by smallholder agriculture without fossil-energy subsidies, as the workload required to keep agro-ecosystems productive becomes physically intolerable. Netting even documents cases in which smallholders work up to 4000 h pro capite and year. Therefore, there are clearly socioecological limits to the amount of energy available to agricultural societies, and the historical evidence indicates that many densely populated European areas were close to these limits at the time industrial revolution began [29].

The transition from the 'controlled solar energy system' of agricultural society to a fossil-energy system was one of the main preconditions for the industrial revolution [28,29]. Fig. 1 shows that the transition of probably less than one third of global population to industrial society (with most of world population currently experiencing a more or less rapid transition process) has lead to a leap in socioeconomic energy flows to over 800 EJ/yr or about 30% of potential terrestrial NPP. This transition process is analyzed in more detail in Fig. 2.

Fig. 2a shows the process of industrialization from an 'industrial society point of view'; that is, based upon conventional energy statistics. Note that, according to this notion of energy use, there seems to be hardly any socioeconomic use of energy at all prior to 1850. This is, of course, non-sense. What was in fact absent is an industrial energy system. This is shown in Fig. 2b in which the use of biomass was taken into account. The same caveats with respect to uncertainty as in Fig. 1 are also valid here: these figures were derived by multiplying human world population by a constant amount of biomass energy (70 GJ/(cap.yr)) allegedly consumed by each person. The results of this admittedly very crude estimate was cross-checked for the 1980s with data derived by Vitousek et al. [38] and found to be reasonable.[4] According to this rough estimate biomass accounts for more than 50% of all global socioeconomic energy input—compared to about only 9%, according to conventional energy statistics [34].

Of course, industrialization is a process that is not at all completed; neither in industrialized countries nor in the so-called 'developing' countries. To illustrate the possible future dimension of

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[3] For example, in Austria 1830 biomass supplied over 99%, whereas the combined contribution of coal and hydropower was below 1%.

[4] Further empirical work to determine the changes in global biomass use over time would, of course, be highly desirable.

