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Abstract

Human land use has major impacts on natural ecosystems. The human appropriation of net primary production (HANPP) is a prominent socio-ecological indicator of land use intensity. HANPP measures two different processes: (1) changes in productivity of natural ecosystems induced by humans, and (2) the amount of biomass harvested or destroyed during harvest. HANPP influences ecosystem processes and services. It affects the amount of energy available for natural food webs, and hence biodiversity. Also it is related to climate through its impact on the carbon balance of ecosystems and it is related to processes such as soil degradation. Although HANPP levels in Africa are rather low compared to other world regions such as Europe and Asia, it grew considerably over the last decades. Total African HANPP increased by 53% from 1980 to 2005 exhibiting large regional variations: HANPP increased by about 84% in West Africa, 55% in East Africa, 50% in North Africa, 27% in Central Africa and only 10% in South Africa. In absolute figures, HANPP is rather low in many countries. However, it is likely that these results are an underestimation, as most national statistics do not account for large fractions of subsistence production which is one of the most important sources for many rural livelihoods. HANPP efficiency in most African countries was low throughout the entire time period investigated, indicating high losses of productivity (ΔNPP_{LC}) compared to relatively low levels of harvested biomass (the HANPP fractions which can be directly used by humans). This is in particular highlighted when compared to other world regions where almost the entire fraction of HANPP consists of societal harvest. Reasons for this are complex and often manifested in economic and political constraints limiting high performing agriculture and causing low agricultural yields, especially on a local scale. Our results suggest that agricultural land is expanding in much of Africa, accompanied by inefficient land use systems in Central African and some Western African countries. Trade-related HANPP (HANPP plus imports minus exports) shows a distinctive pattern over the entire continent. Large net-import countries are the North African desert states, whereas Sub-Saharan countries are mostly HANPP net-exporters, though at a modest rate. However, Africa's share of globally traded HANPP is rather low, covering only 11.42% of global HANPP imports and just 4.2% of global HANPP exports. In the light of population surges and increasing demand for biomass imports dependency is likely to increase in future, exacerbating food insecurity in the coming decades. Additionally the current trends of human induced soil degradation on African drylands pose a further challenge on its agricultural production systems. Yet 10% of Africa's dryland areas are prone to degradation, causing productivity losses between 18% and 50% of the potential productivity on affected areas. In order to address this predicament, integrated policy measures that enhance farmers' access to knowledge and agricultural assets are crucial.

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1. Introduction

Ongoing African population surges, rising international demand for biofuels and the nutrition transition yet occurring in many developing nations increase anthropogenic pressure on African ecosystems and are prominent drivers of many sustainability problems in Africa. Furthermore land degradation and poor agricultural performance are major challenges for sustainable development in many African regions, especially in Sub-Saharan Africa. Here, rising population pressure has led to abandonment of traditional systems of shifting cultivation which was replaced by more intensive agricultural systems with shorter or no fallow periods. The poverty rate is high and many farmers live on less than 1 US$ per day. Low household income and many small scale farmers' lack of agricultural production means (e.g, fertilizers) reduce the reestablishment of soil fertility after harvest (Cooper et al., 1996) and hence contribute to low agricultural performance and continuing environmental degradation. Many of these problems are closely related to a complex set of interlinked processes including the strong population growth, ongoing urbanization trends and land expansion going along with an increasing land depletion of marginal land which is often associated with inappropriate management methods (Diagana 2003).

This report presents the human appropriation of net primary production (HANPP) as a socio-ecological indicator as a means to analyzing and discussing the above described African problems related to human land use. In a first step we analyze patterns of total HANPP for the year 2000 based on medium-resolution spatial data (10 x 10 km at the equator), originating from a global level study on HANPP (Haberl et al. 2007). This assessment is based on 3 year average values and includes above- and belowground net primary production (NPP). In the light of the ongoing discussion on soil degradation we briefly discuss this issue and its connection to land use. Based on the study of Erb et al. (2009) we discuss losses of NPP in dry land areas subject to degradation and compare these losses with HANPP and $\Delta NPP_{LC\ 8}$ (for a detailed description of the HANPP components refer to the next section).

In the section trade related biomass we discuss how the amount of HANPP that is related to the apparent consumption of biomass in a country based on the global eHANPP study by Erb et al. (2009). This concept is an enhancement of the original HANPP concept and takes into consideration HANPP associated with imported and exported biomass. Looking at the ratio of embodied HANPP and HANPP allows for analyzing biomass consumption dislocated from areas of production and thus for consumption related impacts on ecosystem services. We further discuss the share of each country on the provision of biomass exports and imports related to global trade as well as their share among different country groups such as developing countries and industrialized countries and high and low population density countries.

In section 4 we present results from a decadal time-series analysis of HANPP for selected African countries, based on 3 year average values for the years 1980, 1990, 2000 and 2005. The chapter provides an integrated discussion of HANPP, its components and trajectories as well as important indicators such as population growth, fertilizer use, crop yields, livestock numbers and land use efficiency. We finally discuss our main findings for the African continent and provide policy recommendations.

2.The HANPP Indicator and Quality Issues

HANPP concept and definition

In the last decades the Human Appropriation of Net Primary Production (HANPP) has gained considerable attention as a stringent indicator for the human impact on natural ecosystems. HANPP explicitly links natural with socioeconomic processes allowing for integrated analysis of the land system (Vitousek et al. 1986; Imhoff et al. 2004; Wright 1990). A range of studies on HANPP have been conducted so far by authors such as Vitousek et al. (1986), Haberl et al. (2007), Krausmann (2001), Musel (2008), Schwarzlmüller (2007), Kastner (2007), Fetzel (2011), and Niedertscheider et al. (2012).

Net Primary Production (NPP) is the amount of plant material (biomass) produced by plants and other organisms (e.g. cyanobacteria) through photosynthesis. Photosynthesis enables green plants and other photosynthetically active organisms to utilize radiant energy from the sun to produce energy-rich organic materials out of inorganic substances, many atmospheric CO_2 and water (H_2O) as well as some nutrients such as nitrogen (N), phosphorous (P), potash (K) and others. The chemically stored energy captured by photosynthesis is then used for the plant's own metabolism as well as for the build-up of biomass that is then available as energy input to all heterotrophic food webs (grazers, detritivores and, on further levels, carnivores).

Human land use affects NPP as well as its availability in ecosystems (i.e. the availability of energy) in two ways:

(1) Land use, i.e. the replacement of natural vegetation with human managed land surfaces such as agro-ecosystems, forest plantations, gardens or even sealed surfaces, affects NPP. Soil sealing obviously results in a stark reduction of NPP to almost zero, but the replacement of natural ecosystems with agro-ecosystems often also reduces NPP (in some cases, NPP is also increased, e.g. in drylands through irrigation or intensive cultivation). NPP may also be affected by past land use, e.g. in the case of soil degradation.

(2) Many land uses, in particular agriculture and forestry, aim at harnessing the productivity of ecosystems for human purposes, above all for the production of food, fibre and energy. All these activities involve harvest of parts of the NPP, either for direct human consumption (e.g. cereals used for bread) or indirectly as animal feed. Biomass harvest implies that the amount of energy available for natural food webs, as well as biomass for maintaining or building up biomass stocks in biota and soils is reduced compared to the natural state. This may contribute to biodiversity loss, reduced carbon storage and release of CO_2 to the atmosphere as well as loss in soil carbon and hence often soil fertility.

Accordingly, HANPP is defined as follows (see Figure 1):

$$HANPP = \Delta NPP_{LC} + NPP_h$$

ΔNPP_{LC} denotes changes (symbolized by the greek letter Δ or 'delta') in NPP resulting from 'land conversion', which includes current and past changes in land cover and land use as well as their consequences such as soil degradation. These changes are measured as the difference between the NPP of the potential vegetation, i.e. the vegetation that would prevail in absence of land use under current climatic conditions (denoted as NPP_0) and the NPP of the currently prevailing vegetation, denoted as NPP_{act} (actual NPP). Since current productivity is often lower than the potential productivity, differences in most cases can be considered productivity losses occurring in the course of land use.

NPP_h or harvested NPP includes not only the harvested product (e.g. grains in the case of cereals or wood in the case of forestry) but also plant parts destroyed during harvest (e.g. roots and shoots of cereal plants, even if the straw is left on the field, or roots, twigs, bark etc. of felled trees) as well as biomass consumed in human induced vegetation fires. A certain share of this biomass may remain on site, e.g. roots or some straw fractions; which may be accounted for separately as 'backflows to nature' but is conventionally included in the definition of NPP_h.

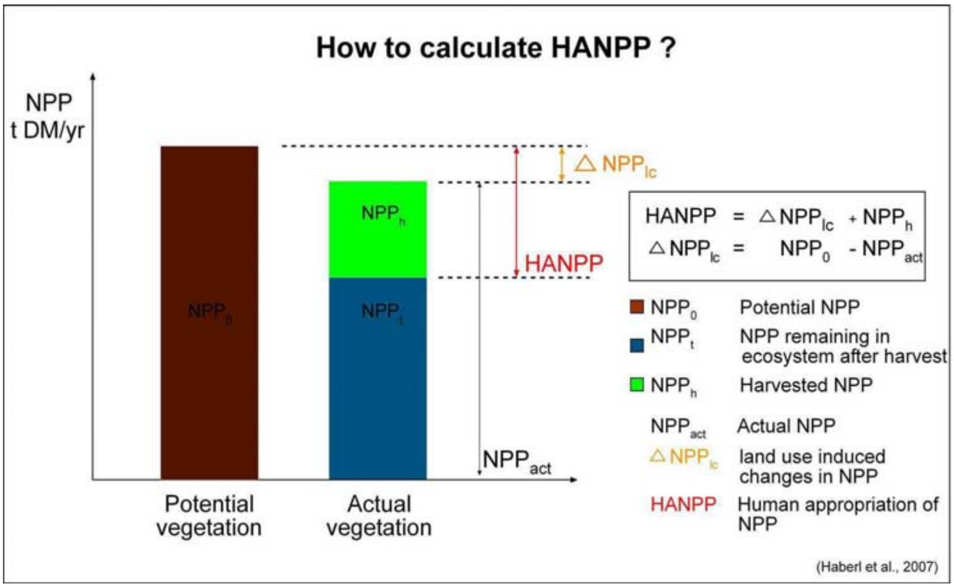

Fig 1 Definition of HANPP; Source: (Haberl et al. 2007)

It is important to note that livestock is considered to be part of human society. Biomass grazed by livestock is hence also included in NPP_h. In contrast to NPP_h which is associated with the provision of biomass-based products (except in the case of human induced fires), human induced changes in NPP (ΔNPP_{LC}) do not directly generate any benefits (in some cases, removal of the vegetation is a prerequisite for certain uses of the land, but the loss of productivity itself does not provide any benefit). This reduction in NPP is accepted because the cultivated plants provide products that the natural vegetation does not provide. For example, a forest produces little plant biomass directly edible for humans, whereas a cereal field does provide edible biomass – even if the NPP of the cereal field is lower than that of the forest, it is a gain for society to replace the forest with a crop field. Reasons why managed ecosystems often have a smaller NPP than natural vegetation include (1) periods in which the land is kept free of vegetation e.g. through plowing, resulting in a reduced length of the growing period compared to natural vegetation, (2) removal of biomass results in depletion of nutrients in the soil, (3) removal of mature plants reduces the amount of photosynthetically active tissue and hence photosynthesis, (4) large-scale removal of vegetation may also result in lower precipitation. On the other hand, irrigation and fertilization can increase the NPP over its natural potential (in this case, ΔNPP_{LC} is negative). In particular in drylands, natural NPP is very low and even modest levels of irrigation can result in strong increases in NPP; the Nile valley in Egypt is one prominent example for that.

HANPP is capable of monitoring one important component of the alteration of ecosystems, i.e. the impact of land use on trophic energy flows. It is related with vital ecosystem functions such as soil fertility, the hydrological cycle, ecosystem productivity and biodiversity. Through linking natural with socioeconomic processes by analyzing changes in the flows of biomass, HANPP allows to gain an integrated picture of the transformation of natural ecosystems, thus being a valuable indicator of strong sustainability (Krausmann et al. 2009).

HANPP can be measured as flow of dry-matter biomass (i.e. biomass with zero moisture content), as energy flow (biomass converted to its gross calorific value) or as carbon flow (i.e. biomass measured as the carbon contained therein). In this study, HANPP flows are expressed as tons of carbon per hectare and per year (t C/ha/yr), based on the assumption that one ton of dry matter of any kind of biomass contains 50% of Carbon. The time series analysis presented in chapter 4 as well as the overall analysis and maps related to the year 2000 comprise both the aboveground and belowground compartment of ecosystems. More information on the concept of HANPP is provided by other authors such as Vitousek et al (1986), Haberl et al. (2007), Krausmann et al. (2009) and Erb et al. (2009).

The concept of embodied HANPP

HANPP is defined with respect to a defined land area, e.g a national territory. National HANPP totals hence do not include HANPP related to biomass imports, nor do they subtract HANPP resulting from the production of exported goods. While this approach is useful to compare land use intensity in different regions and map the pressures on ecosystems related to land use in a spatially explicit manner, it is less directly related with consumption that drives land use, e.g. food, fibre or bioenergy consumption, because these products may be imported. Just as well, a country may also export a large fraction of the biomass-related products it generates, and hence the land use on its territory may be to a considerable extent related to consumption in other regions.

In order to assess these trade-related effects, the HANPP concept has recently been extended by accounts of the HANPP related to traded biomass. By adding the HANPP resulting from imported products and subtracting HANPP related to exported products, it is possible to account for a country's 'embodied HANPP'; that is, the HANPP related to the apparent consumption of biomass-based products in a country's national economy per year. Looking at the ratio of embodied HANPP and HANPP allows for analyzing biomass consumption dislocated from areas of production and thus for production related impacts on ecosystem services (Erb et al. 2009a; Erb et al. 2009b). More detailed information on the concept is provided in section 3 – Trade related biomass.

Data availability and quality

The study at hand was conducted based on readily available data from the global HANPP study by Haberl et al. (2007), the study on embodied HANPP by Erb et al. (2009) and the study on degradation in dry lands conducted by Zika and Erb (2009). Data quality of these studies is varying due to the differences in input dataset and modeling approaches. Most data used in the global HANPP study and in the time series analysis were taken from the FAO database (FAO 2011d) and it is well known that data quality within this database is not uniform across countries. Please note that the results of this study have to be interpreted with caution as we rely upon these data due to a lack of other data sources. Some of the problems related to the collection of statistics in African countries are displayed in Box 1. The quality of environmental reporting schemes directly depends on the quality of input data, and significant improvements of national statistics will be essential for improved reporting. In order to better estimate the extent and impact of HANPP exact data on the extraction are essential. Of outstanding importance would be the collection of data on subsistence production of all kind as well as the complete collection of total agricultural produce. With regard to degradation in dry lands data quality issues arise due to the used input data as we rely in large part upon the GLASOD database (Oldeman et al. 1991) which is known to exhibit inaccuracies (Zika and Erb 2009; Sonneveld and Dent 2009). In order to enhance data quality further available data on degradation on a regional level was used.

