Global human appropriation of net primary production (HANPP)

Encyclopedia of Earth, www.eoearth.org

Lead Authors: Helmut Haberl, Karl-Heinz Erb, Fridolin Krausmann

Published: April 29, 2010, 4:27 am, Updated: December 20, 2012, 12:39 am

Introduction

Humanity's impact on the biosphere's structures (e.g., land cover) and functioning (e.g., biogeochemical cycles) is considerable. It exceeds natural variability in many cases. Sanderson and others have classified up to 83% of the global terrestrial biosphere as being under direct human influence, based on geographic proxies such as human population density, settlements, roads, agriculture and the like; another study, by Hannah et al., estimates that about 36% of the Earth's bioproductive surface is "entirely dominated by man".

HANPP, the "human appropriation of net primary production," is an aggregated indicator that reflects both the amount of area used by humans and the intensity of land use. NPP is the net amount of biomass produced each year by plants; it is a major indicator for trophic energy flows in ecosystems. HANPP measures to what extent land conversion and biomass harvest alter the availability of NPP (biomass) in ecosystems. It is a prominent measure of the "scale" of human activities compared to natural processes (i.e. of the "physical size of the economy relative to the containing ecosystem;" Daly, 2006). As human harvest of biomass is a major component of HANPP, it is also closely related to socio-economic metabolism as measured by material flow accounts.

The basic question of how much of the biosphere's yearly biomass flows is used by humans was first posed in the 1970s (see Whittaker and Likens, 1973), and it took more than a decade until the first comprehensive – and still relevant – answer to that question was given (see Vitousek et al., 1986). This entry gives an overview of the research that has followed these seminal statements and proceeds by discussing issues of definition (section 2), presenting some basics on methodology (section 3) and giving an overview of the current knowledge on global HANPP (section 4). This is followed by a concluding section on interpretation and further research requirements (section 5).

2 Definition of HANPP

Just like any other scientific concept, HANPP has to be rigorously defined, and different definitions may lead to substantially different empirical results (see Haberl et al., 2007). Different authors have approached HANPP from different angles and have consequently used a variety of definitions. This lack of standardization has, however, unfortunately resulted in a range of empirical results (discussed below), thus creating the impression as if it were very difficult, maybe even impossible, to assess HANPP with sufficient accuracy. This has not only hampered the comparability of results but has also fueled critiques that might eventually jeopardize the credibility of the whole concept. This section gives an overview of the different definitions used so far. Harmonization of HANPP definitions seems therefore highly important.

Vitousek et al. calculated HANPP using three different possible definitions, each of which is a measure of a different process or pattern. First, they assessed only biomass directly used by society (food, timber, etc.). Second, they added the net primary production (NPP) of human-dominated ecosystems (e.g. croplands). Third, they additionally considered the NPP lost due to human-induced changes in ecosystem productivity, e.g. ecosystem degradation.

Wright proposed to define HANPP as the difference in NPP available in (hypothetical) undisturbed ecosystems and the amount of NPP actually available to support heterotrophic food chains. He excluded activities such as logging and biomass burning in forests on the grounds that they do not result in a long-term reduction of productivity of the land for wild species if forests are allowed to regrow. There is ample evidence, however, that harvest and biomass burning are very important for forest ecology. NPP appropriated in forests through timber harvest and related processes should therefore be included in any definition of HANPP.

A later study of global HANPP by Rojstaczer et al. focused on uncertainty and, in doing so, only considered Vitousek's second definition. A recent study by Imhoff et al. calculated the global human consumption of NPP – something quite different from Vitousek's original concept – but labeled the resulting figures also as "HANPP." The definition used in this latter paper was between the first two definitions of Vitousek: It did not include the total NPP of human-dominated ecosystems, but parts of plants not actually harvested were considered if they were required for producing the harvested material (e.g. roots). Neither Rojstaczer et al. nor Imhoff et al. considered changes in NPP caused by past or present land use.

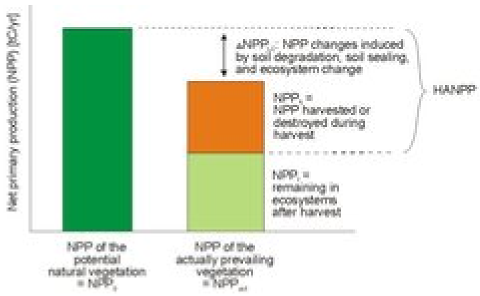

Figure 1. Definition of HANPP proposed by the authors. (Sources: See text)

We have proposed a definition of HANPP that has proven its usefulness in spatially explicit as well as long-term studies on a national scale. This definition (Figure 1) is related to Wright's suggestion and defines HANPP as the difference between the amount of NPP that would be available in an ecosystem in the absence of human activities (NPP_0) and the amount of NPP which actually remains in the ecosystem, or in the ecosystem that replaced it under current management practices (NPP_t). NPP_t can be calculated by quantifying the NPP of the actual vegetation (NPP_{act}) and subtracting the amount of NPP harvested by humans (NPP_h). HANPP is then defined as NPP_0-NPP_t with $NPP_t = NPP_{act} – NPP_h$. If one denotes as $?NPP_{LC}$ the difference between NPP_0 and NPP_{act}, HANPP becomes equal to NPP_h+$?NPP_{LC}$.

This definition has the following advantages: (1) It avoids being too inclusive. Even in strongly human-impacted systems such as grasslands, managed forests, or even cropland, some of the NPP is used by wild-living organisms not controlled or used by humans, thus supporting some, in grasslands often even a very high, biodiversity. (2) It is robust in time-series calculations. Land use sometimes reduces NPP, even prevents it altogether (e.g. soil sealing), but technologies such as irrigation, fertilization or use of improved crop varieties may also raise NPP over its natural potential. Such effects are significant and historically variable, and should thus be included in any comprehensive HANPP assessment. For example, in Austria changes in agricultural technology increased above-ground productivity on agricultural land by a factor of 2.6 from 1830 to 1995.

Some problems remain, however. For example, how should wood harvest be dealt with? Wood is accumulated in a forest over many years, so harvest is the product of NPP accumulated over a period longer than the current year. This may result in negative NPP_t values, even if averaged over larger regions, if stock-depleting forest management practices prevail. How should crop residues not actually harvested, but ploughed into the soil after harvest, be dealt with? In our studies on Austria we chose to include them as "appropriated," because these studies focused on the aboveground compartment, and the biomass was clearly removed from that compartment. Other definitions may be more useful under different circumstances. Biomass returned to the ecosystem on-site (e.g. dung excreted by grazing animals) is often also included in a definition of HANPP. Some authors have include biomass killed during harvest (e.g. roots) in their HANPP definition (see O'Neill et al., 2006, Imhoff et al., 2004, Haberl et al. 2007). A final weakness is that in some ecosystems the notion of a natural NPP in the absence of human activity may be questionable; NPP is variable on the timescale of decades and will be influenced by variations in climate, grazing and nutrient conditions. Human influence (e.g. regular burning of praries) may also reach back thousands of years.