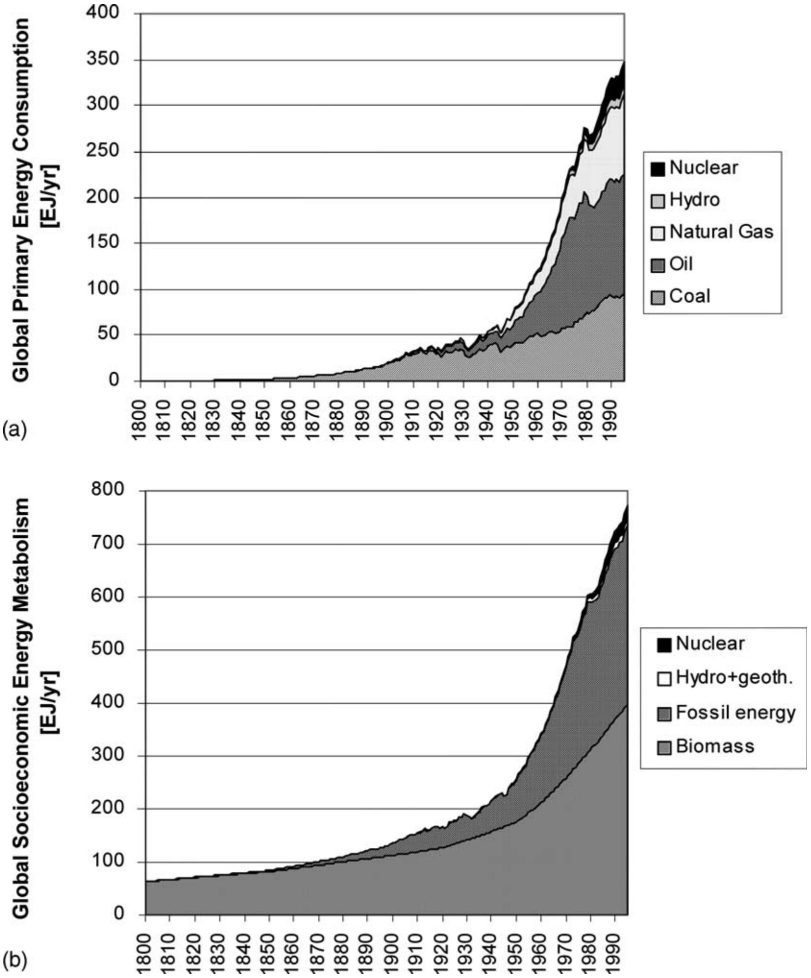

Fig. 2. (a) Primary energy used for ‘technical’ conversion; that is, the energy accounted for in energy statistics (net calorific value). Note that there seems to be practically no energy use prior to 1850 because biomass is not accounted for. (b) Socioeconomic energy metabolism; that is, socioeconomic energy flows assessed using the methods discussed in Section 2 of this paper (gross calorific value). Sources: [14,16,32–34].

the problem at hand, the scenario analysis presented in Fig. 3 was performed. It is again based upon an assumption of a constant pro capite demand (70 GJ/(cap.yr)) for biomass. The ‘low’ estimate uses the low world population scenario of the United Nations Population Division [39] and one (C1) of the two low-energy scenarios derived by the World Energy Council [40]. The ‘medium’ estimate is based upon the UNs medium population scenario and the medium WEC scenario, while the ‘high’ scenario accordingly uses the high population scenario and one (A1) of the high-energy scenarios of the WEC. It should be added that the medium WEC scenario is lower than the forecasts by the IEA and the US-Department of Energy [41,42], but higher than that of the European Commission [43]. The resulting scenarios (Fig. 3) span a range of possible future developments of global socioeconomic energy inputs.

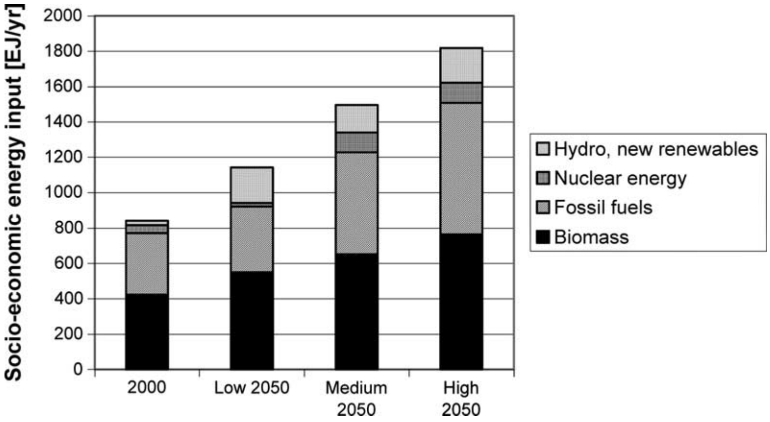

Fig. 3. Scenarios of global energy metabolism in 2050. The 'low' estimate is based on the low UN population scenario [39] of 7.9 billion people and the low WEC [40] scenario C1. The 'medium' estimate assumes the medium UN population scenario (9.3 billion people) and the medium WEC scenario B. The 'high' value is based upon the high UN population scenario (10.9 billion people) and the high WEC scenario A1.

According to this scenario analysis (Table 2), biomass use will increase by 30–80%, eventually leading to a consumption of biomass of 550–765 EJ/yr of biomass in 2050. This amounts to between 20 and 27% of the global terrestrial NPP of the potential natural vegetation (which is estimated at 2800 EJ/yr [35]) or 23–32% of the actual terrestrial NPP (which is about 2400 EJ/yr [35]). The total socioeconomic energy throughput in 2050 would rise by 35–116% over the value of 2000, amounting to 41–65% of the global potential terrestrial NPP or 48–76% of the current terrestrial NPP.

Fossil energy use would rise by 6–113%, depending upon the scenario assumed for technical energy use [40]. That is, even in the low-energy scenario an enormous increase in the use of 'new renewables' would not suffice to stabilize or even reduce fossil energy use—which would be a prerequisite for stabilizing the atmospheric CO_2 concentration.