However, with the exception of South Africa data on degradation on the African continent are almost completely based on the GLASOD database. Data on the extent of degradation given in this database were completed by overlaying the Global Humidity Index in order to exclude areas other than dry land (arid, semi-arid and dry sub-humid). The most important constraint in terms of data quality is the high uncertainty related to estimates of area prone to degradation. Also information on the actual loss of NPP through degradation is scarce. Other issues such as input material with different underlying definition, purpose and extent, and uncertainties resulting from the definition of land degradation which is commonly related to production potentials of agricultural land rather than unused land also influence data quality. Further information on the detailed methodology used in the degradation study can be gathered from Erb et al. (2009).

Box 1. Data quality for Africa

The FAO Statistical Database reports several indicators for data quality such as 'relevance, accuracy, timeliness, punctuality, accessibility, clarity, comparability, coherence and completeness (FAO 2001). With regard to the calculation of HANPP accuracy and completeness are likely to be the most important criteria as incomplete and inaccurate data would result in substantial errors in the calculation. A prominent problem is that many countries do not report statistical data in time when requested. According to the FAO (2001) '*Angola, Comoros, Democratic Republic of Congo, Djibouti, Eritrea, Gabon, Guinea Bissau, Liberia, Libya and Somalia*' did not reply to the request for agricultural statistics in 1999. For agricultural statistics 48% of all countries replied in time and with regard to trade statistics the figure (26%) was even worse with major countries which did not reply (Algeria, Angola, Benin, Burkina Faso, Cape Verde, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Gabon, Gambia, Guinea, Guinea Bissau, Liberia, Libya, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome y Principe, Sierra Leone, Somalia, Sudan, Tanzania, Togo and Uganda). In some countries, however, this can be traced back to social or political unrests or war. Also the number of commodities reported varies considerably as reporting schemes often concentrate on the commercial sector. This is particularly relevant in countries with a very small agricultural sector. Further inconsistencies may arise from a lack of clear definitions and concepts, and a lack of information on the underlying collection method (FAO 2001). A considerable source of error is the fact that non-commercial production such as subsistence agriculture is not included in most statistics. Finally, a large part of domestic production (i.e. subsistence agricultural production, fishing and hunting) is not included in these statistics. With regard to the calculation of HANPP there is certainly a strong need for the development of a statistical framework surveying these missing data. Also data on livestock are often incomplete or even not reported by many countries. Animals slaughtered and animal products (such as milk) generated for own consumption are often not reported. Data on official trade are expected to be accurate for many countries, however, it is estimated that illegal/unrecorded cross border trade occurs in some countries. An evaluation of data quality of biomass trade data showed that data quality was sufficient in most African countries. In some countries such as Burundi, Rwanda, Lesotho, and Gambia only some data on biomass flows were missing. Despite that overall good quality of trade data some countries were excluded from the analysis due to insufficient data. These countries are: Réunion, Equatorial Guinea, Somalia, Swaziland, Comoros, Djibouti, and Cape Verde.

3. Patterns of HANPP in Africa

The discussion of HANPP patterns in Africa aims discussing spatial patterns within Africa based on ten selected countries and a comparison to other world regions. The selection of the 10 countries represented in Fig 2 is mainly based upon three criteria, country size (large countries often are representative for broader regions), region (two countries from each of the 5 African regions), and data quality. The data presented are taken from the study on global HANPP by Haberl et al. (2007) and are based on the FAO Agricultural Statistics database. As already discussed in the previous chapter, some issues of data quality arise. Particularly the fact that subsistence agricultural produce often is not totally accounted for should be kept in mind. Additionally, the FAO provides information on the data source, hence whether the data are original reports by the countries of origin or estimated by the FAO.

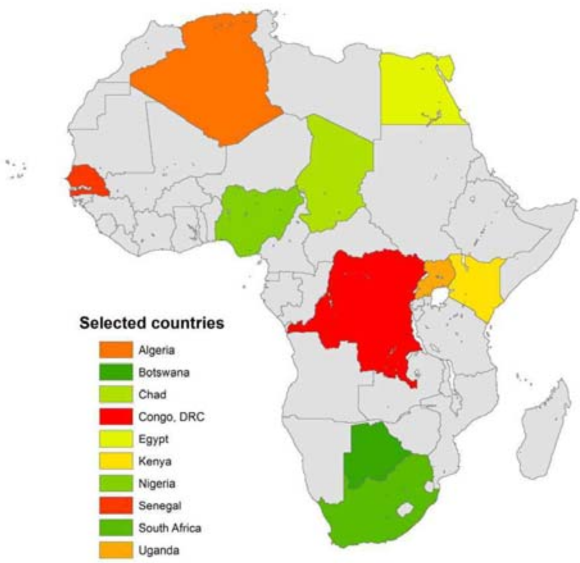

Fig 2 African countries analyzed in this report

As it was beyond the scope of this report to analyze all African countries we derived a list of ten countries, were data quality as reported by the FAO database was reliable and which are considered representative for each geographic region. These countries are:

Box 2. Selected countries analyzed in this report	
North Africa:	Algeria, Egypt
South Africa:	South Africa, Botswana
East Africa:	Kenya, Uganda
West Africa:	Senegal, Nigeria
Central Africa:	Democratic Republic of the Congo, Chad

Spatial patterns of HANPP in Africa

The appropriation of Net Primary Production (HANPP) consists of (a) a harvest fraction (NPP_h) and (b) productivity changes induced by land-cover changes (ΔNPP_{LC}). Fig 3 shows the appropriation for each African country in t C/ha/yr exclusive non-productive areas such as deserts or snow covered areas, as these are considered unproductive in this study (Fig 3, grey areas). HANPP in most African countries ranges from zero to two tons carbon per hectare per year (t C/ha/yr). HANPP levels above average (4 to 7 t C/ha/yr) were observed in Eastern Africa, basically covering the territories of Rwanda, Uganda and Burundi. Additionally higher HANPP vales can be found along the Western Atlantic coast (Nigeria, one of the most densely populated countries on the African continent, Togo, Cote D'Ivoire) and Madagascar (between 2 and 4 t C/ha/yr). In comparison to other world regions such as Europe, South East Asia and Central America HANPP levels in Africa are rather low. However, most African countries showing HANPP/ha levels above African average also feature a rather high population density, i.e. Nigeria, Uganda, Rwanda, and so forth (compare Fig 20, Annex B).

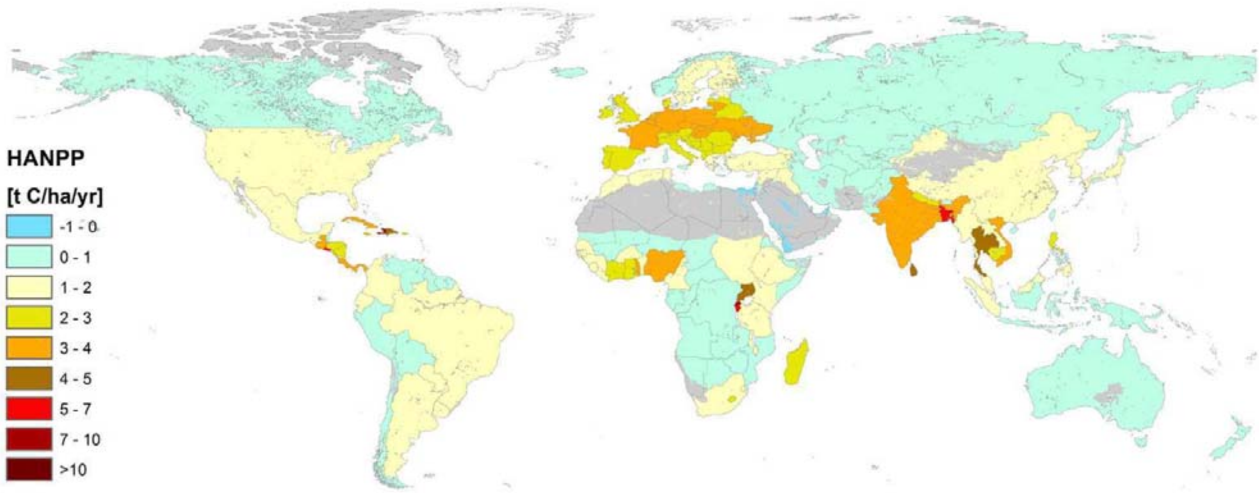

Fig 3 Total HANPP in t C/ha/yr. Non-productive area (grey colour) was excluded before calculating numbers per unit area and year; For detailed figures refer Table 9, Appendix A

Looking at the HANPP as a percentage of the potential Net Primary Production (NPP_0) enables the direct comparison of the level of appropriation of NPP to the potential NPP (that would prevail in the absence of human land use) providing valuable information on the extent of anthropogenic impact on ecosystems. Fig 4a and Fig 4b depict HANPP as percentage of NPP_0 and HANPP per person respectively. The African continent shows a diverse pattern of HANPP as percentage of NPP_0, with Tunisia, Rwanda, and Burundi being hot-spots with an appropriation of the potential NPP exceeding 64% in 2000 (cf. Table 10, Appendix A). Other countries showing levels higher than 40% in 2000 are Djibouti, Morocco, Nigeria and Uganda. Differences in the appropriation of net primary production are high in Western Africa where it ranges up to 47% in Nigeria and 39% in Togo. In Central Africa the appropriation of NPP_0 is comparatively low with the exception of Chad and Cameroon which exhibit 11% and 15.9% respectively. Apparently, the lowest levels are to be found south of the equator in the Western part of the continent. In general, lower shares of HANPP on NPP_0 imply higher amounts of NPP_t, e.g. the amount of biomass left in the ecosystem (e.g. energy available for other organisms) and consequently a lower fraction of appropriated biomass. Highly industrialized countries (such as in Central and Northern European countries) as well as densely populated countries (such as Nigeria and India) tend to use potential NPP_0 to a higher degree than low industrialized (large parts of central Africa) and scarcely populated nations (North Eastern Europe, Canada, South America). HANPP in percent of NPP_0 also points out Western Europe, South-East Asia and the USA as hotspots where between 30% and 70% of the total NPP is appropriated (see Fig 23, Annex B).

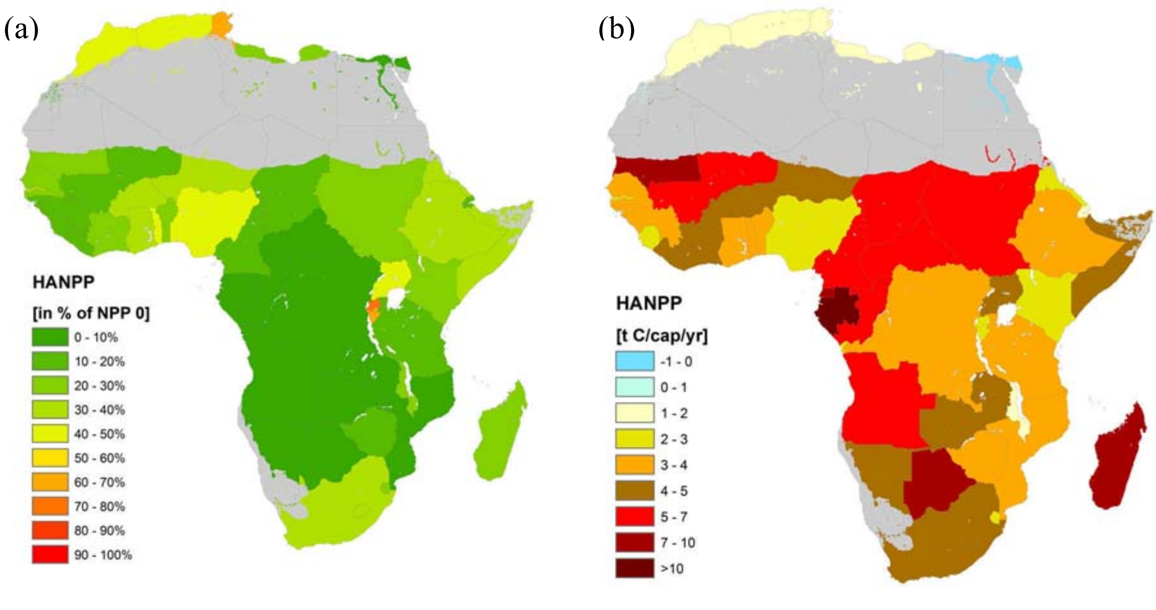

Fig 4 HANPP (a) in % of NPP_0 and (b) per capita; Source: Haber et al. (2007); For detailed figures refer Table 9, Appendix A.

Another important factor is the relationship between HANPP and population density which is visualized in Fig 4b. HANPP per capita is strongly linked to population density. We find extremely low populated countries such as Western Sahara, Gabon and Namibia to exhibit high values of HANPP/cap/yr, whereas high populated countries, e.g. Nigeria and other Western African countries show comparably low HANPP/cap values. Countries in Sub-Saharan Africa generally show a higher level of appropriation per capita. However, HANPP per capita is rather low in the majority of the countries with the exception of Botswana, Namibia, Madagascar, Gabon and Mauritania. Apparently most countries showing a high HANPP per capita also display low population density. A good example for this is Botswana which is a hotspot for HANPP per capita where a rather low population density of 2.2 persons per square kilometers provides an explanation for the high levels. The same is true for Madagascar, even though population density is a little higher with 27 persons per square kilometer. Similar patterns can be found in almost all countries, with the exception of Uganda, where HANPP per capita amounts for almost 5 t C/cap/yr going along with a high population density of 118 persons per square kilometer. On a global scale, the findings for Africa are well in line with results for other world regions, in particular with the scarcely populated North and South Americas, Australia and Russia, which also show high rates of HANPP/cap due to low population densities. In contrast, densely populated countries like Japan and South Korea exhibit comparably low HANPP/cap values (see Annex, Fig 19).

Components of HANPP (harvest vs. ΔNPP_{LC})

To understand HANPP patterns, it is essential to analyze its constituents, i.e. (a) harvest (NPP_h) and (b) human induced productivity changes (ΔNPP_{LC}).

(a) The share of harvest on total HANPP is an indicator on land use efficiency. A high share of harvest indicates a more efficient use of the total appropriate biomass whereas a low share of harvest implies that large amounts of HANPP result from losses through productivity changes, i.e. by the conversion of the original vegetation into other land uses.