In any case, it is important that HANPP studies be explicit in their definitions as to which biomass flow was or was not included in the definition of harvest used. We argue that a minimum requirement for any indicator to be called HANPP is that it (1) refers to a defined area of land, not to the biomass or NPP consumed by a defined population (additional indicators to assess this property are very interesting, but should be given a different name), (2) comprises an assessment of $?NPP_{LC}$ and NPP_h, (3) avoids being too inclusive, while not being restricted only to biomass directly used by humans.

3 Some basics of HANPP methodology

In order to be able to calculate HANPP it is necessary to assess three properties: (1) NPP_0, i.e. the NPP of the vegetation that would be assumed to prevail in the absence of human land use (potential vegetation), (2) NPP_{act}, i.e. the NPP of the currently prevailing vegetation and (3) NPP_h, i.e. the human harvest of NPP. Different methods are available to estimate these three properties. Which one is most appropriate depends on the scope and purpose of the study. One of the strengths of HANPP is that it can be assessed in a spatially explicit way, i.e. it is possible to produce maps of HANPP that localize the human impact on ecosystems. In this case, the three above-mentioned parameters must be calculated in a spatially explicit way, using geographic information systems (GIS) technology.

The most important factors influencing NPP in the absence of human activities are climate (above all, temperature and precipitation) and soil quality. Numerous models, so called Dynamic Global Vegetation Models, DGVMs, exist that can be used to calculate NPP_0 on a global level. These models are spatially explicit and can mostly be used at a resolution of 0.5° (c. 50x50 km at the equator). Similar models are available that can be used for smaller spatial scales. An alternative method is to extrapolate typical values of NPP per unit area and year from the literature or to use simple models such as Lieth's "Miami model" that only requires data on mean annual temperature and precipitation. While the credibility of the latter two simple approaches might be limited, a cross-check of DGVM results with data from the literature on the NPP of potential vegetation can be useful. Spatially explicit studies require gridded (GIS) data on potential vegetation, soil and climate. Credible results will require the availability of a suitable ecosystem model capable of reliably calculating NPP at the spatial resolution needed for the particular study.

Several methods are available to assess the NPP of the currently prevailing vegetation. In any case, the availability of a reliable dataset on land use and land cover is essential. A spatially explicit HANPP assessment is obviously only possible if spatially explicit (i.e. gridded) land-use and land-cover data are available in a suitable GIS database. In order to be able to make use of data from agricultural and forestry statistics as well as forest inventories – indispensable sources of any HANPP calculation – it is required that cropland area in this dataset be consistent with cropland areas recorded in the specific agricultural statistics that should be used; the same holds for forestry. Availability of reliable data consistent with statistical sources on urban areas, wilderness and grazing land is often a major challenge for spatially explicit HANPP studies. A global 5min resolution (i.e. approximately 10x10 km at the equator) dataset for the year 2000 fulfilling these requirements has recently been published by Erb et al. and is freely available for future use. Note, however, that while the data can be useful on larger (e.g., continental) scales, they should not be used on too small spatial scales, e.g. for national or even sub-national studies.

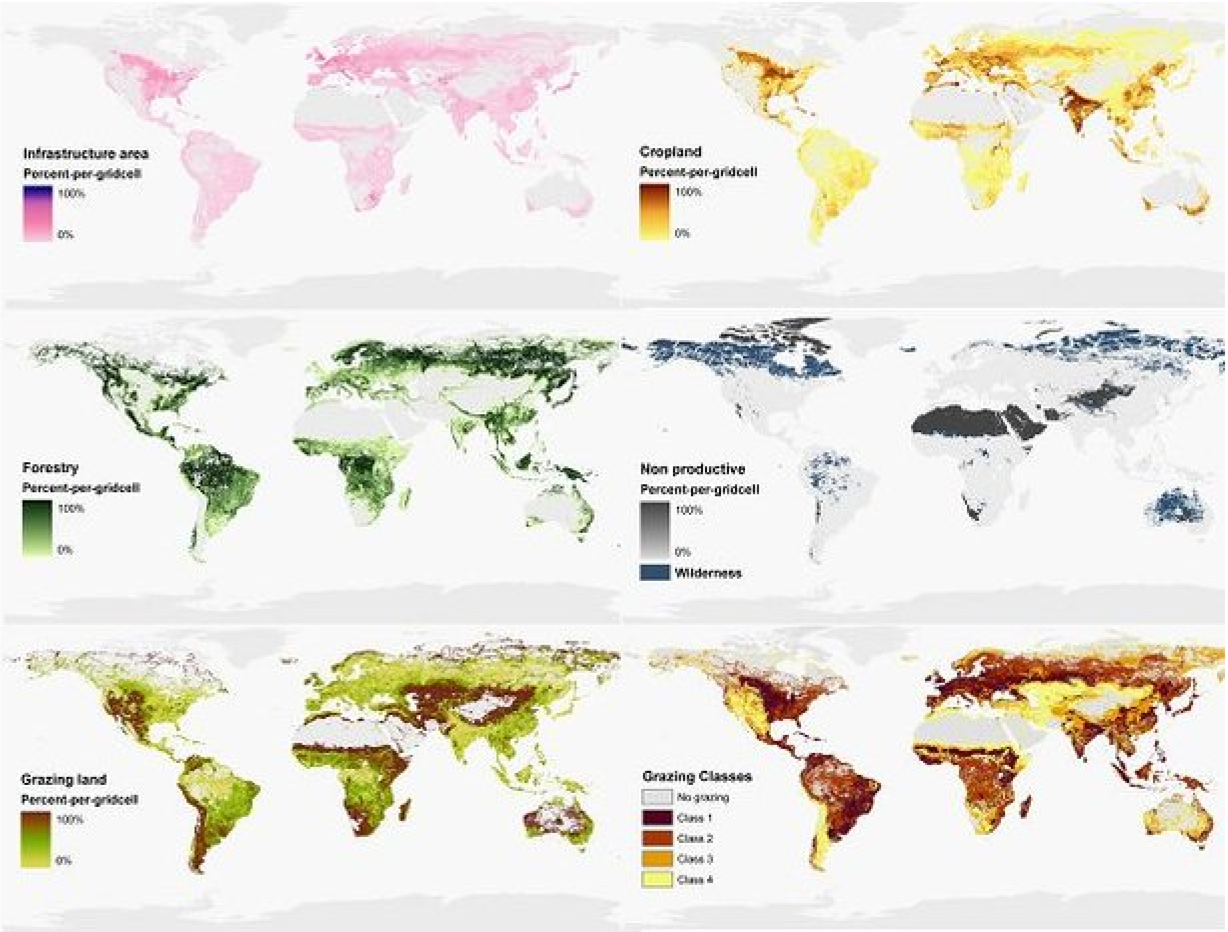

Figure 2. A global land-use dataset consistent with FAO data on cropland and forest areas on the country level. (Source: Erb et al., 2007. Data can be downloaded from the Institute for Social Ecology.)