That is, current trajectories indicate that humanity embarks on the project of managing a yearly flow of energy that equals about 41–65% of the potential NPP of terrestrial ecosystems in as little as 50 years. This shows that the current situation is indeed a historically new situation that poses at least two significant (and interrelated) sustainability problems: (1) the problem of sustaining the supply of biomass without depleting biodiversity and (2) the problem of increasing atmospheric carbon content that leads to climate change.

Table 2
Changes in global socioeconomic energetic metabolism from 2000 to 2050 according to the scenario analysis

	2000	Low 2050	Medium 2050	High 2050
Biomass (%)	100	130	154	180
Fossil fuels (%)	100	106	165	213
Nuclear energy (%)	100	46	250	250
Hydro, new renewables (%)	100	800	617	783
Total (%)	100	135	177	216

Sources: see Fig. 3 and text.

5. Land use and energetic metabolism

From the point of view of energy metabolism, the crucial point of industrialization seems to be the large-scale exploitation of area-independent sources of energy [28,29,44]. The energy system of both hunter-gatherers and agricultural societies was more or less exclusively dependent upon biomass taken (mostly) from terrestrial ecosystems: nearly ‘natural landscapes’ in the case of hunter-gatherers in which human influence was probably not very different from that of other large mammals, more or less intensively human-controlled ‘cultural landscapes’ in the case of agricultural societies in which agro-ecosystem replaced a considerable part of the natural ecosystems. In both cases, society’s energetic metabolism is constrained by area availability, although in a different way: for hunter-gatherers only a small part of the NPP of the region they inhabited could be used for human nutrition. This is the reason why hunter-gatherers use only about 1/10,000–1/100,000th of the NPP of the regions they inhabit [30]. In contrast, the energy metabolism of agricultural societies seems to be constrained by the productivity of agro-ecosystems which is a function not only of the natural conditions (climate, soil, etc.), but also of the amount of work invested into agricultural colonization [37].

The impacts of land use on the functioning of terrestrial ecosystems can be analyzed using the indicator ‘human appropriation of net primary production’ (HANPP) [35,38,45,46]. HANPP is defined as the difference between the NPP of potential vegetation and the amount of NPP remaining in ecosystems; that is, the NPP of the actually prevailing vegetation minus the amount of biomass harvested by human society. HANPP is determined by two processes: (1) the reduction in productivity caused by changes in land cover (e.g. replacement of forests with grasslands, croplands, or built-up land) and (2) the harvest of biomass. If we assume that hunter-gatherers did not change land cover,[5] HANPP caused by hunter-gatherers must have been negligible. In contrast, agricultural societies reach quite considerable levels of HANPP. For example, our studies of a contemporary agricultural village in northeast Thailand suggest a level of HANPP of 76%, a large proportion of which is due to the poor productivity of Sang Saeng’s agro-ecosystems [47,48]. A study by Krausmann [36] of HANPP in Austria 1830–1995 shows that HANPP was about 56% in 1830. In Austria 1830 the productivity of agro-ecosystems was also quite significantly lower than that of the potential vegetation.

In contrast to both hunter-gatherers and agricultural societies industrial society is not constrained by the availability of area because it relies strongly on fossil energy (and, later on, nuclear power, hydropower, etc.). As a consequence, the role of agriculture for the energy system changes fundamentally: instead of being the main source of energy, agriculture becomes a sector supplying special kinds of biomass. Whereas the ‘energy return on investment’ of all agricultural activities was essential for the viability of agricultural societies this changed fundamentally in industrial societies which had other sources of energy at their disposal to ‘subsidize’ agriculture. Therefore, in industrial society agriculture need not be a net energy gaining activity [49–52].