(b) A high share of ΔNPP_{LC} on total HANPP in general is associated with low land use efficiency and high indirect losses of ecosystem productivity. It is often associated with the conversion of high productive vegetation types to low productive systems, i.e. the conversion of forest to pasture area and low external inputs (fertilizer, irrigation…).

Fig 5 (a - d) depicts harvest and ΔNPP_{LC} in t C/ha/yr and harvest in % of the potential Net Primary Production (NPP_0) for each country. In Africa Nigeria, Togo, Uganda, Rwanda, Burundi, Swaziland and Egypt show comparably high harvest levels whereas all other African countries exhibit patterns ranging from 0 to 1 t C/ha/yr. Higher rates of NPP_h/ha either indicate a more advanced status of industrialization or higher yields due to favorable climatic conditions. Harvest per hectare was highest in Egypt, where advanced cultivation techniques such as large-scale irrigation infrastructure and intensive application of mineral fertilizer triggered formidable harvest output per land unit. Very low levels of NPP_h/ha are documented for some Southern African countries (Botswana, Angola, Namibia, Zambia) and for Central African countries such as Chad, the Central African Republic, Congo and Gabon. As stressed above, harvest per hectare seems to be comparably low here, which stands in contrast to the favorable climatic conditions in many central African countries. This is possible due to the combined effect of low population densities and a comparably low condition of agricultural industrialization in these nations. In general, peaks of harvest per hectare and year (with values between 1 and 3 t C/ha/yr) are mainly found in Europe (excluding Scandinavia), South East Asia as well as the USA and Central America (see Fig 21, Annex B). Harvest in percent of the potential NPP (NPP_0) is distributed evenly all over Africa, generally showing low levels. Harvest peaks are located in Egypt, particularly along the Nile River, where it exceeds the potential NPP by more than 90%. Above average levels of harvested NPP for the year 2000 can be found in Somalia, Nigeria and Swaziland with 32%, 25%, and 24% respectively (cf. Table 10). Most other countries range within 0% – 30% which is generally low when compared to other parts of the world (see Fig 24, Annex B).

ΔNPP_{LC} per hectare points out the overall share of land use induced changes on the total HANPP (Fig 5b and Fig 5d). We find that ΔNPP_{LC} is also linked to population density. Densely populated areas are subject to higher ratios of ΔNPP_{LC}, as illustrated in the case of Nigeria, or the highly populated Lake Victoria regions, Uganda, Burundi and Rwanda. A higher share of ΔNPP_{LC} in densely populated areas is likely to be the result from a higher level of conversion of the natural ecosystem in order to feed the population. Also this hints at the fact that these areas are subject to high productivity losses resulting from a lack of productivity increasing inputs such as fertilizer or irrigation. On a global level ΔNPP_{LC} per hectare is lowest -even negative- in parts of Northern Europe, South and Central Asia, the

Arabic Peninsula, parts of Egypt, and parts of the Northern most Americas. The rest of the world is dominated by ΔNPP_{LC} values ranging around 0 to 1 t C/ha/yr, except for central Europe, South Asia and Central America (see Annex, Fig 22). Also the share of ΔNPP_{LC} on the total potential NPP is a stringent indicator for land use induced changes in productivity. In a time-series it also may indicate inter-annual climatic fluctuations indirectly through changes in the actual vegetation. However, the pattern of this indicator in African countries is very heterogeneous, showing a structure similar to that of harvest. The share of ΔNPP_{LC} is low in countries showing a low overall level of HANPP, particularly in Central African countries. Again, Burundi, Rwanda and Tunisia are hotspots with a share of 43%, 41% and 36% of ΔNPP_{LC} on the total NPP respectively.

To understand the HANPP indicator it is crucial to look at the ratio of both ΔNPP_{LC} and NPP_h on the total HANPP. The ratio of harvested NPP per HANPP (NPP_h/HANPP, Fig 6 b) serves as an indicator for land use efficiency. A high share of harvest in total HANPP indicates a high level of efficiency and a low level of indirect reduction of productivity due to land use induced productivity changes (ΔNPP_{LC}). Reasons for a high share include high agricultural system efficiency or a high share of area covered with natural vegetation, as these could keep productivity reductions (ΔNPP_{LC}) low and harvest high. Somalia, Swaziland, Libya, Egypt, Djibouti, and Mauritania appear as the only countries with a share of harvest in HANPP exceeding 80% (cf. Table 9, Appendix A). Explanations for this are only based on rough assumptions; however, in the case of Somalia 80% of the land surface is regarded as pasture land and around 88% are classified as shrublands, savanna, and grasslands, which are likely to have not experienced major land cover change processes over time (Earth Trends 2003). This can be highlighted by the fact that more than 50% of Somalia's total population is believed to live as pastoralists (Prothero 1972). Despite the possible negative effects of livestock grazing on grazing areas, it can be assumed, however, that land use in countries exhibiting similar conditions to Somalia is rather extensive and thus causes ΔNPP_{LC} values of minor importance. Data quality may, however, also be a constraint for robust assessments of HANPP in Somalia.

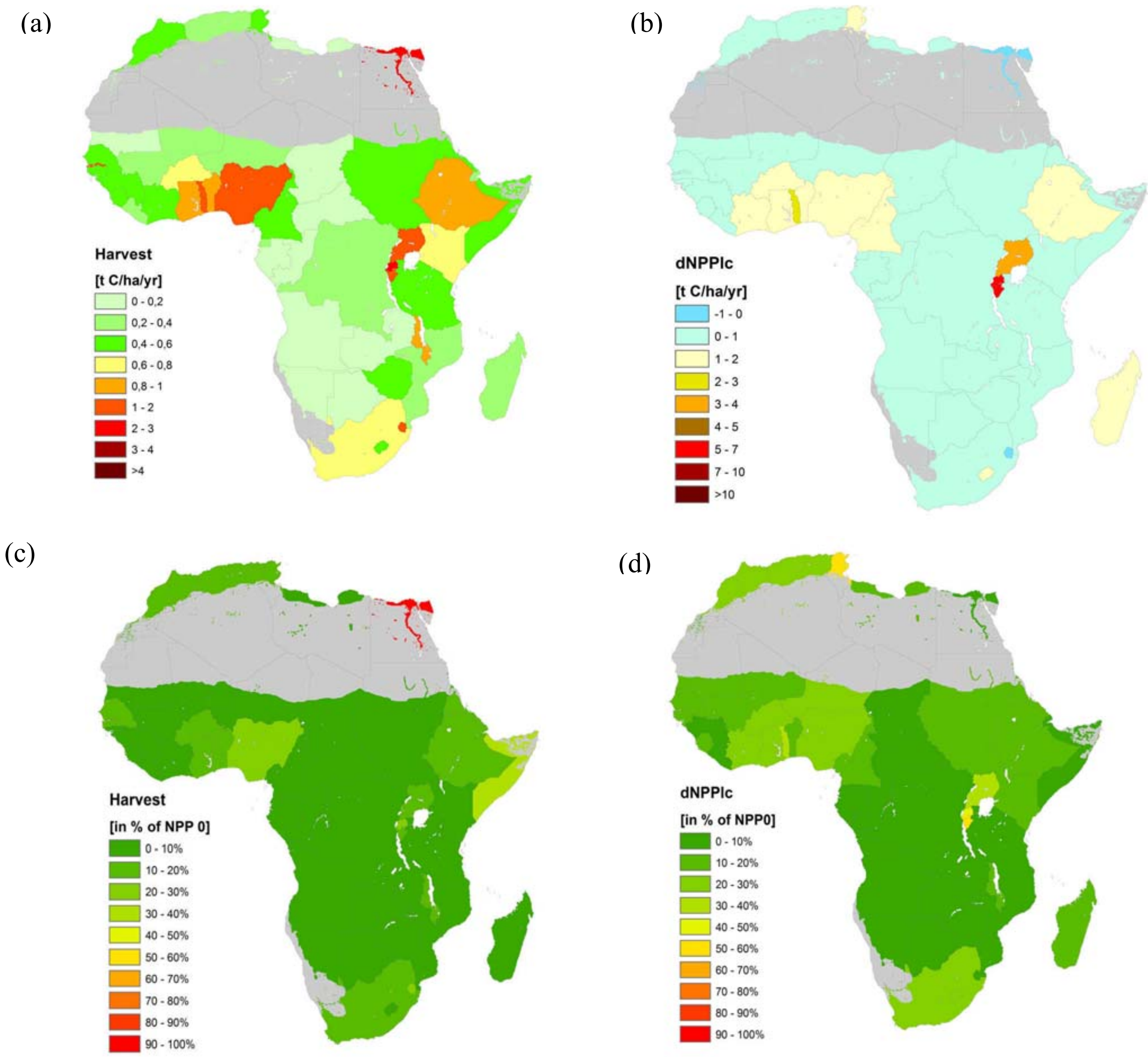

Fig 5 Constituents of HANPP (a) Harvest in t C/ha/yr exclusive non-productive area (grey color) (b) ΔNPP_{LC} in t C/ha/yr exclusive non-productive area (c) Harvest in % of NPP_0 exclusive non-productive area (grey color) (d) ΔNPP_{LC} in % of NPP_0 exclusive non-productive area (grey color); Source: Haberl et al. (2007); For detailed figures refer Table 9, Appendix A.

In contrast, Angola, the Republic of the Congo and Madagascar exhibit one of the lowest ratios worldwide. Here, NPP_h/HANPP ranges from 0% to 25%, mainly as a result of large-scale land-cover changes (i.e. deforestation) and degradation. Hotspots of high land use efficiency on a global scale are again found in Central Europe and South East Asia, where we find NPP_h/HANPP higher than 90% (cf. Fig 26, Appendix B). This means that almost the entire amount of HANPP gets appropriated through harvest and very little is 'lost' through land conversion processes (ΔNPP_{LC}) or degradation. Southern Europe obtains comparably high levels as well, whereas hotspots of low NPP_h/HANPP ratios are overwhelmingly located in Central and Eastern Africa as well as in large parts of North Eastern Europe, including Russia.

Fig 6 (a) illustrates the ratio between used extraction (e.g. the share of harvested biomass that is directly used by humans, thus entering the socio-economic system) and HANPP for the entire African continent. Higher ratios of used extraction are linked to a lower proportion of harvest 'losses' due to more efficient ways of extracting biomass. Hence it serves as an additional means for discerning land use efficiency. 100% implies that the total amount of national HANPP is actually used within the country. Also the share of used extraction to total HANPP possibly exceeds total HANPP which can be explained by a strong increase in productivity. When the productivity per land unit on a certain land use class (e.g. cropland) exceeds the potential NPP of the area, this results in negative ΔNPP_{LC} values, thus reducing HANPP and enabling a higher share of harvest. Agricultural industrialization processes, aimed at optimizing harvest outputs per land area and minimizing harvest losses (e.g. losses due to pest, unused residues and indirect losses through associated ΔNPP_{LC}), are the main drivers reflected in the picture. We find a concentration of low NPP_h/HANPP levels in less developed, central Africa and Western African countries. These countries are characterized by high biomass 'losses' due to high fractions of ΔNPP_{LC} (Fig 6c) and low fractions of used biomass (Fig 6b). In contrast, industrialized countries such as South Africa tend to show the reversed picture. Moreover, some countries strongly depend on subsistence pastoral agriculture and large natural grasslands, such as Somalia and Namibia. Land use change induced productivity losses are mainly due to overgrazing or erosion problems—therefore being indirect outcomes of land use change. These countries thus show a low share of ΔNPP_{LC} but a high share of harvest in the total HANPP, indicating an intensive use of grazing land. The same might be true for Mauritania, where almost 90% of total HANPP results from grassland, which covers around 13% of the total land area. In Libya the share of used extraction to total HANPP is higher due to higher actual productivity on cropland when compared to the potential. It is likely that the potential productivity of the land was pushed by external water inputs, mainly derived from fossil groundwater (FAO 2011a). Detailed figures on the ratio of used extraction, harvest and ΔNPP_{LC} on total HANPP for each African country can be gathered from Table 9, Appendix A.

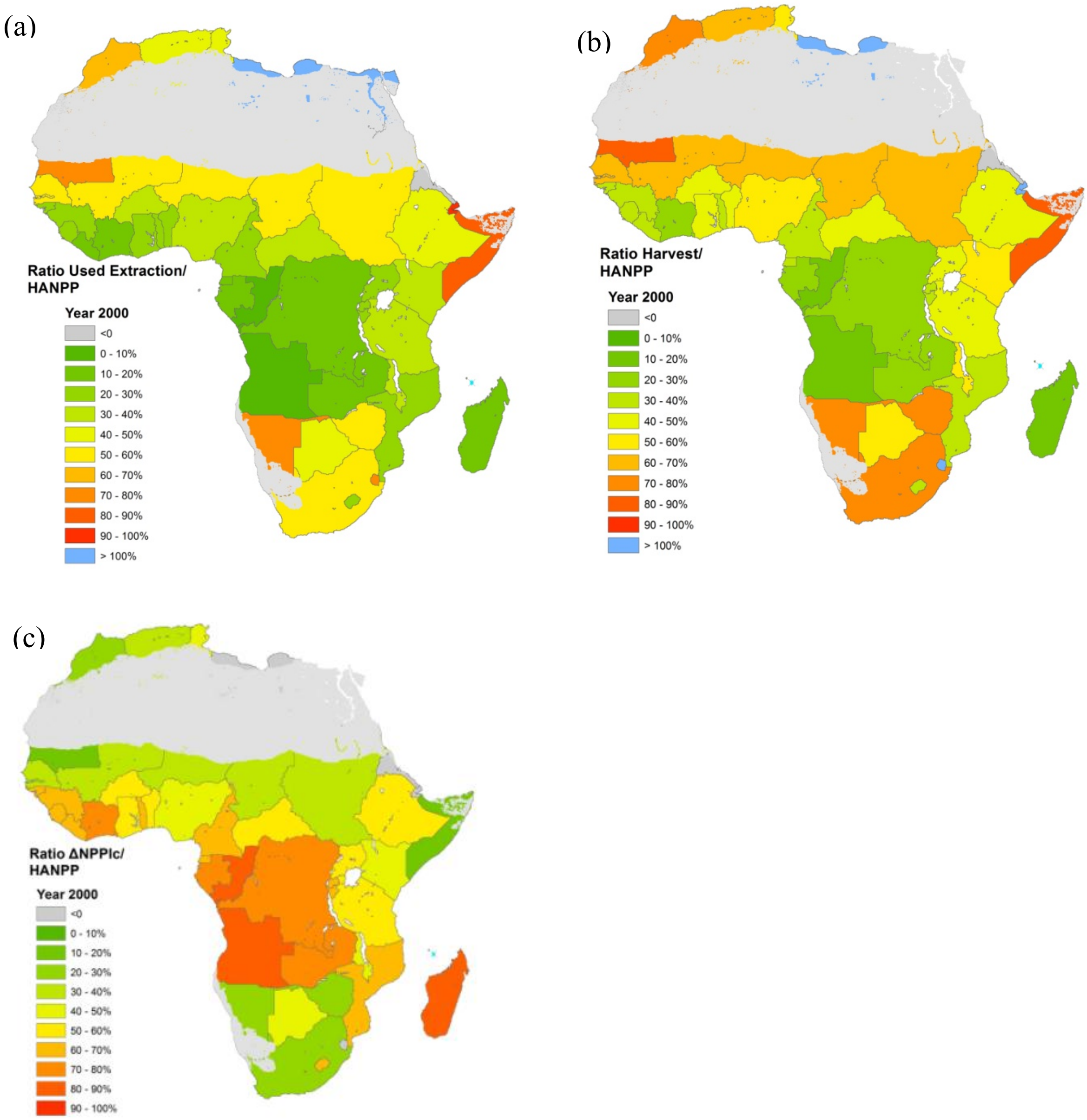

Fig 6 Ratio of (a) used extraction, (b) Harvest and (c) ΔNPP_{LC} on total HANPP exclusive non-productive area; Source: Haberl et al. (2007); For detailed figures refer Table 9, Appendix A.