For cropland, the most reliable method is to use harvest indices that extrapolate total NPP from the amount of crop harvested according to agricultural statistics. For managed forests, most HANPP studies conducted so far used the assumption that their NPP were equal to that of unmanaged forests. This assumption may be questionable, as some authors have argued that forest management would greatly increase NPP because it would favor younger, more productive stages in forest succession – but other authors have made exactly the opposite claim, arguing that forestry often results in degradation of forest ecosystems. For alternative approaches see O'Neill et al. For areas with little or no human use the assumption $NPP_0 = NPP_{act}$ is obviously plausible. Built-up land is commonly assumed to be devoid of NPP ($NPP_{act} = 0$), but it is important to note that data on urban land usually include areas covered by vegetation such as parks, gardens or vegetation along roads. These areas are often irrigated and therefore quite productive which must of course be taken into account.

Grazing land is the most challenging item to be considered in calculating NPP_{act}. First, data on the area covered with different kinds of grazing land (meadows mowed with different intensities, pastures with different grazing intensities, rangelands and other grazed ecosystems) are mostly of poor quality and often unreliable due to their low economic value and to the existing ambiguities in definitions. Second, the effect of grazing and mowing on the productivity of grasslands and grazed ecosystems in general is also not well understood and documented. Case studies show that grazing may both enhance ("compensatory growth") or reduce productivity ("degradation"), depending on its intensity and a host of other factors such as precipitation or soil quality. Moreover, the effect of land clearing (removal of forests) for pastures or grazing land on NPP is also not documented.

Assessing biomass harvest may also be less straightforward than one might think. Data on crop and timber harvest are usually readily available from statistical sources (e.g FAO). These are quite reliable for crops but often less so for harvest in forests, especially due to underreporting of illegal logging in the tropics and subsistence woodfuel gathering. For forests it is also important to note that wood harvest is actually not taken from the NPP of the current year but is a stock accumulated in the past decades or even centuries. This may in theory even result in negative NPP_t values if the above-mentioned formulae are applied, but this can usually be avoided by using averages of forest growth and wood harvest over larger regions. A similar problem may occur in regions with strong net forest losses.

The most difficult part of any assessment of NPP_h is the estimation of NPP harvested on grazing land (i.e. biomass grazed by livestock or hay mowed) because these flows are usually not recorded in agricultural statistics. This biomass flow can be estimated by calculating the so-called “grazing gap;” that is, the amount of roughage required to feed the existing stock of ruminants after market feed has been taken into account. A useful approach in that context is the use of livestock feed balances based on data on livestock numbers and livestock production from agricultural statistics. The result of such a calculation can be cross-checked with the productivity of grazing land calculated in the above-discussed steps. An in-depth discussion of methods to assess NPP_h, including a global dataset for the year 2000, is provided by Krausmann et al.

As data on below-ground NPP are considerably more uncertain than those on aboveground NPP many HANPP studies were restricted to the above-ground compartment. In any case, it seems highly desirable to account for aboveground and below-ground processes separately. More detailed information on HANPP methods can be found in the literature (e.g., Haberl et al., 2001, Haberl, 2002, Haberl et al, 2007).

4 Global HANPP – an overview

Biomass flows can be expressed in terms of flows of dry matter biomass (kg/yr), in terms of energy (J/yr, usually expressed as Gross Calorific Value = Upper Heating Value) or in terms of carbon flows (kg C/yr). In order to facilitate comparison of the global results reviewed below we converted all results to Pg C/yr (1 Pg = 10^{15} g = 10^{9} t = 1 Gt = 1 billion tons), using the following conversion factors: 1 kg dry matter biomass = 0.5 kg C and 1 kg dry matter biomass = 18.5 MJ.

As early as 1973 Whittaker and Lieth reported that humans harvested 1.6 Pg C/yr from terrestrial ecosystems as food and wood in the 1950s, a flow of biomass that amounted to only 3% of their estimate of total global terrestrial NPP (54 Pg C/yr). This finding (Table 1) hardly raised concerns, but this changed rapidly with the publication of the famous study by Vitousek and colleagues that reported the following result: “We estimate that organic material equivalent to about 40% of the present net primary production in terrestrial ecosystems is being co-opted by human beings each year. People use this material directly or indirectly, it flows to different consumers and decomposers than it otherwise would, or it is lost because of human-caused changes in land use. People and the associated organisms use this organic material largely, but not entirely, at human direction, and the vast majority of other species must subsist on the remainder.” (Vitousek et al., 1986). Wright's study was a recalculation of the study by Vitousek and colleagues that used more recent data sources and a different definition (see above); differences in definitions explain a much larger proportion of the differences in the result than the use of more recent data.

A more recent probabilistic study by Rojstaczer et al. that adopted Vitousek et al.’s intermediate definition and was based on Monte-Carlo techniques reported an alarmingly large uncertainty of global HANPP, a conclusion that was criticized by other authors (e.g. Field, 2001, Haberl et al., 2002). Using again another definition (outlined above), Imhoff and others arrived at an estimate of global human consumption of NPP of 14.7 Pg C/yr or 20% of terrestrial NPP. A recent study of the authors based on extensive use of spatially explicit (gridded) data reported a global HANPP value of 15.6 Pg C/yr or 24% of total terrestrial NPP. These are the only available data available so far on the global level that are (1) compatible with the HANPP definition outlined in Figure 1, (2) based on country-level data on land use, livestock grazing, forestry, urban areas, and so on, (3) include biomass consumed in human-induced fires and (4) are available in a 5min (10x10 km) geographic grid. For the aboveground compartment, this study reported a considerably higher HANPP of 29%. A recalculation of HANPP according to the definition used by Vitousek et al., but using the far more detailed database available for that latter study, confirmed that differences resulting from the use of different definitions were by far larger than differences resulting from uncertainties in the data.

Table 1. Overview of estimates of global HANPP given by different authors.

Study	Reference time	HANPP absolute* [Pg C/yr]	HANPP relative* [%]**
Whittaker and Lieth (1973)	1950s	1.6	3%
Vitousek et al. (1986) low	1970s	2.6	3%
Vitousek et al. (1986) intermediate	1970s	20.3	27%
Vitousek et al. (1986) high	1970s	29.5	39%
Wright (1990)	1970s-1980s	17.7	24%
Rojstaczer et al. (2001)	1980s-1990s	19.5±14	32% (10-55%)
Imhoff et al. (2004)	1995	11.5 (8.0-14.8)	20% (14-26%)
Haberl et al. (2007)	2000	15.6	24%

* Note the differences in definitions used in each study discussed in the text.