On the other hand, this ‘energy subsidy’ made it possible that, during the process of industrialization, biomass harvest could be essentially ‘delinked’ from HANPP: because it was possible to greatly increase the productivity of agro-ecosystems through fertilization, irrigation, etc.—essentially, through the application of more power—more biomass could be harvested on smaller cropland and grassland areas. This is the conclusion arising from Krausmann’s [36] analysis of HANPP in Austria 1830–1995: during

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[5] Cases where fire was used for hunting [65] are an exception to this.

this period cropland and grassland areas in Austria decreased considerably while forests and built-up areas increased. Despite this loss of farmed area the amount of biomass harvested nearly doubled, mostly due to the rising productivity of agro-ecosystems. We have not made an agricultural energy analysis for this period, but it is highly likely that the ‘energy efficiency’ of agriculture (products divided by energy investment in agriculture) fell significantly throughout this period [52]. On the other hand, the ‘colonization efficiency’ (biomass harvested per unit of HANPP) of agriculture obviously could be increased considerably through agricultural energy subsidies.

6. Discussion: energetic metabolism and sustainable development

The analysis presented above indicates that ecological problems associated with socioeconomic energy metabolism are central for sustainable development, understood here as a strategy of trying to achieve social and economic goals (e.g. equity, poverty reduction, improvement of human health and quality of life) while not threatening the ecological functions and services upon which humans depend [53,54]. The sheer scale of human-induced energy flows which could reach about half of the potential NPP of all terrestrial ecosystems on earth in a few decades shows the extent to which human activities dominate earth’s ecosystems [46]. Moreover, the fact that humanity ‘appropriates’ a considerable proportion of the globally available NPP is highly relevant in this context because, as Vitousek and Lubchenko [55] have put it (p. 60), “to the extent that (…) natural systems, species and populations provide goods or services that are essential to the sustainability of human systems, their shrunken base of operations must be a cause of concern”.

One conclusion is that increasing the use of biomass for energy generation will not solve the sustainability problems associated with fossil fuels. Even if no major substitution of biomass for fossil fuels is assumed, global biomass use could increase by some 30–80% to 550–765 EJ/yr in 2050. If we assume that global NPP remains constant this would lead to an increase of global HANPP of some 5–12 percentage points. If we assume Vitousek’s estimate of current HANPP of 24–40% [38] this would mean that HANPP could reach 30–50% in 2050. However, as the example of Austria has showed, things are probably much more complicated: if most of this biomass could be produced on already existing cropland or grassland areas that can be made more productive through the application of higher fossil-energy subsidies, HANPP could maybe even decline. On the other hand, trends like the deforestation of the tropics, the desertification in sub-saharian Africa, etc. could also contribute to increases in HANPP.

Current estimates by Tilman et al. [56] assume that until 2050 about it will be necessary to create about 0.35 billion hectares cropland and about 0.54 billion hectares pasture land to meet the demands of the growing world population.[6] This would mean an increase in agricultural areas of about 18% which would be accompanied by an increase of N inputs by a factor of 2.7, of P inputs by a factor of 2.4, of irrigated land by a factor of 1.9 and of pesticide of 2.7 [56]. Because the percentage of total area covered by agricultural area is an important determinant of HANPP, the analysis by Tilman et al. suggests that HANPP will probably rise. In any case, Tilman et al. show that land use is an important driving force of global environmental change. Technologies to increase the productivity of agro-ecosystems with less

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[6] This estimate is based upon the medium UN population scenario of 9.3 billion people in 2050.

fossil energy and with less adverse ecological impacts than with current agricultural practices should be high on the agenda of sustainability research.

The calculations presented in this paper indicate that it would be flawed to regard biomass as an abundant resource that should be used instead of fossil fuels to the maximum possible extent—as is sometimes the case, at least in Europe. This is so because substituting biomass for a significant proportion of the fossil fuels currently used could lead to a surge in HANPP and cause the destruction of many valuable ecosystems around the globe. If biomass should contribute (to some extent) to a sustainable energy scenario, this would be possible within a strategy of 'cascade utilization' of biomass; that is, through a strategy of re-use, recycling, use of biomass by-products or residues, etc.—in order words, by increasing the efficiency of biomass use. In contrast to technologies that use biomass grown only for energy production such a strategy would focus on energy production from biomass that has before been used for other socioeconomic purposes and does, therefore, not contribute to HANPP [57,58].

This indicates that strategies aiming at a more sustainable development should focus on energy conservation [59,60] and renewable energy options such as wind power, direct use of solar energy, etc. that require much less area than biomass energy.

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