Degradation

Land degradation is one of the most important factors influencing productivity and ecosystem processes and is commonly defined as the permanent reduction in the capacity of land to provide ecosystem goods and services and to assure its functions production over a period of time (Nachtergaele et al. 2010). Accelerating losses through desertification processes and losses through degradation can seriously undermine a country´s ability to feed its own population, as is already becoming the case in a considerably high number of countries: In Africa, 22 countries were affected severely by food-shortages in 1975, this number is forecasted to increase to 35 by 2025 (FAO 2011b). Ongoing degradation processes are likely to further accelerate this development. However, most areas endangered by degradation are fragile arid and semi-arid areas with low annual rainfall and high variability (Zika and Erb 2009).[1] Land degradation on drylands is denoted as *desertification* (Zika and Erb 2009). Dryland areas inhabited almost 1/3 of the African total population in the year 1986 (Darkoh 1996). However, the process of desertification is widespread and covers 61% of rain-fed croplands, 18% of irrigated land, and 74% of rangelands which makes up for ¾ of the total agricultural land in drylands. In 1996 it was estimated that 25% of total productivity was lost due to desertification processes (Darkoh 1996).

Degradation is caused by a complex interplay of various underlying processes which have to be considered (Scherr and Yadav 1996). In African countries, the prevailing causes of land degradation are overgrazing by anthropogenic livestock (Scherr and Yadav 1996; FAO 2011b): It is estimated that 49% of degradation losses result from overgrazing, 24% from inappropriate management methods, 14% from deforestation, and 13% from overexploitation (Oldeman et al. 1991, cited in Diagana 2003). However, outcomes of degradation are versatile and not only comprise losses in biophysical productivity

[1] Much controversy and disagreements relates to the estimates of the actual magnitude of land degradation. It is frequently reported that as much as 70% of the world's drylands may suffer from desertification, although others strongly contest this interpretation (see Zika and Erb 2009). Globally, land degradation is found to prevail in the humid zones; nevertheless, the strong fluctuations of the environmental conditions in drylands, and the fact that countries in humid zones are often characterized by an above-average economic performance and the ability to counteract to declines in soil fertility (e.g. by fertilization) render degradation particularly virulent in drylands.

accompanied by lower yields, but also changes in land use towards less valuable uses (i.e. cropland to grazing land), deposition of material (downstream), water pollution, water scarcity due to irrigation, and a decline in biodiversity due to a habitat destruction (Scherr and Yadav 1996). These factors all feed back to the living conditions of people and render degradation a critical sustainability challenge: For example, small scale and subsistence farmers are particularly affected by degradation because they often lack the necessary infrastructure or means of production to combat degradation. Rural exodus and uncontrolled urbanization is often the consequence of degradation (FAOa 2011).

Drivers of desertification and degradation

The drivers of degradation are manifold and interact in complex ways (Geist and Lambin 2004). Positive feedback loops exist between degradation, the loss in net primary production and yield reductions induced by degradation, causing negative outcomes for subsistence agriculture such as declining household incomes. This forces poor people to adopt inappropriate management methods, which lead to overgrazing, deforestation, and further land expansion. Policy implications aiming to change this situation are discussed in chapter 5.

The reasons for the ongoing process of desertification are multifaceted and subject to continuing discussion. Population growth and resultant pressures on the land (reduction of original fallow periods, cultivation of marginal lands, and the expansion of agricultural land through deforestation; FAO 2011b; Diagana 2003) certainly play an important role, in particular for Africa, where population grew about 2.2% annually between 1950 and 2000 (Le Houerou 2009). Population growth, however, must not necessarily lead to degradation processes. In many cases, e.g. by improved management and technological changes, agricultural output can be increased substantially without causing degradation. Poverty is another major factor influencing degradation processes, usually being associated with a limited ability to avoid or counterbalance degradation, e.g. by fertilization (UNU/INRA 1998). Also, many poor rural households have limited access to capital and are hampered by insecure land tenure. Hence, many of the poor are forced to exploit easily accessible natural resources (UNU/INRA 1998; Diagana 2003). As outlined above, land degradation is strongly linked to the welfare of the poorest population group, as they often depend on marginal land due to restrictions in the access of capital and high productive land (UNU/INRA 1998).

Export orientation of the agricultural sector can be an indirect factor causing land degradation, because it can be a driver for the displacement of poor people towards less productive areas. Short-term increases of agricultural output can be achieved by shortening fallow periods. This however leads – in the absence of sufficient fertilizer - to severe nutrition depletion and subsequent degradation (Barbier 2000b, cited in Diagana 2003). Low commodity prices in most countries in Sub-Saharan Africa, pro-urban policies, and high export taxes further aggravate this trend (Diagana 2003).

Another important driver of degradation is deforestation and wood-fuel use: Tree removal on grassland dominated ecosystems is common in many areas and can lead to degradation, because the loss of vegetation cover can lead to increased wind erosion and water runoff, and an accelerated break-down of organic matter which decreases the water retention capacity of soils. This problem is severe in Africa's dryland areas and is highlighted by the fact that according to the FAO (2011) almost 37 million ha of forest and woodland are lost each year in all Africa. Particular attention gained the deforestation of the Miombo forests for commercial tobacco crops (Jürgens 2002). However, wood is still the major source of energy for many African regions (FAO 2011b). In the Sahel, almost 98% of rural and 90% of urban households use wood and charcoal as a primary energy source (Krings 2006). Particularly in densely populated areas and their surroundings, wood resources are strongly depleted for energy purposes.

Degradation due to scrubland invasion is prevailing in the semi-arid and arid Karoo area in the south-west of South Africa (Jürgens 2002). In this area livestock herds traditionally were moved to another place during drought events. Since 1912 all farms have to be delineated by a fence which disables farmers to move their livestock. This results in overstocking, changes in the vegetation cover and degradation.

Assessing the extent of dryland degradation in Africa

We here assess the magnitude of dryland degradation on basis of the study on human induced soil degradation in dry lands conducted by Zika and Erb (2009). This study is focusing on drylands only, covering arid, semi-arid and dry-sub-humid areas, and thus excludes degradation effects in hyper-arid areas in Africa, such as the Sahara or Namib Deserts. Here, the human-induced share of desertification is assumed to be negligible due to the inhabitability of these areas. In Africa around 13 million km² (almost 44% of the continents total area) are situated in dryland areas of which around 3 million km² (10% of the total area) are subject to degradation (Zika and Erb 2009) (see Fig 7). Drylands dominate in Botswana, Djibouti, Egypt, Lybia, Mauritania, Namibia, Somalia and Western Sahara (Dregne and Chou 1992).

Results highlight that dryland degradation is prevailing particularly in regions adjacent to deserts, such as in the Sudano-Sahel, North Africa and the Kalahari regions (Darkoh 1996). Degradation hotspots in Africa are also located in the sub-humid areas of southeastern Nigeria (sandy soils), in the Sahel (mainly wind erosion), North and West Africa (wind and water erosion caused by cultivation mechanization and inappropriate plowing techniques respectively). Arid and semi-arid areas in the north, south and the Sudano-Sahel area are affected most by erosion of rangeland and grazing-land covering countries such as Cameroon, Ethiopia, Kenya, and Nigeria (FAO 2011b). In Southern Africa the countries Namibia, Botswana, south Angola, parts of Zimbabwe, Zambia and Mozambique are prone to processes of desertification (Jürgens 2002).

The area subject to degradation in dry lands in each African country is shown in Fig 7. Please note that this map only displays areas prone to dryland degradation and thus does not contain any information on degradation outside of areas classified as dry lands (cf. Zika and Erb 2009). Also, only areas prone to human induced degradation are included in this analysis. The total area subject to human induced degradation found in Africa in this study amounts to 301 million ha. Apparently, countries in Western and Northern Africa exhibit the highest share of areas subject to human induced degradation which amounts up to 52 % and 42% of the total land area (i.e. Tunisia and Burkina Faso respectively). In Niger the share amounts up to 29%, and in Senegal, Mali and Eritrea up to 23% and 22% are classified as degraded land. In most other countries area prone to degradation makes up less than 20% (Fig 7). Large areas in the Sahel region are subjected to dryland degradation too. These countries show high variability of rainfall patterns, are often subject to drought and are thus ecologically vulnerable at a high degree. In Central African countries, dry land degradation plays a minor role, chiefly because dry land areas and areas prone to human induced soil-erosion are small in these countries.

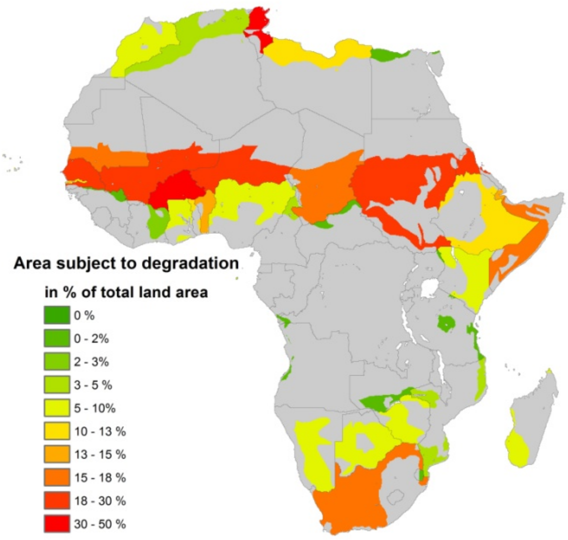

Fig 7 Area subject to human induced degradation in drylands in each country, Note: Areas in grey are not considered as these areas are either not subject to dry land degradation or desert land; Source: Erb et al. 2009a; For detailed figures refer Table 6 , Appendix A.

The study conducted by Zika and Erb (2009) quantifies the amount of NPP lost to dryland degradation. It is based on recent maps of soil degradation (Oldeman et al. 1991; Hoffmann et al. 1999) and a classification scheme of degraded land according to the degree of degradation, discerning four degree classes. NPP losses due to degradation range between 5% and almost 100% of the actual Net Primary Production, depending on the degradation degree class (see Table 1).

Degree	Description	Range of NPP loss
1 (slight)	The terrain has somewhat reduced agricultural suitability, but is suitable for use in local farming systems. Restoration to full productivity is possible by modifications of the management system. Original biotic functions are still largely intact.	5 –25%
2 (moderate)	The terrain has greatly reduced agricultural productivity but is still suitable for use in local farming systems. Major improvements are required to restore productivity. Original biotic functions are partially destroyed.	18 – 50%
3 (strong)	The terrain is non-reclaimable at farm level. Major engineering works are required for terrain restoration. Original biotic functions are largely destroyed.	38 – 75%
4 (extreme)	The terrain is irreclaimable and beyond restoration. Original biotic functions are fully destroyed.	63 – 100%

Table 1 Productivity losses for degradation classes (Zika and Erb 2009). Descriptions from Oldeman (1991; GLASOD)

Productivity losses within the areas displayed in Fig. 7 range between 18% and 50% of the total NPP_0 (in dry land areas subject to degradation). By reducing the productivity of the vegetation cover, these losses substantially contribute to HANPP by contributing a significant share to the overall ΔNPP_{lc}. It has to be noted, however, that the uncertainty related to these flows is large and range between 20% and 38% of the potential NPP (NPP_0) of drylands. To highlight this large range of potential losses we highlight minimum losses and maximum losses separately in fig 8a and 8b respectively. Degradation hotspots are found in Uganda, Eritrea, Western Sahara and Swaziland where a share between 63% and 67% of the total NPP is lost due to dryland degradation. In the Sahel Zone large areas are subject to degradation, however, these do not envisage proportional NPP losses, hence lower degradation degrees prevail. Detailed information on the extent and severity of degradation in drylands for each African country is provided in Table 6, Appendix A. These results, however, have to be interpreted in combination with the extent of degraded area in relation to the total country area (Fig. 7) as only a fraction of the area displayed is actually subject to degradation. For example losses due to degradation in dryland areas in Niger range between 16% (minimum losses; fig. 8a) and 33% (maximum losses; fig. 8b) of total NPP. The extent of drylands subject to degradation in Niger is 29% of the total country area (as displayed in fig. 7). This means that 29% of the total land in Niger is likely to be subject to degradation losses which range between 16% and 33% of the total NPP.