** Per cent of actual or potential NPP. Note that estimates of NPP_{act} and NPP_0 also vary considerably; for example Whittaker and Lieth's value of NPP_{act} (54 Pg C/yr) was much lower than Vitousek et al's estimate (75 Pg C/yr). The current "best guess" of NPP_0 is 66 Pg C/yr and that of NPP_{act} 59 Pg C/yr (Haberl et al. 2007).

A global HANPP map is shown in Figure 3. It demonstrates large regional differences in the amount of NPP appropriated by humans per unit area and year. Areas with high HANPP include scarcely populated, but intensively cropped areas such as the North American Corn Belt as well as densely populated regions such as large parts of Europe, India, China and South-East Asia. HANPP may be negative (see, for example, the Nile delta) in cases where barren areas are irrigated and used for agriculture, even though in such cases most of the additional NPP (compared to NPP_0) is harvested.

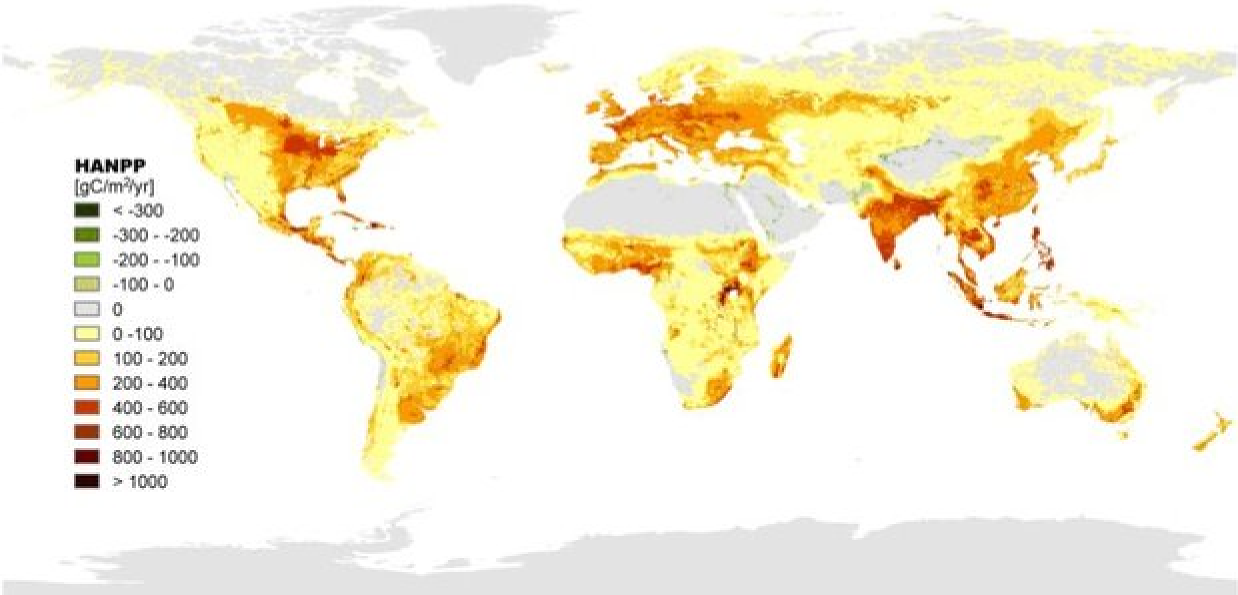

Figure 3. Map of global HANPP in the year 2000 in absolute units ($gC/m^2/yr$). This and other HANPP maps can be downloaded from the Institute for Social Ecology.)

It is interesting to take a closer look at the various components of global HANPP, and in particular on the global human use of harvested biomass (for more details see Krausmann et al.). Table 2 presents an in-depth overview of the components of global HANPP and of global human-induced biomass flows. These data suggest that land conversion – i.e., past and present land use – lowers NPP by almost 9.6%, i.e. over two thirds of the amount of biomass actually harvested or destroyed during harvest (NPP_h). A considerable amount of the biomass harvested flows back to ecosystems, for example as dung excreted by grazing animals, roots of harvested crops or trees remaining in the soil or unused agricultural residues.

Table 2 also suggests that biomass use is associated with considerable "upstream requirements": The amount of biomass that actually enters socioeconomic processing (6.07 Pg C/yr) and is then further processed to derive biomass-based products such as food, feed, fiber or energy is just a bit over one third (39%) of global HANPP. In fact, figures presented in Krausmann et al. even suggest that, in the global average, the final consumption of one ton of biomass requires the harvest of 3.6 tons of primary biomass and is associated with a $?NPP_{LC}$ of 2.4 tons. Taken together, this implies that – in the global average of all regions and biomass-based products, one ton of biomass use results in 6 tons of HANPP, measured as dry matter biomass.

Table 2. Components of global HANPP and global human-induced biomass flows. Sources: Haberl et al. (2007) and Krausmann et al. National-level data on socioeconomic biomass flows can be downloaded from the Institute for Social Ecology.

	NPP / biomass flow [Pg C/yr]	Percentage of NPP_0 [%]
Components of global HANPP		
NPP of the potential terrestrial vegetation (NPP_0)	65.51	100.0
NPP of the actually prevailing vegetation (NPP_{act})	59.22	90.4
NPP remaining in ecosystems after harvest (NPP_t)	49.90	76.2
Change in NPP resulting from land use ($?NPP_{LC}$)	6.29	9.6
NPP harvested or destroyed (NPP_h)	9.31	14.2
HANPP (= $?NPP_{LC}$ plus NPP_h)	15.60	23.8
Backflows to nature	2.46	3.7
Global human-induced biomass flows		
Used extraction of biomass*	6.07	9.3
* of which: harvested primary crops	1.72	2.6
* of which: harvested crop residues	1.47	2.2
* of which: grazed biomass	1.92	2.9
* of which: wood removals	0.97	1.5
Unused extraction*	3.24	5.0
* of which: human-induced fires	1.21	1.8
* of which: unused belowground biomass	0.96	1.4
* of which: unused residues on cropland	0.75	1.1
* of which: felling losses in forests	0.33	0.5

* Used plus unused extraction equals NPP_h.

5 Outlook – the meaning and significance of global HANPP

HANPP is definitely useful as a measure of the physical size of the economy relative to the containing ecosystem: It demonstrates how much of the trophic energy that would be available for wild-living animals and other heterotroph organisms in the absence of human activities is still in place. As such, it is an extremely valuable indicator of the "human domination of ecosystems" on the global scale (Vitousek et al., 1997) and of the intensity of socio-economic "colonization of ecosystems" (Fischer-Kowalski and Haberl, 1997, Haberl et al., 2004a).

Studies of global HANPP gained attention in the literature on sustainable development because HANPP was often interpreted as an indicator for ecological limits to growth. This notion has meanwhile lost credit, however, because (a) economic growth may proceed even without growing biomass use and (b) long-term studies of HANPP have shown that HANPP may decline during industrialization if biomass harvest grows due to agricultural intensification rather than due to an extension of farmed areas.

An obvious implication of HANPP is that growth in the amount of biomass used by humans for their socio-economic metabolism must be envisaged with caution. In particular, caveats are warranted with respect to policies aiming to promote the use of biomass as a source of technical energy as well as raw material. Biomass already plays a significant role in global socio-economic energy supply. Biomass currently contributes some 9-13%, that is 35-55 EJ/yr (1 EJ = 10^{18} Joule), to the global supply of technical energy (see Table 2). This figure, however, by far underestimates the importance of biomass for humanity's "energetic metabolism" (Haberl, 2001a, Haberl, 2001b): Global human biomass harvest, including crops, by-products, grazing by livestock, fiber consumption and forest products amounted to about 235 EJ/yr around 1993 (Table 2). This value includes an estimate of biomass used in subsistence economies for energy provision unaccounted for in statistical data such as those of the FAO.

Notable future increases in biomass demand are expected. The projected growth of world population to 7.5-8.5 billion in 2030 and 7-11 billion in 2050 together with likely improvements in human diets are strong driving forces for further increases in the amount of biomass required as food and feed. Moreover, many energy scenarios also predict strong increases in the amount of biomass used for energy provision (Table 3). Further growth of biomass energy use might not only result in increased competition between food and energy supply, but also in further increases in HANPP with possible adverse ecological effects.

Policies aimed at promoting the use of biomass for energy provision should therefore aim at the highest possible efficiency in biomass use. The utilization of biomass from residues (i.e., agricultural crop residues, forest residues, manure, organic wastes) should be given priority over biomass utilization schemes that require the additional harvest of biomass. There exist considerable potentials for such a strategy of "cascade utilization of biomass" (Fraanje, 1997, Haberl and Geissler, 2000, Haberl et al., 2003, Lal 2004). On a global level, biomass residues could yield some 30-112 EJ/yr.

Moreover, empirical studies increasingly demonstrate that HANPP is a major indicator of human pressures on ecosystems and may have adverse effects on biodiversity. On an abstract level it is obvious why HANPP is ecologically relevant: NPP is a central parameter of ecosystem functioning, human-induced changes of NPP thus affect patterns, processes and functions of ecosystems almost by definition. HANPP is directly associated to the provision of ecosystem services, such as the provision of biomass through agriculture and forestry. But land-use induced changes in productivity (?NPP_{LC}) may also affect many important ecosystem services such as the resilience, buffering capacity or the absorption capacity for wastes and emissions.

Table 3. Current and projected future level of global biomass and energy use and global terrestrial net primary production: A compilation of estimates.

	Energy flow [EJ/yr]	Year	Sources
1. Current global use of energy and biomass			
Biomass used for the provision of technical energy	35-55	mid 1990s	[1,2,3,4]
Global technical energy consumption excluding biomass	350 (376)	1995	[5]
Global used biomass extraction	225	2000	[6]
Global human biomass harvest (NPP_h)	344	2000	[6]
2. Scenarios of future use / biomass potentials			
Short-term potential according to WEA	145	2025	[2]
Mid-term potential according to WEA	94-280	c2050	[2]
Long-term potential according to WEA	132-325	2100	[2]
Range of mid-term potentials/scenarios found in a review	35-450	2050	[1]
WEC/IIASA scenarios mid-term	78-154	2050	[3]
WEC/IIASA scenarios long-term	174-266	2100	[3]
IPCC-SRES scenarios mid-term	52-193	2050	[7]
IPCC-SRES scenarios long-term	67-376	2100	[7]
Potential according to Fischer/Schrattenholzer	370-450	2050	[8]
Potential according to Hoogwijk et al.	33-1135	2050	[9]
3. Global terrestrial NPP			
Average from PIK model comparison project	2 140	mid 1990s	[10]
NPP estimate by Ajtay et al. (1979)	2 460	1970s	[11]
Current "best guess" according to Saugier et al. (2001)	2 440	mid 1990s	[12]

[1] Berndes et al., 2003 (summarizes findings of 17 studies, including some of the below-quoted).
[2] Turkenburg, 2000.
[3] Nakicenovic et al., 1998.
[4] Hall et al., 1993b.
[5] Podobnik, 1999, own conversion assuming 1 toe = 41.868 GJ (net calorific value). Value in brackets: estimate of gross calorific value.

[6] Haberl et al., 2007.
[7] Nakicenovic and Swart, 2000.
[8] Fischer and Schrattenholzer, 2001.
[9] Hoogwijk et al., 2003.
[10] Cramer et al., 1999, converted assuming a carbon content of biomass of 47.5% and 18.5 MJ/kg gross calorific value of dry matter biomass.
[11] Ajtay et al., 1979, converted assuming 18.5 MJ/kg gross calorific value of dry matter biomass.
[12] Saugier et al., 2001, converted as in [10].

HANPP alters energy flows within food webs. Based on the species-energy hypothesis, HANPP has been hypothesized to contribute to biodiversity loss. Only few empirical studies have been conducted so far to probe this idea, however. These studies have generated evidence in support of the HANPP-biodiversity hypothesis, but further evidence referring to a wider range of ecosystems seems desirable. HANPP is relevant in the context of global water flows, carbon flows and – as biomass contains nitrogen (N), and N fertilizer is an important factor for agricultural productivity – N flows.

HANPP relates to important global sustainability issues such as endemic malnourishment of a large proportion of world population, the ongoing conversion of valuable ecosystems (e.g., forests) to infrastructure, cropland or grazing land with detrimental consequences for biodiversity and global, human-induced alterations of biogeochemical cycles.

We conclude that the analysis of socio-economic drivers of HANPP as well as of its ecological impacts should remain high on the agenda of sustainability science. In particular, understanding the interrelations between HANPP and changes in economic structures and processes, especially those related to transitions from agrarian to industrial society, should be a priority of global change research.

6 Acknowledgements

We acknowledge support by the Austrian Science Funds (FWF), project P16692-G05 and from the FP6-funded integrated project MATISSE. This text contributes to the Global Land Project.

7 Further Reading

To access and download more HANPP and global land-use data, please visit the Institute for Social Ecology.