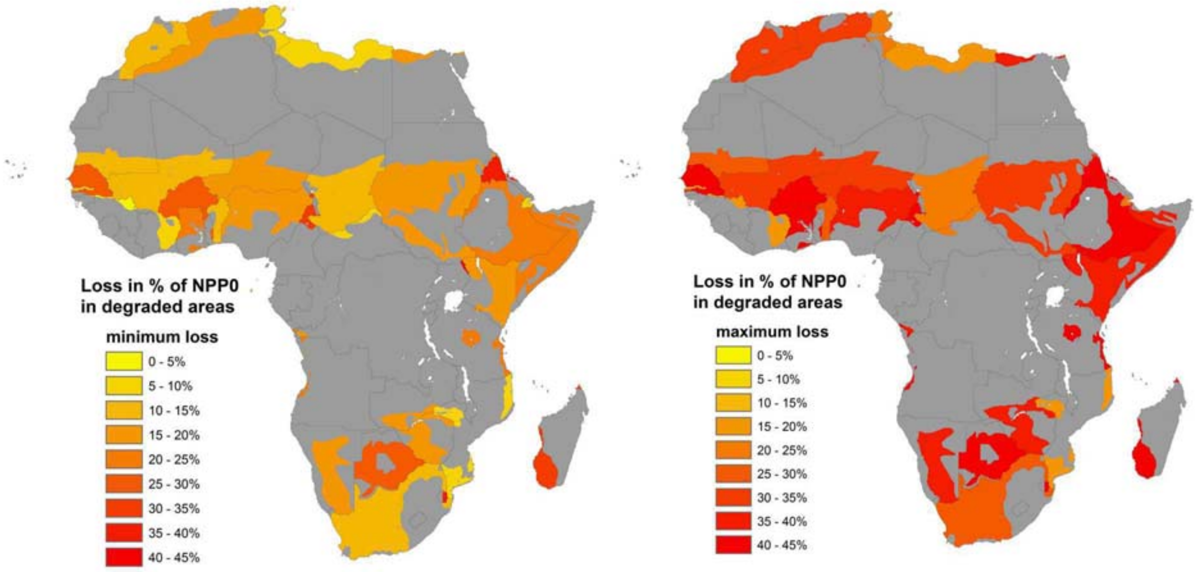

Fig 8. Potential (a) minimum and (b) maximum loss in of NPP0 in degraded areas;

Cost of soil degradation

It is very difficult to determine the economic value of production capacity losses through soil degradation. The actual loss depends on a plethora of factors, such as the variety of crops planted, as well as economic and social conditions. Degradation processes result in a reduction of yield induced by decreasing Net Primary Production. This also means that degradation losses translate into a loss of agricultural GDP. The share of agricultural GDP is known for almost all countries and could be used as a means to determine such losses. It is, however, beyond the scope of this report calculating these costs, but we provide figures on the share of agriculture on total GPD in Table 6, Appendix A. The scale of economic losses due to degradation, however, is significant, as research has shown: Several authors have attempted to estimate the cost of soil degradation on the global scale. Scherr and Yadav (1996) cite studies from the FAO, UNDP and UNEP which estimate the costs of soil erosion to 26 billion US$ per year worldwide, 46% of which origin from developing countries. Dregne and Chou (1992) estimated costs of degradation on cropland, rangeland and irrigated land based on an Australian case study. They estimated the economic loss per ha and year to 250 US$ on irrigated land, 38 US$ on rainfed cropland, and 7 US$ on rangeland. Other studies (e.g. Cohen et al. 2006) analyzed the economic cost of topsoil loss and found a value of 11.000 US$ per ha and year. Cohen et al. (2006) also estimate the total costs of soil loss and forest loss to 7% of the GDP in Kenya. Soil erosion alone amounts to 3.8% of total GDP mainly due to communal livestock production, which is found to be less sustainable compared to other land uses such as subsistence and commercial agriculture (Cohen et al. 2006). Bishop and Allen (1989) estimated losses due to soil erosion in Zimbabwe to 1.5 billion US$ per year of which 150 US$ result from arable land and an average loss of 50 US$ per ha and year on communal farm land.

Restrictions of the analysis

With respect to data quality the results presented here have to be interpreted with caution. According to Zika and Erb (2009), large uncertainties related to the estimate of the extent of degraded area occur because the underlying definitions of degradation vary considerably. For Africa, with the exception of the Republic of South Africa, the only source of degradation information is the GLASOD Database from the late 1980ies, the quality of which is hotly disputed (Sonneveld and Dent 2009; Safriel). Additionally, the information on loss of NPP due to degradation has to be interpreted carefully as most underlying information on loss for certain degradation classes is qualitative. In the study conducted by Zika and Erb (2009) the potential primary production was used as a proxy for the loss due to degradation. This definition of degradation possibly leads to a further bias, as quantitative information on losses often refers to agricultural production potentials, rather than potential production of the vegetation cover.

Trade related biomass flows and embodied HANPP

Embodied HANPP or eHANPP is the amount of HANPP related to the apparent consumption of biomass in a country per year. Compared to the '*original*' HANPP which only accounts for the HANPP related to domestic land use and biomass extraction, the concept of embodied HANPP also considers HANPP associated with imported and exported biomass. It is calculated as domestic HANPP plus HANPP associated with biomass imports minus exports. Looking at the ratio of embodied HANPP and HANPP allows for analyzing biomass consumption dislocated from areas of production and thus for production related impacts on ecosystem services (Erb et al. 2009a; Erb et al. 2009b). Embodied HANPP quantifies the magnitude of all organic carbon flows caused in the production chain of traded biomass (e.g. food, feed, bio-energy, wood products, and textiles, including associated losses of biomass through land-cover change ΔNPP_{LC}).

HANPP associated to trade flows varies strongly by products: animal products, for example are associated with very high upstream HANPP flows, because of the low conversion efficiency from plant to animal products, while HANPP related to roundwood is much smaller. Calculating and illustrating these flows is useful for distinguishing regions that act as net exporters of HANPP (in case they produce biomass surplus and add to the world market), from net importing regions of HANPP (where domestic HANPP is lower than the "consumed HANPP). The results presented are derived from the global study on embodied HANPP (eHANPP) published by Erb et al. (2009a) which presents eHANPP calculations for 175 countries of the world. Please note that some countries such as Réunion, Equatorial Guinea, Somalia, Swaziland, Comoros, Djibouti, and Cape Verde are excluded from this analysis due to the insufficient quality of trade data (cf. chapter 2). For further details on the calculation and applied methods refer Erb et al. (2009a, b).

Fig 9 illustrates patterns of HANPP consumed domestically (eHANPP) in g C per square meter. Peaks of eHANPP/m2/yr are found on densely populated and urbanized areas, reflecting worldwide urbanization trends (Millennium Ecosystem Assessment 2005). Here, eHANPP often exceeds production related HANPP by several orders of magnitude. In Africa hotspots of HANPP consumption are mostly found along the coasts, around the Lake Victoria, in the densely populated Western parts of Nigeria, Benin, Togo, Cote d'Ivoir, and along the Nile River. Globally concentrations of HANPP consumption are depicted for Northern Europe and in particular for Northern India and East China. Within the consumption hot spots eHANPP consumption ranges from 750 to more than 5000 gC/m2/yr. The wide areas of very low domestic HANPP consumption patterns (illustrated in grey color) basically represent countries of low biological productivity and scarcely populated areas.

Fig. 10 depicts the ratio between HANPP and embodied HANPP per grid cell. It is calculated as the difference between HANPP and eHANPP per square meter and shows net HANPP flows, distinguishing net producing from net consuming areas. Net producing areas appear in cold (i.e. blue) and net consuming areas in warm colors (orange, red). Again, net consuming areas are mostly situated in highly urbanized and densely populated areas and appear as small red spots on the map. In contrast, net producing areas are likely to cover broader areas and are often located as broad circles surrounding net consuming spots, highlighting the spatial dislocation of consuming and producing areas due to urbanization trends. In Africa net consuming areas reflect urban agglomerates, where HANPP inflows by far exceed HANPP outflows due to a combination of high population densities and environmental settings (cf. relation between HANPP and population density). But in Africa, net producing areas are spatially limited to smaller patches compared to other producing areas in the rest of the world. Globally regions with the highest net consumption of HANPP are mainly located in North America, South East America, and South East Asia. Particularly in Europe significant heterogeneity within small regions appears to be very common.

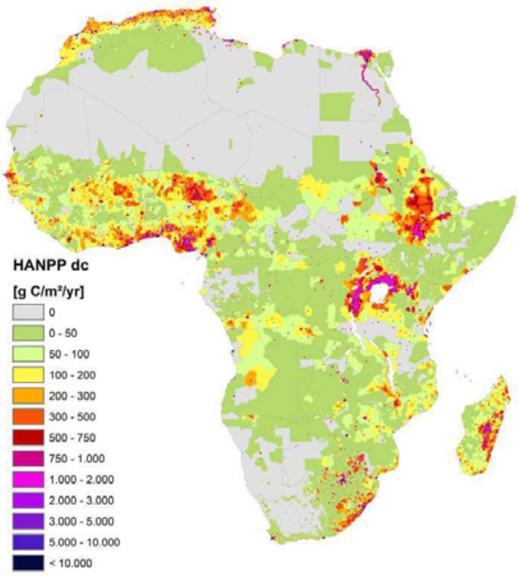

Fig 9 Consumption of embodied HANPP in gC/m²/yr per grid cell

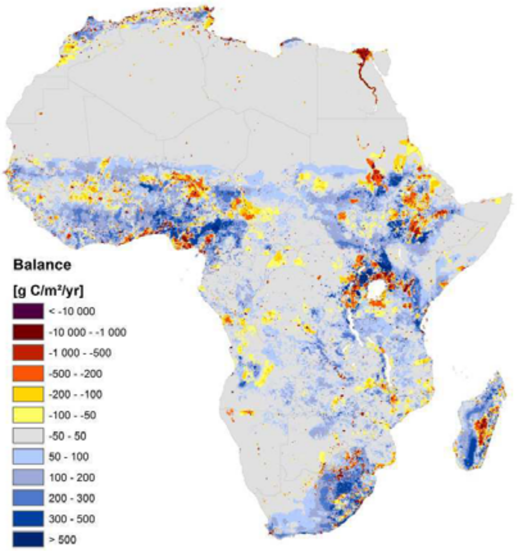

Fig 10 Difference between HANPP and embodied HANPP per Grid Cell

eHANPP patterns as the ratio of domestic HANPP to embodied HANPP (domestic consumption) on a country level are illustrated in Fig. 11. Ratios higher than 100 (highlighted in cold colors – i.e. blue) indicate that these countries produce a surplus of national HANPP, i.e. they are net producing areas which export HANPP (i.e. HANPP associated with exported biomass). Countries highlighted in red are net consuming areas, showing consumption levels higher than their domestic HANPP. These countries increase their domestic HANPP by importing biomass. Net consuming countries with values ranging between 30% and 60% are only found in Northern Africa and globally on the Arabian Peninsula, some European countries and Japan (cf. Fig 29, Appendix B). Highest imports of embodied biomass in Africa can be found in Egypt where the ratio between national

HANPP and eHANPP is even below 30%. The HANPP importing countries are either situated in regions extremely unfavorable for agricultural production (e.g. aridity), or obtain large proportions of urban areas compared to their agricultural productive areas. Globally, countries with high HANPP surpluses are North and South American nations as well as Australia. All these countries exhibit a large country area compared to a relatively small domestic market. Most African sub-Saharan countries, except for Mauretania, Namibia and Eritrea are net producers of HANPP, however, at a low scale (e.g. exhibiting HANPP/eHANPP- ratios of 105% to 120%).

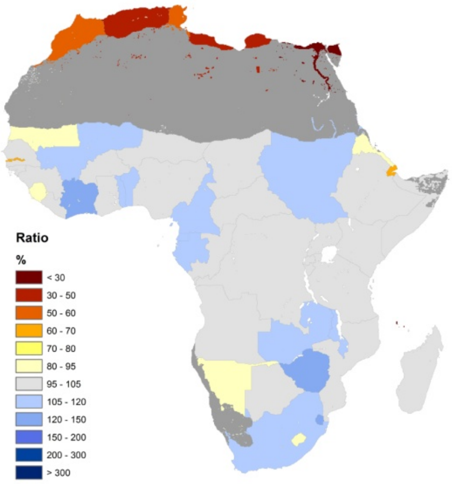

Fig 11 Ratio HANPP to embodied HANPP on a country´s territory (exclusive non-productive area displayed in dark grey).

In addition the share of a country in the global provision and consumption of trade-related embodied HANPP is of interest (Fig. 12). Cold colors (i.e. blue) indicate net producing countries (i.e. countries which are net exporters of embodied HANPP), warm colors (i.e. yellow, orange, red) in contrast indicate net consuming countries (countries contributing to the total global net imports of HANPP). This figure highlights the minor role of most African countries when it comes to global biomass trade. Exceptions are North African countries such as Morocco, Algeria, Libya, and Egypt which are considerable net importers of biomass and global HANPP, i.e. consuming countries. Also Nigeria is among these countries possibly reflecting the high population density of the country. Sudan and South Sudan, South Africa and Côte d'Ivoire are net producing countries, even though their share on the global provision of embodied HANPP is rather low with 0.5 – 5%. The role of most African countries in global transfers of embodied HANPP, however, is of minor importance, ranging between only -0.5 and 0.5 percent. Most countries in sub-Saharan

Africa hardly participate in the global trade of biomass products and embodied HANPP (see also the section on biomass trade in chapter 4).

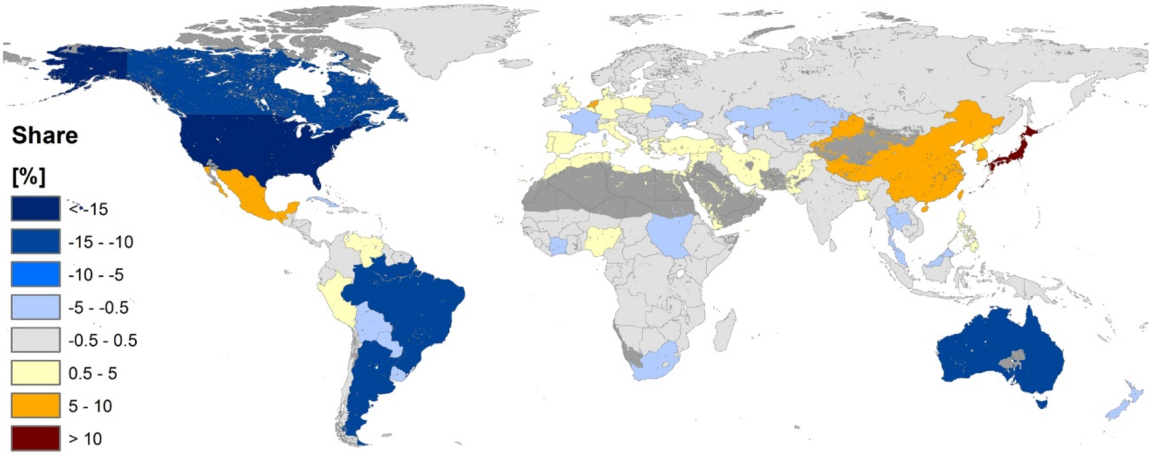

Fig 12 Share in the global provision and consumption of trade-related embodied HANPP (exclusive non-productive areas displayed in dark grey)

The 6 African countries displayed in table 2 account for 87% of the total export-related and 80% of the total import-related embodied HANPP of the African continent. When compared to other exporting and importing countries it becomes evident that Africa's contribution to global transfers of embodied HANPP is relatively low and dominated by imports. Egypt contributes the largest share of all African countries to total global net imports and even ranks at the 11 position on a global level importing 3.35% of the total international transferred biomass of 1.7 Pg/yr (Erb et al. 2009a). The share of the African continent in global net imports of eHANPP is relatively high covering almost 11.5%. The lion's share of these imports is due to the high biomass imports of North African desert states such as Egypt, Algeria, Morocco, etc. On a global level Asian and European countries are the most important biomass importing regions with Japan and China being the two most important global players.