8 References

- Ajtay, G. L., Ketner, P., Duvigneaud, P., 1979. Terrrestrial Primary Production and Phytomass. In: Bolin, B., Degens, E. T., Kempe, S., Ketner, P. (Eds.), The Global Carbon Cycle. Chichester, New York, Brisbane, Toronto, John Wiley & Sons, pp. 129-182.
- Allgeier, H. J., Caratti, G., Sandberg, O., 1995. Towards a European bio-energy strategy. In: Chartier, P., Beenackers, A. A. C. M., Grassi, G. (Eds.), Biomass for Energy, Environment, Agriculture and Industry, Vol. 1. Oxford, New York, Tokyo, Pergamon Press and Elsevier, pp. 11-19.
- Ayres, R. U. and Simonis, U. E., 1994. Industrial Metabolism: Restructuring for Sustainable Development. Tokyo, New York, Paris, United Nations University Press.
- Berndes, G., Hoogwijk, M., van den Broek, R., 2003. The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy 25, 1-28.
- Cannell, M. G. R., 1982. World Forest Biomass and Primary Production Data. London, Academic Press.
- Caspersen, J. P., Pacala, S. W., Jenkins, J. C., Hurtt, G. C., Moorcroft, P. R., Birdsey, R. A., 2000. Contributions of Land-Use History to Carbon Accumulation in U.S. Forests. Science 290, 1148-1151.
- Costanza, R., Cumberland, J., Daly, H. E., Goodland, R., Norgaard, R. B., 1998. An Introduction to Ecological Economics. Boca Raton, FL/USA, CRC Press.
- Cramer, W., Kicklighter, D. W., Bondeau, A., Moore III, B., Churkina, G., Nemry, B., Ruimy, A., Schloss, A., Kaduk, J., The Participants of the Potsdam NPP Model Intercomparison, 1999. Comparing global models of terrestrial net primary productivity (NPP): overview and key results. Global Change Biology 5(Supplement 1), 1-15.
- Crutzen, P. J. and Steffen, W., 2003. How long have we been in the anthropocene era? Climatic Change 61(3), 251-257.
- Daily, G. C., Alexander, S., Ehrlich, P. R., Goulder, L., Lubchenco, J., Matson, P. A., Mooney, H. A., Postel, S. L., Schneider, S. H., Tilman, D., Woodwell, G. M., 1999. Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. Issues in Ecology 2.
- Daly, H. E. 2006. The Concept of Scale in Ecological Economics: Its Relation to Allocation and Distribution. Internet Encyclopedia of Ecological Economics, International Society for Ecological Economics (ISEE).
- Davidson, C., 2000. Economic Growth and the Environment: Alternatives to the Limits Paradigm. BioScience 50(5), 433-440.
- DeFries, R. S., Field, C. B., Fung, I., Collatz, G. J., Bounoua, L., 1999. Combining satellite data and biogeochemical models to estimate global effects of human-induced land cover change on carbon emissions and primary productivity. Global Biogeochemical Cycles 13(3), 803-815.
- Erb, K.-H., Haberl, H., Krausmann, F., Gaube, V., Plutzar, C., Gingrich, S., Bondeau, A., and Lucht, W. 2005. Global Human Appropriation of the Products of Photosynthesis in 2000 – a new spatially explicit estimate. Presentation at the 6th Open Meeting of the Human Dimensions of Global Environmental Change Research Community, University of Bonn, Germany, 9-13 October 2005.
- Erb, K.-H., V. Gaube, F. Krausmann, C. Plutzar, A. Bondeau, H. Haberl, 2007. A comprehensive global 5min resolution land-use dataset for the year 2000 consistent with national census data. Journal of Land Use Science 2(3), 191-224.
- European Commission 1997. Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan. Luxembourg, European Commission.
- Evans, L. T., 1993. Crop Evolution, Adaption and Yield. Cambridge, Cambridge University Press.
- FAO 2002. FAO-STAT 2001 Statistical Database. Rome, FAO, CD-Rom and www.fao.org.
- FAO 2004. FAOSTAT 2004, FAO Statistical Databases: Agriculture, Fisheries, Forestry, Nutrition. Rome, FAO.
- FAO 2005a. FAOSTAT 2005, FAO Statistical Databases: Agriculture, Fisheries, Forestry, Nutrition. Rome, FAO.

- FAO 2005b. The State of Food Insecurity in the World 2005. Eradicating world hunger - key to achieving the Millennium Development Goals. Rome, Food and Agriculture Organization of the United Nations.
- Field, C. B., 2001. Sharing the Garden. Science 294, 2490-2491.
- Fischer-Kowalski, M. and Haberl, H., 1997. Tons, Joules and Money: Modes of Production and their Sustainability Problems. Society and Natural Resources 10(1), 61-85.
- Fischer-Kowalski, M. and H. Haberl (eds.), 2007. Socioecological Transitions and Global Change. Trajectories of Social Metabolism and Land Use. Edward Elgar, Cheltenham, UK and Northampton, USA.
- Fischer, G. and Schrattenholzer, L., 2001. Global bioenergy potentials through 2050. Biomass and Bioenergy 20, 151-159.
- Fraanje, P. J., 1997. Cascading of pine wood. Resources, Conservation and Recycling 19, 21-28.
- Gaston, K. J., 2000. Global patterns in biodiversity. Nature 405, 220-227.
- Gerten, D., Hoff, H., Bondeau, A., Lucht, W., Smith, P., Zaehle, S., 2005. Contemporary "green" water flows: Simulations with a dynamic global vegetation and water balance model. Physics and Chemistry of the Earth, Parts A/B/C 30(6-7), 334-338.
- Gough, C. M., Vogel, C. S., Harrold, K. H., George, K., Curtis, P. S., 2007. The legacy of harvest and fire on ecosystem carbon storage in a north temperate forest. Global Change Biology 13(9), 1935-1949.
- Haberl, H., 1997. Human Appropriation of Net Primary Production as an Environmental Indicator: Implications for Sustainable Development. Ambio 26(3), 143-146.
- Haberl, H., 2001a. The Energetic Metabolism of Societies, Part I: Accounting Concepts. Journal of Industrial Ecology 5(1), 11-33.
- Haberl, H., 2001b. The Energetic Metabolism of Societies, Part II: Empirical Examples. Journal of Industrial Ecology 5(2), 71-88.
- Haberl, H., 2002. Human appropriation of net primary production (HANPP): Tools to relate socio-economic metabolism and land use. In: Schandl, H., Grünbühel, C. M., Haberl, H., Weisz, H. (Eds.), Handbook of Physical Accounting. Measuring bio-physical dimensions of socio-economic activities MFA - EFA - HANPP, Version 1.0. Vienna, Federal Ministry of Agriculture and Forestry, Environment and Water Management, Report No. 9/2002, pp. 47-62.
- Haberl, H. and Geissler, S., 2000. Cascade Utilisation of Biomass: How to cope with ecological limits to biomass use. Ecological Engineering 16 (Supplement), S111-S121.
- Haberl, H. and Erb, K.-H., 2006. Assessment of Sustainable Land Use in Producing Biomass. In: Dewulf, J. and Langenhove, H. V. (Eds.), Renewables-Based Technology: Sustainability Assessment. Chichester, John Wiley & Sons, pp. 175-192.
- Haberl, H., Erb, K.-H., Krausmann, F., Loibl, W., Schulz, N. B., Weisz, H., 2001. Changes in Ecosystem Processes Induced by Land Use: Human Appropriation of Net Primary Production and Its Influence on Standing Crop in Austria. Global Biogeochemical Cycles 15(4), 929-942.
- Haberl, H., Erb, K.-H., Krausmann, F., Adensam, H., Schulz, N. B., 2003. Land-Use Change and Socioeconomic Metabolism in Austria. Part II: Land-Use Scenarios for 2020. Land Use Policy 20(1), 21-39.
- Haberl, H., Krausmann, F., Erb, K.-H., Schulz, N. B., Rojstaczer, S., Sterling, S. M., Moore, N., 2002. Human Appropriation of Net Primary Production. Science 296(14. June), 1968-1969.
- Haberl, H., Fischer-Kowalski, M., Krausmann, F., Weisz, H., Winiwarter, V., 2004a. Progress Towards Sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. Land Use Policy 21(3), 199-213.
- Haberl, H., Schulz, N. B., Plutzar, C., Erb, K.-H., Krausmann, F., Loibl, W., Moser, D., Sauberer, N., Weisz, H., Zechmeister, H. G., Zulka, P., 2004b. Human Appropriation of Net Primary Production and Species Diversity in Agricultural Landscapes. Agriculture, Ecosystems & Environment 102(2), 213-218.
- Haberl, H., Plutzar, C., Erb, K.-H., Gaube, V., Pollheimer, M., Schulz, N. B., 2005. Human Appropriation of Net Primary Production as Determinant of Avifauna Diversity in Austria. Agriculture, Ecosystems & Environment 110(3-4), 119-131.
- Haberl, H., Krausmann, F., Gingrich, S., 2006a. Ecological Embeddedness of the Economy. A Socioecological Perspective on Humanity's Economic Activities 1700-2000. Economic and Political Weekly XLI(47), 4896-4904.
- Haberl, H., Weisz, H., Amann, C., Bondeau, A., Eisenmenger, N., Erb, K.-H., Fischer-Kowalski, M., Krausmann, F., 2006b. The energetic metabolism of the EU-15 and the USA. Decadal energy input time-series with an emphasis on biomass. Journal of Industrial Ecology 10(4), 151-171.
- Haberl, H., K.-H. Erb, F. Krausmann, V. Gaube, A. Bondeau, C. Plutzar, S. Gingrich, W. Lucht, M. Fischer-Kowalski, 2007. Quantifying and mapping the human appropriation of net primary production in earth’s terrestrial ecosystems. Proceedings of the National Academy of Sciences of the USA 104, 12942-12947
- Hall, D. O., Scurlock, J. M. O., Bolhàr-Nordenkampf, H. R., Leegood, R. C., Long, S. P. (eds.), 1993a. Photosynthesis and Production in a Changing Environment. A Field and Laboratory Manual. London, New York, Tokyo, Chapman & Hall.
- Hall, D. O., Rosillo-Calle, F., Williams, R. H., Woods, J., 1993b. Biomass for Energy: Supply Prospects. In: Johansson, T. B., Kelly, H., Reddy, A. K. N., Williams, R. H. (Eds.), Renewable Energy, Sources for Fuels and Electricity. London, Washington DC, Covelo, CA, Earthscan, Island Press, pp. 653-698.
- Hannah, L., Lohse, D., Hutchinson, C., Carr, J. L., Lankerani, A., 1994. A Priliminary Inventory of Human Disturbance of World Ecosystems. Ambio 23(4-5), 246-250.
- Harmon, M. E., Ferrell, W. K., Franklin, J. F., 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science 247, 699-702.
- Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkaemper, G. W., Cromack, K., Cummins, K. W., 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15, 133-302.
- Heywood, V. H. and Watson, R. T., 1995. Global Biodiversity Assessment. Cambridge, Cambridge University Press, United Nations Environment Programme (UNEP).
- Hinterberger, F., Giljum, S., Hammer, M. 2003. Material Flow Accounting and Analysis (MFA). A Valuable Tool for Analyses of Society-Nature Interrelationships. Internet Encyclopedia of Ecological Economics, International Society for Ecological Economics.
- Hoogwijk, M., Faaij, A., Broek, R. v. d., Berndes, G., Gielen, D., Turkenburg, W., 2003. Exploration of the ranges of the global potential of biomass for energy. Biomass and Bioenergy 25, 119-133.
- Imhoff, M. L., Bounoua, L., Ricketts, T., Loucks, C., Harriss, R., Lawrence, W. T., 2004. Global patterns in human consumption of net primary production. Nature 429, 870-873.
- Krausmann, F., 2001. Land Use and Industrial Modernization: an empirical analysis of human influence on the functioning of ecosystems in Austria 1830 - 1995. Land Use Policy 18(1), 17-26.
- Krausmann, F., K.-H. Erb, S. Gingrich, C. Lauk, H. Haberl. Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. Ecological Economics, in print.
- Lambin, E. F. and Geist, H. J., 2006. Land-Use and Land-Cover Change. Local Processes and Global Impacts. Berlin, Springer.
- Lieth, H., 1975. Modeling the Primary Productivity of the World. In: Lieth, H. and Whittaker, R. H. (Eds.), Primary Productivity of the Biosphere. Berlin, Heidelberg, New York, Springer, pp. 237-264.
- Lieth, H. and Whittaker, R. H., 1975. Primary Productivity of the Biosphere. Berlin, Heidelberg, New York, Springer.