Net importing countries	Share in global transferred HANPP (consumption)	Net exporting countries	Share in global transferred HANPP (provision)
Egypt	3.35%	Cote d'Ivoire	-1.10%
Algeria	2.46%	South Africa	-0.87%
Morocco	1.80%	Sudan	-0.54%
Nigeria	0.85%	Zimbabwe	-0.42%
Tunisia	0.77%	Cameroon	-0.26%
Libya	0.73%	Mali	-0.19%
All African countries	**11.42%**	**All African countries**	**-4.21%**
Japan	13.83%	USA	-23.09%
China	8.67%	Australia	-14.89%
Netherlands	6.24	Argentina	-14.21%
Korea, Republic of	6.00	Brazil	-11.89%
Mexico	5.37	Canada	-10.61%
Italy	4.97	Thailand	-3.81%
Belgium	4.64	Kazakhstan	-3.03%
Germany	4.42	Ukraine	-1.72%
United Kindom	3.81	Malaysia	-1.42%
Spain	3.81	France	-1.30%
Egypt	3.35	Paraguay	-1.28%

Table 2 Share in the global provision (total of all net exports) and consumption (total of all net exports) of trade-related embodied HANPP (Erb et al. 2009a)

When looking at export related eHANPP transfers Africa’s role is even smaller accounting for 4.21% of the total global exports only. Côte d’Ivoire is the continent’s most important exporter of eHANPP contributing some 1.1% to the global total, followed by South Africa, Sudan and Zimbabwe covering 0.87%, 0.54%, and 0.42% respectively. All other countries account for the remaining 1.28%. The most important exporters globally are the USA, Australia, Argentina, Brazil and Canada; together they account for almost 75% of the total (globally) export related embodied HANPP. Detailed figures on the domestic consumption of HANPP and trade related HANPP for all countries can be gathered from Table 8, Appendix A. Table 3 shows the that 66% of all Africans live in HANPP net-importing countries, which cover 55% of the continent’s surface. Apparently 34% live in exporting countries, which cover 45% of the African territory, indicating that population density in HANPP net-exporting countries is lower than in HANPP net-importing nations. On a global perspective African HANPP imports contribute 11.42% of global HANPP imports, while exports only cover 4.21% of the global exports of HANPP. In fact the North African region alone is responsible for almost 82% of all African HANPP imports (not shown in figure), which can be chiefly attributed to the climatic constraints to grow crops in these regions classified as arid and hyper arid. African HANPP exporters are exclusively found in sub-Saharan Africa, however only playing a minor role in the globally trade related HANPP.

	Population [% Africa]	**Area** [% Africa]	**Trade related eHANPP** [% of globally traded HANPP]
Exporters	34%	45%	4.21%
Importers	66%	55%	11.42%
Total Africa	100%	100%	

Table 3 Africa's contribution to total trade related eHANPP (population distribution, covered area and % of globally traded HANPP).

4. Trajectories of HANPP, analysis of the time series with focus on the ten selected case countries

In order to investigate patterns, drivers and trajectories of HANPP, it is crucial to detect HANPP trends over time. Discerning HANPP trends over time allows for integrated discussion of socio-economic and political drivers and pressures and human impact on earth's ecosystems. To provide an overview on how HANPP and its components developed in Africa, ten countries were chosen for a discussion of HANPP trends in the period 1980 to 2005. The selection of these countries is based on three selection criteria, namely country size, quality of available data and the statistical region. The analysis was based on HANPP data for the years 1980, 1990, 2000 and 2005. Of the countries selected, Senegal, the Democratic Republic of the Congo (in the following chapters abbreviated with DRC) are classified as Least Developed Countries (LDCs), South Africa currently has been classified as a newly industrialized country and all remaining countries are classified as Developing Countries (DC). The DRC covers the largest territory and at the same time exhibits very low population density, whereas Egypt, the smallest country, obtains moderate population density (78 cap/km²). The most densely populated country is Nigeria, with 155 people per km², followed by Uganda, with 146 people per km². Most countries primarily rely on agriculture and services and belong to either lower or middle income groups. In 2011 the DRC was considered the country with the lowest HDI (Human Development Index) worldwide, however, several remaining case countries, particularly the LDC-s, were also ranked very low in the year 2011. Algeria as number 96 was ranked highest among the ten countries. Gross national income in 2011 was highest in Botswana which experienced fast economic growth in the 1990s, followed by South Africa and Algeria and it was lowest in the LDC countries (the DRC, Chad, Senegal, and in Uganda). Economies primarily relying on agricultural production typically exhibit higher percentages of people employed in agriculture, however, also Senegal`s and Uganda's service-based economies show a high share of agricultural labor (69% and 76% agricultural population). These figures indicate that agricultural output plays a major role in the countries welfare situations. In many of these countries subsistence agriculture and pastoralism are very common, particularly in rural areas of sub-Saharan Africa and the horn of Africa (Morton 2007). The GINI index classified income distribution as most unequal in South Africa, Kenya and the DRC, and as most equal in Egypt and Senegal in the year 2011.

Country	Region	Development status	Country size [1000 ha]	Pop. density (2005) [cap/km^2]	Income group	Main contribution to GDP	HDI rank (2011)	GNI/ capit (201	Agric. pop. (2005)	GINI coefficient (2011)	Natural resources
DRC	Central	LDC	226,705	26	low	agriculture	187	279	58%	44.4	petroleum, timber, potash, lead, zinc
Chad	Central	LDC	125,920	8	low	agriculture	183	1105	69%	39.8	petroleum, uranium, natron, kaolin, fish
Kenya	East	DC	56,914	63	low	agriculture	143	1491	73%	47.7	limestone, soda ash, salt, gemstones, fluorspar
Uganda	East	DC	19,710	146	low	services	161	1124	76%	44.3	copper, cobalt, hydro-power, limestone, salt
Algeria	North	DC	23,8174	14	upper middle	industry	96	7657	23%	no data	petroleum, natural gas, iron ore, phosphates, uranium
Egypt	North	DC	15,536	78	lower middle	services	113	5269	30%	32.1	petroleum, natural gas, iron ore, phosphates, manganese
Botswana	South	DC	56,673	3	upper middle	services	118	1304	44%	no data	diamonds, copper, nickel, salt, soda ash
South Africa	South	NIC	122,104	39	upper middle	services	123	9469	12%	57.8	gold, chromium, antimony, coal, iron ore, manganese
Nigeria	West	DC	91,077	155	lower middle	services	156	2069	29%	42.9	natural gas, petroleum, tin, iron ore, coal
Senegal	West	LDC	19,253	59	lower middle	services	155	1708	69%	39.2	fish, phosphates, iron ore

Table 4 Country profiles and development indicators for ten selected case study countries. DRC… Democratic Republic of Congo; DC…developing country; LDC…least developed country; NIC…newly industrialized country; HDI…Human development Index, global ranking 2011; GNI…Gross National Income, in constant 2005 PPP$; Gini coefficient…Indicator for distribution of income (high Gini…unequal distribution of income); Sources: World Bank (world development indicators, website), CIA world factbook, FAO (2011d)

The population development of each case country as well as the trend of the proportion of agricultural population to total country population over the last three decades is displayed fig 13. Results highlight that all countries experienced vast population growth over time, with population numbers more than doubling from 1980 to 2005, except for South Africa, Egypt and Algeria, where population numbers grew around 1.7 fold. The number of people employed in agriculture relative to the total country population dropped in all case countries. However, the share of agricultural labor in more industrialized countries such as South Africa, Egypt, and Algeria dropped at faster pace reaching a share of only 13-30% of agricultural population in 2005. Senegal, Kenya, the Chad and Uganda were the countries with the highest share of agricultural population in the year 2005 (around 70%). This indicates that the dependency of livelihoods on the agricultural sector is very high over large African regions, particularly in the poorest countries of sub-Saharan Africa (Uganda, Chad, DRC, Senegal, and Kenya). Considering low agricultural performance and rather inefficient land use systems (see the above chapters on HANPP patterns) which are dominating large parts of these areas, a tremendous vulnerability to climatic induced crop failures and degradation of agricultural land exacerbate African food security (cf. chapter 3, Degradation). From a global perspective the combined effects of rising international demand for biomass for food and energy purposes, and expected price increases for biomass at the world market are furthermore exacerbating social, political and economic stability.

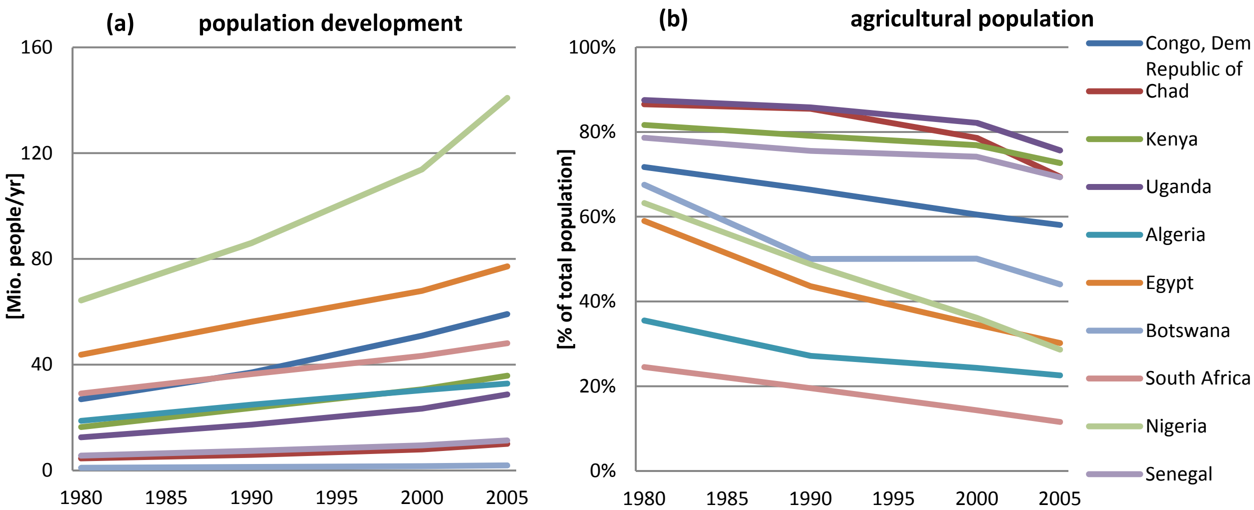

Fig 13 Population development of the ten selected case countries in million people (a) and in % agricultural population of total population (b)

The development of HANPP (in million tons of carbon per year) on the main land use classes (forest land, grassland, cropland, build-up land) for the selected African countries and the entire continent in the years 1980, 1990, 2000, and 2005 is displayed in fig. 14. The overall trends indicate significant HANPP growth except for South Africa and Botswana, were the HANPP trend shows a different pattern. While accelerations were most prominent in Nigeria, Uganda, Chad and Kenya (increases by 72%, 67%, 62% and 55%), the rise in HANPP was moderate in the Senegal, the DRC, Algeria and South Africa (rise by 37%, 27%, 21% and 3%). In Botswana HANPP even declined by 17% from 1980 to 2005 which was mainly due to declining HANPP on grazing land, probably an effect of the 1996 mass slaughters of cattle following the outbreak of cattle lung disease (Darkoh and Mbaiwa 2010).

Special focus has to be laid on the outstanding Egyptian HANPP patterns: HANPP on Egypt's croplands was negative throughout the entire time period, resulting even in a negative HANPP in the 1980s. This positive effect on agricultural productivity was chiefly a result of massive inputs into the land, e.g. large share irrigation and fertilization use. However, HANPP on forest land and grazing land counterbalanced this negative HANPP trend, and values rose from -2.1 million tons Carbon (Mio. t C/yr) in 1980 to around 2.4 Mio t C/yr in 2005 due to increased biomass extraction in the livestock and forestry section. Particularly the livestock sector steadily grew over the last decades, with livestock numbers doubling over the investigated time period (measured in large animal units (LAU)). Negative HANPP in Egypt was a result of the highly industrialized agricultural production system which led to actual productivity surpassing the potential productivity by far und thus resulting in negative ΔNPP_{LC} values. This was chiefly made possible through large scale intensification of the agricultural production systems, particularly by making use of new technologies introduced in the course of the Green Revolution which commenced in the second half of the last century. Almost the entire Egyptian cultivated area is irrigated (FAOSTAT 2011) and fertilizer use per hectare of cropland is by far the highest compared to the other African case countries analyzed in the study at hand (FAOSTAT 2011), (IFA 2011). In 2005, 370.7 t N/km^2 were consumed on Egyptian cropland, compared to 25 t N/km^2 in the Republic of South Africa, a highly industrialized country, or to 0.2 t N/km^2 in the DRC. Thus agricultural yields increased continuously, experiencing a drop back only in the year 2000, probably a consequence of the 1995 fertilizer crisis in Egypt.

The lion´s share of HANPP in Africa results from cropland and grassland. HANPP through grazing accounted for the highest share (over 90%) to the total HANPP in Botswana, which is dominated by large grassland areas. The share of HANPP on cropland to total HANPP was highest in South Africa, the most industrialized country, and in Uganda, where cropland has an exceptionally high share in land use due to favorable bio-geographic and climatic conditions. In Nigeria, Kenya, Uganda and the Chad, the increase of HANPP on cropland was most prominent due to considerable expansion of cropland area. With regard to HANPP on forest land, which is a major contributor to harvested biomass in several countries, it is important to note that here no productivity losses are considered, which is based on the conservative assumption that actual productivity equals potential productivity in forest areas. Thus no productivity losses are considered here, and only harvested NPP contributes to HANPP. Hence, the HANPP contribution of forestry is likely to be slightly underestimated in several case countries, as intensive wood collection and forest grazing can cause degradation on forest land and reduce NPP. In the DRC where forests cover more than 60% of the total country area, the underestimation could be more severe.

HANPP per capita is an indicator on the intensity of biomass appropriation per person and is strongly linked to population density. High HANPP per head levels either indicate very low population densities (e.g. Botswana and the DRC), or high HANPP levels (Uganda). HANPP per head declined considerably in all countries except for Egypt, where HANPP/cap/yr drastically increased due to rising harvest and rising ΔNPP_{LC} levels. This rise in HANPP per capita is attributed to rising HANPP on grazing land, probably related to increasing shares of grazed biomass. The decline in HANPP per head in all other countries was due to population increases that by far outgrew the increases in HANPP. The decline was most pronounced in Algeria, Botswana and South Africa, where despite considerable population growth HANPP increased only moderately (Algeria), or even slightly declined.

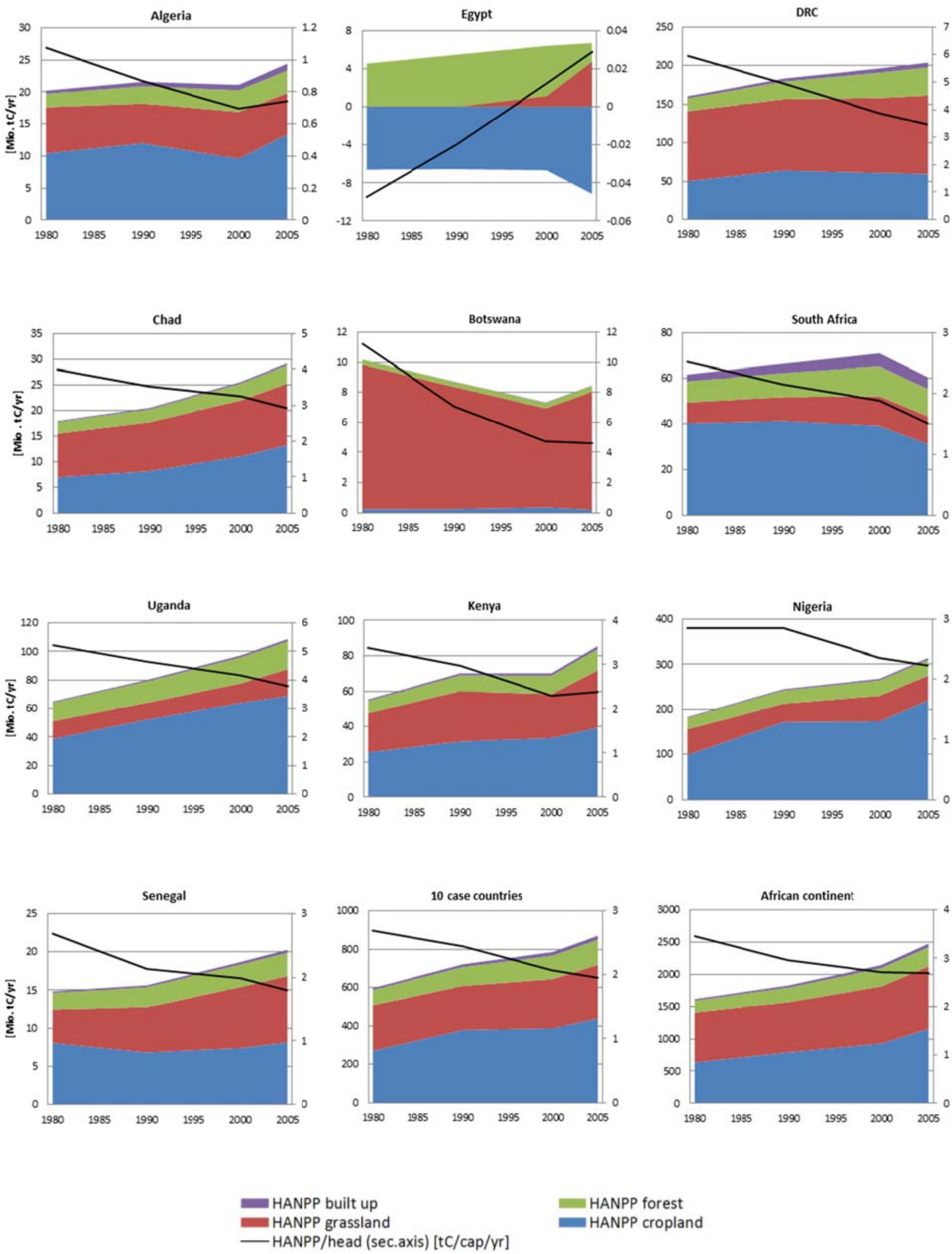

Fig 14 HANPP in Mio t C per year for the selected case countries, as a sum of the case countries and for the African continent

Whereas HANPP in total numbers was highest in the DRC and in Nigeria and lowest in Botswana, Senegal and Egypt, HANPP as a percentage of NPP_0 reveals a different picture. Fig. 15 illustrates HANPP (as percent of NPP_0) split into its components NPP_h and ΔNPP_{LC} and the development of NPP_0 depicted as the black line. NPP_0 shows slightly increasing trends in all countries with strong fluctuations in the desert countries (Algeria and Egypt). High total values indicate that large fractions of the available productivity are appropriated by humans. It is not surprising that in Nigeria, the most densely populated country in Africa annual HANPP is high and grew from 33% to 53% of NPP_0 over time. The HANPP increase was a result of agricultural expansion, with cropland areas experiencing massive expansion over the last decades (almost doubling from 20% to 40% of the total country area). Land use efficiency (the ratio of NPP_h to ΔNPP_{LC}) in Nigeria increased by 40% from 1980 to 2005, which is likely to reflect higher crop yields and simultaneously decreasing productivity losses, due to more intensified land use (e.g. an increase of irrigation and fertilizer inputs). Similar high HANPP levels as in Nigeria have been observed in Uganda, where HANPP rose from 33% to 51% of NPP_0. However, in Uganda land use efficiency was lower and continuously deceasing, indicating that harvest in Uganda is associated with high productivity losses. Fertilizer application in Uganda is among the lowest of the continent, which is chiefly a result of restricted access of farmers to modern agricultural production techniques. Although crop yields in Uganda are naturally high compared to the other case countries that are situated in less favorable climatic regions, there was no sign of yield increases over the investigated time period. Thus increases in agricultural harvests have been an effect of cropland expansion (from 20% to 38% of total country area), rather than of higher outputs per unit of land.

HANPP in Kenya, South Africa and Senegal was clustered at around 20 percent of NPP_0. The increase in Kenya was most prominent (from 17% to 26%), while it grew only slightly in Senegal (from 19% to 22%) and was rather constant in South Africa (around 23%). The low level of HANPP in the year 2000 in South Africa can be attributed to comparably high levels of NPP_0 in the same year. Please note that data quality is a major constraint and these figures are likely to be underestimated as subsistence agriculture often is not fully accounted for in FAO data (FAO 2001). Land use efficiency was lowest and slightly declined in Kenya, where fertilizer use and crop yields grew only slightly over time (Salami et al. 2010). Similar to other eastern African countries, including Uganda, low land use efficiency is a result of many farmers' lack of advanced cultivation techniques. Lacking access to new cultivable land furthermore enhances depletion of the existing land under production and thus often leads to soil degradation. The same trajectories can be found in Senegal too, which experienced declining land use efficiency from 1990 onwards, accompanied by declining crop yields and fertilizer application. This is likely to be a side effect of the economic recession since the 1990ies. However, the ratio of NPP_h to ΔNPP_{LC} is somewhat higher in Senegal than in the above discussed countries. In Senegal NPP_h increased from 11% of NPP_0 in 1980 to 14% of NPP_0 in 2005, while ΔNPP_{LC} remained around 8% over the entire investigated time period. Land use efficiency in South Africa, the most industrialized economy on the African continent, increased over time, except for the period of economic crisis of Apartheid in the early 1990ies, when fertilizer inputs and crop yields drastically decreased (Niedertscheider et al. 2012). Nevertheless harvest in South Africa by far outgrows ΔNPP_{LC}, with NPP_h representing between 60% and 70% of HANPP. Fertilizer use per unit cropland as well as crop yields were second highest in South Africa, and were only surpassed by fertilizer application in Egypt. Botswana, the Chad and the DRC obtain the lowest HANPP values remaining below 15% throughout the time period. Grazing land and livestock production dominate Botswana's agricultural sector, thus the decline of HANPP from 12% to 8% of NPP_0 can be attributed to the declining livestock numbers from 1990 to 2000. Fertilizer inputs in Botswana increased tenfold from 1990 to 2000; however, this trend is not reflected in an increase of yields or of overall land use efficiency. Therefore data on fertilizer production in Botswana should be considered with care and would require further reliability proofs. HANPP patterns in the Chad and DRC, two countries with extremely low household income, clearly reflect the difficult economic situations (Table 4). The territory of the Chad is classified as desert and semi-desert over large areas and is characterized by low agricultural yields, which can be chiefly attributed to the combined effects of agricultural mismanagement, economic recession and partly to fluctuating rainfall, particularly in the northern parts. Land use efficiency in the Chad did not improve over time, reflecting the country's low use of fertilizers per hectare, accompanied by low and stagnating crop yields throughout the entire period. As livestock production is a major contributor to the Chad's economic performance and serves as a basis for livelihood (over 80 % of the country population is considered to maintain subsistence based livelihoods (CIA World Factbook 2009) the increasing livestock numbers (rise by 50% from 1980 to 2005) also mirror the country's drastic population increase resulting in increasing pressure on grazing land, which is already prone to degradation processes (cf. chapter 3 Degradation). HANPP levels in the DRC are very low but show a slight increase from 7% to 9% of NPP_0 in 2005. The DRC, one of the most industrialized economies in the 1960ies, did not experience improvements of agricultural production from the 1980ies onwards: The use of fertilizers and total livestock numbers, already at a low level in 1980, further declined until the end of the investigated time period, while crop yields more or less stagnated. Land use efficiency ($NPP_h/\Delta NPP_{LC}$) in the DRC is very low compared to the other nine case country studies. However it slightly improved as a result of rising harvest of forestry products which, as mentioned above, are not associated with productivity losses. Livestock numbers in the DRC rapidly declined from 1990 to 2005, which is indicating the country's alarming nutritional situation. The DRC experienced severe decline in nutritional supply since the economic crisis in the early 1990ies and recently around 16 million people suffered from chronic malnutrition (Martin-Prével et al. 2000; Buresh and Tian 1997b). Reasons for the severe Congolese food crisis are on the one hand related to the complex land tenure system, which promotes large scale land ownership, and on the other hand to the lack of access to basic agricultural infrastructure, including access to land and to agrochemicals. All these factors favored yield reductions and repeatedly led to crop failures due to pests (Vlassenroot et al. 2007). The two recent conflicts (the First and Second Congo Wars) that commenced in 1996 left the country war torn and in economic recession.

HANPP on the African continent and for the total of the ten countries discussed in this section increased by about 54% from around 13% in 1980 to around 20% of NPP_0 in 2005. However, land use efficiency for the entire continent was rather low and did not improve over time. The contribution of ΔNPP_{LC} to HANPP outgrew the growth of biomass harvest throughout the entire time period, indicating large indirect productivity losses that accompany agricultural harvest in Africa. These HANPP patterns are likely to mirror the interplay of several factors including the widespread lack of access to modern cultivation techniques, failures to restore degraded land and to combat degradation, as well as the expansion of agricultural land at the cost of forest land. For more information on the risks of ecological and economic losses caused by degradation refer to the degradation chapter (cf. chapter 3, Degradation). This trend is alarming, particularly when compared to European and South East Asian conditions, where the contribution of ΔNPP_{LC} to HANPP was reduced dramatically since the second half of the last century and the HANPP increase came to a halt, or even declined in the last decades (however, HANPP in these industrialized world regions is at a significantly higher level compared to HANPP in Africa).

Low levels of HANPP in relation to the potential productivity in general indicate a lower anthropogenic impact on natural ecosystems. Several African countries analyzed in this section exhibit moderate to low HANPP values. From a mere ecological perspective, low HANPP levels are very promising: Low HANPP levels imply high levels of productivity that remains in the ecosystems after harvest, and thus has positive feedbacks on vital ecosystem functions such as biodiversity. From a socio-economic perspective, however, the very low but increasing African HANPP levels indicate inefficient land use systems, in which increases of harvest (NPP_h) are associated with massive productivity losses (ΔNPP_{LC}). No major increases in current productivity and agricultural yields respectively have been achieved in the last decades and increasing HANPP was mainly an effect of cropland expansion. The high level of poverty prevailing in many countries analyzed in the study at hand is strongly related to degradation, limited access to modern agricultural production techniques, restrictive land tenure systems and other related issues. Current HANPP trends highlight that land use is inefficient and below global average in many African countries. Therefore much hope for future social, economic and political welfare in Africa is expected from measures to increase future land use efficiency through e.g. applying appropriate agricultural policies, restoring degraded land, improving access to advanced cultivation means, promoting educational programs and many more. In the final section of this report we address some policy implications for the improvement of the current situation of African land use. Please note, however, that results of this study have to be viewed in the light of constraints of data quality (see also chapter 2, Data availability and quality). It is therefore possible that the presented results considerably underestimate HANPP values for African countries.