- Lindemann, R. L., 1942. The Trophic-Dynamic Aspect of Ecology. Ecology 23(4), 399-418.
- Loomis, R. S., 1983. Produktivity of Agricultural Ecosystems. In: Lange, O. L., Osmond, C. B., Ziegler, H. (Eds.), Physiological Plant Ecology IV, Ecosystem Processes: Mineral cycling, Productivity, and Man's influence. 151-172.
- Loomis, R. S. and Gerakis, P. A., 1975. Productivity of agricultural ecosystems. In: Cooper, H. P. (Eds.), Photosynthesis and productivity in different environments. Cambridge, London, New York, Melbourne, International Biological Programme 3, Cambridge University Press, pp. 145-172.
- Loreau, M., Biodiversity loss and the Maintenance of Our Life-Support System. In: Steffen, W., Jäger, J., Carson, D. J., Bradshaw, C. (Eds.), Challenges of a Changing Earth. Berlin, Springer, pp. 169-173.
- Lutz, W., Sanderson, W. C., Scherbov, S., 2004. The End of World Population Growth. In: Lutz, W., Sanderson, W. C., Scherbov, S. (Eds.), The End of World Population Growth in the 21st Century. New Challenges for Human Capital Formation and Sustainable Development. London, Sterling, Earthscan, pp. 17-83.
- McGuire, A. D., Sitch, S., Clein, J. S., Dargaville, R., Esser, G., Foley, J. A., Heimann, M., Joos, F., Kaplan, J., Kicklighter, D. W., Meier, R. A., Melillo, J. M., Moore III, B., Prentice, I. C., Ramankutty, N., Reichenau, T., Schloss, A., Tian, H., Williams, L. J., Wittenberg, U., 2001. Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land-use effects wieht four process-based ecosystem models. Global Biogeochemical Cycles 15(1), 183-206.
- Meadows, D. L., Meadows, D. H., Randers, J., 1992. Beyond the Limits: Global Collapse or a Sustainable Future. London, Earthscan.
- Millenium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being, Synthesis. Washington, D.C., Island Press.
- Nakicenovic, N., Grübler, A., McDonald, A., 1998. Global Energy Perspectives. Cambridge, Cambridge University Press.
- Nakicenovic, N. and Swart, R., 2000. Special Report on Emission Scenarios. Cambridge, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press.
- O'Neill, D. W., Tyedmers, P. H., Beazley, K. F., 2006. Human appropriation of net primary production (HANPP) in Nova Scotia, Canada. Regional Environmental Change in press.
- Podobnik, B., 1999. Toward a Sustainable Energy Regime, A Long-Wave Interpretation of Global Energy Shifts. Technological Forecasting and Social Change 62(3), 155-172.
- Rojstaczer, S., Sterling, S. M., Moore, N., 2001. Human Appropriation of Photosynthesis Products. Science 294(5551), 2549-2552.
- Sagoff, M., 1995. Carrying capacity and ecological economics. BioScience 45(9), 610-620.
- Sampaio-Nunes, D., 1995. The role of biomass in the European energy policy. In: Chartier, P., Beenackers, A. A. C. M., Grassi, G. (Eds.), Biomass for Energy, Environment, Agriculture and Industry, Vol. 1. Oxford, New York, Tokyo, Pergamon Press and Elsevier, pp. 20-30.
- Sanderson, E., Jaiteh, M., Levy, M., Redford, K., Wannebo, A., Woolmer, G., 2002. The human footprint and the last of the wild. BioScience 52(10), 891-904.
- Saugier, B., Roy, J., Mooney, H. A., 2001. Estimations of Global Terrestrial Productivity: Converging toward a Single Number? In: Roy, J., Saugier, B., Mooney, H. A. (Eds.), Terrestrial Global Productivity. San Diego, Academic Press, pp. 543-557.
- Scurlock, J. M. O. and Hall, D. O., 1990. The Contribution of Biomass to Global Energy Use (1987). Biomass 21, 75-81.
- Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J. O., Levis, S., Lucht, W., Sykes, M. T., Thonicke, K., Venevsky, S., 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global Change Biology 9(2), 161-185.
- Steffen, W., Sanderson, A., Tyson, P. D., Jäger, J., Matson, P. A., Moore III, B., Oldfield, F., Richardson, K., Schellnhuber, H. J., Turner II, B. L., Wasson, R. J., 2004. Global Change and the Earth System. A Planet Under Pressure. Berlin, Springer.
- Turkenburg, W. C., 2000. Renewable Energy Technology. In: Goldemberg, J. (Eds.), World Energy Assessment: Energy and the challenge of sustainability. New York, United Nations Development Programme (UNDP), United Nations Department of Economic and Social Affairs, World Energy Council (WEC), pp. 219-272.
- Tüxen, R., 1956. Die heutige potentielle natürliche Vegetation als Gegenstand der Vegetationskartierung. Angewandte Pflanzensoziologie 13, 5-42.
- Vitousek, P. M., Ehrlich, P. R., Ehrlich, A. H., Matson, P. A., 1986. Human Appropriation of the Products of Photosynthesis. BioScience 36(6), 363-373.
- Vitousek, P. M., Mooney, H. A., Lubchenco, J., Melillo, J. M., 1997. Human Domination of Earth`s Ecosystems. Science 277, 494-499.
- Weisz, H., Krausmann, F., Amann, C., Eisenmenger, N., Erb, K.-H., Hubacek, K., Fischer-Kowalski, M., 2006. The physical economy of the European Union: Cross-country comparison and determinants of material consumption. Ecological Economics 58(4), 676-698.
- Whittaker, R. H. and Likens, G. E., 1973. Primary Production: The Biosphere and Man. Human Ecology 1(4), 357-369.
- Wirsenius, S., 2000. Human Use of Land and Organic Materials. Modeling the Turnover of Biomass in the Global Food System. Göteborg, Sweden, Chalmers University.
- Wirsenius, S., 2003. Efficiencies and biomass appropriation of food commodities on global and regional levels. Agricultural Systems 77, 219-255.
- Wright, D. H., 1990. Human impacts on the energy flow through natural ecosystems, and implications for species endangerment. Ambio 19(4), 189-194.

Citation

Helmut Haberl, Karl-Heinz Erb, Fridolin Krausmann (Lead Author);Mark McGinley (Topic Editor) "Global human appropriation of net primary production (HANPP)". In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth April 29, 2010; Last revised Date December 20, 2012; Retrieved December 29, 2012 <http://www.eoearth.org/article/Global_human_appropriation_of_net_primary_production_%28HANPP%29>

The Authors

Helmut Haberl holds a doctoral degree in plant ecology from the University of Vienna and is qualified to teach in human ecology at its Department of Anthropology. He is now associate professor of Human Ecology at the Vienna Institute of Social Ecology of Klagenfurt University. His research is focused on the analysis of society-nature interactions with the aim of providing scientific underpinnings for sustainable development. He has worked on socioeconomic metabolism, in particular socioeconomic ... (Full Bio)

PhD in human ecology 2003, MSc in ecology in 1999 (University of Vienna, Austria). Project coordinator and researcher at the Potsdam Institute for Climate Impact Research (PIK), Potsdam (Germany), since 2008, and at the Vienna Institute of Social Ecology of Klagenfurt University, since 2000. Lecturer at the University of Vienna, Institute for Biology since 2001. Presented with the IHDP-Dissertation Concept Award 2002 by the Austrian Committee of the International Human Dimensions Programme on Gl ... (Full Bio)

Fridolin Krausmann holds a doctoral degree in ecology from the University of Vienna and is qualified to teach (venia docendi) in social ecology at University of Klagenfurt. He is now associate professor of Sustainable Resource Use at the Vienna Institute of Social Ecology of Klagenfurt University and responsible for the coordination of the research area Historical Sustainability Research. He is a founding member of the Austrian Centre for Environmental History. His research is focused on the ana ... (Full Bio)