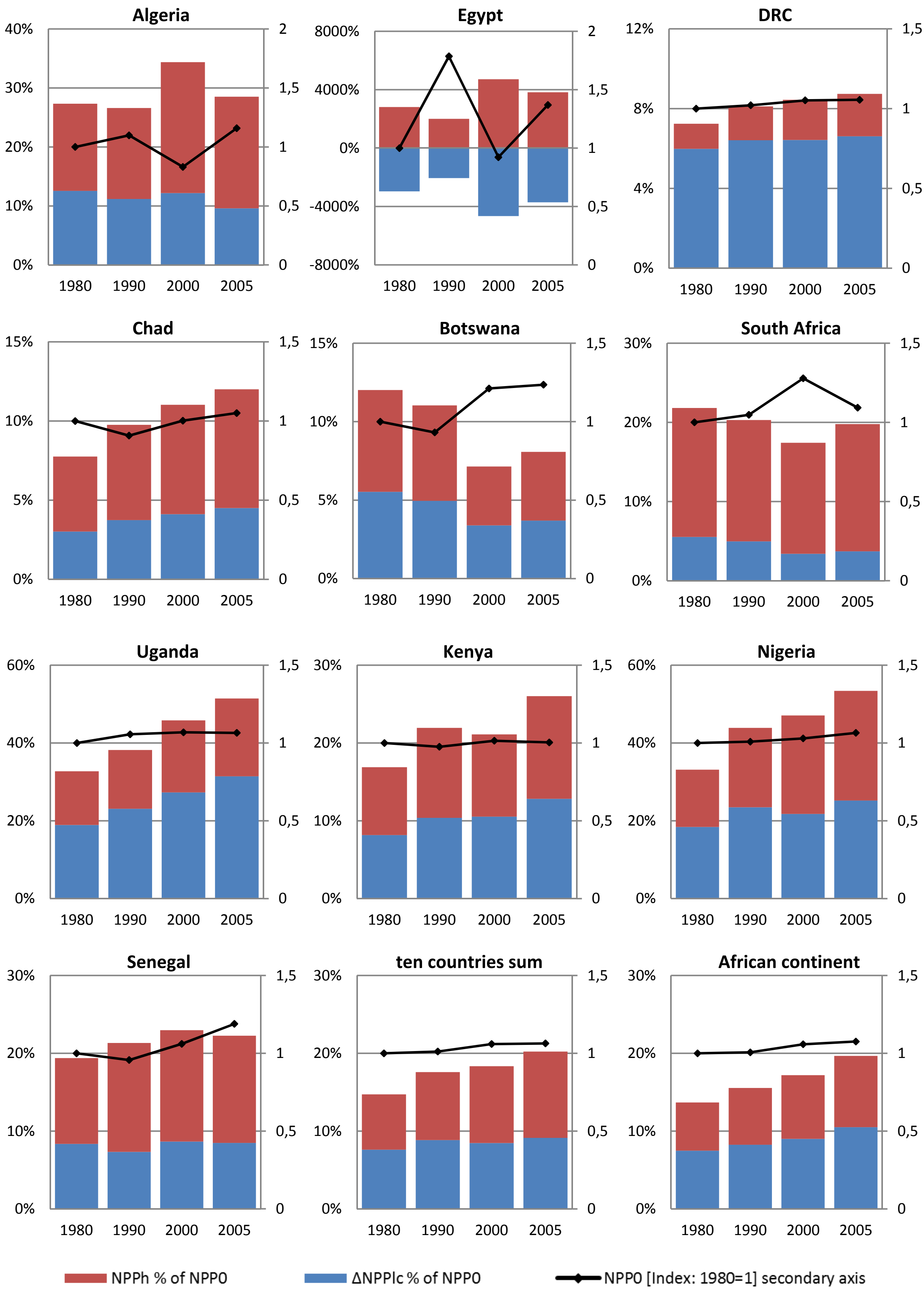

Fig 15 Development of NPP_h and ΔNPP_{LC} as percentage of NPP_0 from 1980 to 2005; Second axis: Potential NPP (NPP_0); (Index: 1980=1; black line)

HANPP trends for Africa on a regional scale are summarized in Table 5. In the period from 1980 to 2005 HANPP expressed in tons Carbon per year increased in all regions, with West Africa experiencing the strongest growth of almost 84%. The lowest growth by 10% of HANPP was observed in Southern Africa. HANPP in % of NPP_0 increased in all parts of Africa, again facing the strongest growth in West Africa where it increased by almost 65%. Also ΔNPP_{LC} in % of NPP_0 increased in all parts, showing the lowest increase in Central Africa and again the highest increase of 56% in West Africa. Increasing HANPP is, however, likely to reflect an expansion of the agricultural land at the expense of woodlands and natural grasslands. The ratio of harvested NPP to indirect productivity losses ($NPP_h/\Delta NPP_{LC}$) increased by 6% over all Africa from 1980 to 2005, indicating increasing HANPP efficiency (decreasing ΔNPP_{LC} and increasing harvest), however, only at a modest rate. The highest rates were found in Central Africa followed by West Africa (increase by 45% and 14% respectively). The remaining regions exhibit decreasing ratios, indicating declining HANPP efficiency, here the decrease of $NPP_h/\Delta NPP_{LC}$ in South Africa was most pronounced.

Change of HANPP in Mio t C/yr	**1980**	**1990**	**2000**	**2005**	**Change in % 1980 - 2005**
North Africa	53	62 (+18%)	58 (-6%)	79 (+35%)	50%
East Africa	682	760 (+12%)	908 (+20%)	1.058 (+17%)	55%
Central Africa	343	364 (+6%)	407 (+12%)	434 (+7%)	27%
West Africa	424	520 (+23%)	621 (+19%)	781 (26%)	84%
South Africa	116	123 (+6%)	133 (+8%)	127 (-4%)	10%
Total Africa	1.617	1.828 (+13%)	2.128 (+16%)	2.479 (+17%)	53%
Change of HANPP in % of NPP_0	**1980**	**1990**	**2000**	**2005**	**Change in % 1980 - 2005**
North Africa	34,0%	33,6%	42,8%	40,2%	+18%
East Africa	15,2%	17,3%	19,5%	22,5%	+48%
Central Africa	7,2%	8,0%	8,6%	9,1%	+26%
West Africa	22,0%	26,7%	30,9%	36,5%	+65%
South Africa	23,6%	24,6%	21,3%	23,0%	-2,6%
Total Africa	13,7%	15,8%	17,5%	20,0%	+46%
Change of ΔNPP_{LC} in % of NPP0	**1980**	**1990**	**2000**	**2005**	**Change in % 1980 - 2005**
North Africa	15,5%	18,6%	31,1%	20,7%	33,8%
East Africa	8,2%	9,1%	10,5%	12,4%	51,1%
Central Africa	5,8%	6,2%	6,4%	6,7%	15,8%
West Africa	12,9%	15,1%	16,1%	20,2%	56,1%
South Africa	3,5%	4,7%	5,5%	4,5%	28,1%
Total Africa	**7,5%**	**8,3%**	**9,1%**	**10,7%**	**42,3%**
Ratio NPP_h/ ΔNPP_{LC}	**1980**	**1990**	**2000**	**2005**	**Change in % 1980 - 2005**
North Africa	-3.19	-2.81	-2.37	-2.94	-8%
East Africa	0.86	0.89	0.86	0.82	-4%
Central Africa	0.25	0.30	0.35	0.36	45%
West Africa	0.71	0.77	0.91	0.81	14%
South Africa	5.71	4.18	2.83	4.10	-28%
Total Africa	0.83	0.90	0.92	0.88	6%

Table 5 Changes of HANPP in %, HANPP in % of NPP_0 and ΔNPP_{LC} in % of NPP_0 per African region 1980 – 2005 and ratio of NPP_h to ΔNPP_{LC} of 1980, 1990, 2000 and 2005; Source: Haberl et al. 2007

Indicators on land-system change

Indicators of land system change have already been discussed to some extent in the previous section. The overall picture presented in fig. 16a reveals an extremely low level of fertilizer application in most African case countries, except for South Africa and Egypt. In contrast to many Asian and European countries which quickly adopted modern cultivation methods and continuously increased crop yields over the last decades, African crop yields (fig. 16 b) did not rise, but rather declined, as it was the case in the DRC or in Kenya. The same is somewhat true for the trajectories of land use efficiency (fig. 16 d) which also stagnated in several of the investigated countries. The reasons for this are related to lacking agricultural infrastructure, low household incomes, and lacking access to agricultural expertise, to armed conflicts and restrictive land tenure systems (De Soysa et al. 1999; Sanchez 2002). Many developing regions currently only achieve a relatively small share of their yield potential. Closing the existing yield gaps is considered a chance for warranting future biomass demand and food security (Foley et al. 2011). However massive yield increases in the industrialized world have been achieved through drastic increases of inputs (mineral fertilizers, irrigation) into the land, which can have detrimental effects on ecosystem services as well as on greenhouse gas emissions. These effects are not detected within the HANPP account, but also are crucial factors when discussing sustainable land use.

Moreover fossil energy carriers are expected to get scarcer and thus more expensive in future. Thus the sustainable development of African land use should to a large extent rely on renewable resources, in order to avoid path dependency on fossil energy carriers. The development in the livestock sector presented in fig 16c is shown in relation to the country's population (numbers of livestock per capita). Note that livestock numbers in absolute terms did increase considerably in all countries except for South Africa where the trend was constant, and in Botswana where livestock numbers decreased. However, the figures reveal that livestock growth more or less kept pace with the tremendous population increases in several countries, except for Botswana, were the drop was most prominent. This trend in combination with increasing amounts of imports of animal products reported for several African countries indicates a transition to a more protein based diet observed in many developing countries. This change in diet is likely to pose further pressure on African ecosystems, as additional area will be needed for the maintenance of growth in the livestock sector. Where no surplus area for grazing and fodder crop production is available, livestock will increasingly become a food competitor to human beings. Issues such as deforestation in order to meet the growing demand for grazing land and land degradation due to overgrazing can even further exacerbate regional intactness of basic ecosystem services.

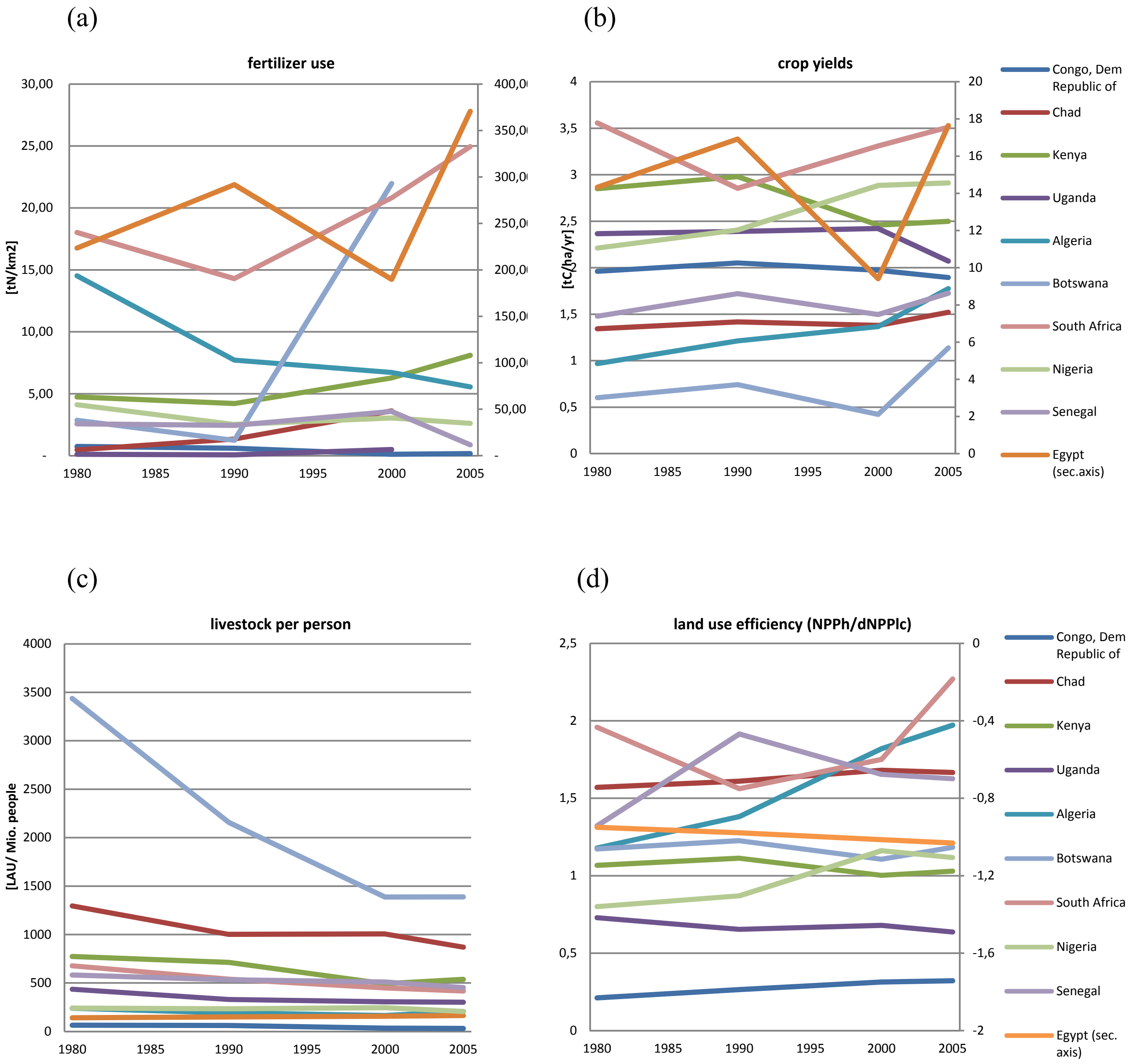

Fig 16 Indicators of land system change: (a) Fertilizer consumption(Egypt on secondary axis) , (b) crop yields,(c) livestock development (Egypt on secondary axis) and (d) land use efficiency for the ten selected countries from 1980 to 2005 (Egypt on secondary axis)

Biomass trade – imports and exports

The development of biomass trade in the ten case countries and for the African continent is displayed in fig. 17. Note, that in this chapter only biophysical trade without taking into account the HANPP fraction associated with traded biomass (embodied HANPP). However, traded agricultural commodities imply embodied HANPP at differing scales: Meat imports are associated with much higher HANPP in the exporting nations than agricultural biomass and forestry products, which is mainly due to the low conversion efficiencies from plant biomass into meat. Unfortunately there are no time series on embodied HANPP (eHANPP) available at the moment. For a detailed analysis on eHANPP flows in the year 2000 refer to the chapter on Trade related biomass flows.

Most African case countries appear as net importers of biomass and show increasing net imports from 1980 to 2005. Exceptions were the Chad, Uganda and South Africa, where exports were higher than imports until the year 2000. In Egypt and Botswana net trade declined from 2000 to 2005. Whereas the Chad largely exported cattle meat and agricultural products, South Africa is a huge net exporter of forestry products. Also the DRC mainly exported forestry products in the observed time period. In Uganda mainly coffee, tea and tobacco contributed to net biomass exports in the last decades. The Chad and Kenya were the only meat exporting countries in 2005, however, at declining rates from 1980 to 2005.

Overall, imports of plant biomass contributed the lion's share to the high increases in biomass imports. Imports of animal and wood products were less significant. Reasons for the growing reliance of African countries on biomass imports are related to the growing African population and increases of food requirements on the one hand and to the low agricultural performances of many countries on the other hand which were already discussed in the previous sections. Particularly the North African desert countries, Egypt and Algeria, meet their domestic biomass demand almost exclusively by biomass imports. These countries are characterized by very small areas suitable for agricultural production, which are, however, used very intensively, whereas many sub-Saharan countries that are situated in climatically more favorable regions, are lacking agricultural input means (fertilizers, irrigation, machinery…).

Due to low household incomes and expected increases of agricultural commodity prices on the world market, the dependency on biomass imports of African countries is alarming and threatens food security, especially for the poorest households. In order to guarantee food provision and to achieve independence from imported biomass, it has been suggested to promote productive small scale subsistence farming (Baipheti and Jacobs 2009). However, a trend towards the other direction has been observed recently: due to restrictive land tenure systems, increasing land degradation, lack of access to irrigation and knowledge, and rather a tendency towards abandonment of subsistence based agriculture and increasing dependence of poor rural households on market products has been recorded. Reversing this trend by providing small scale farmers with the most crucial assets for the cultivation of land (land, water, fertilizer and human capital), would be essential for reducing the vulnerability towards inflation, prize fluctuations and land degradation (Baipheti and Jacobs 2009).

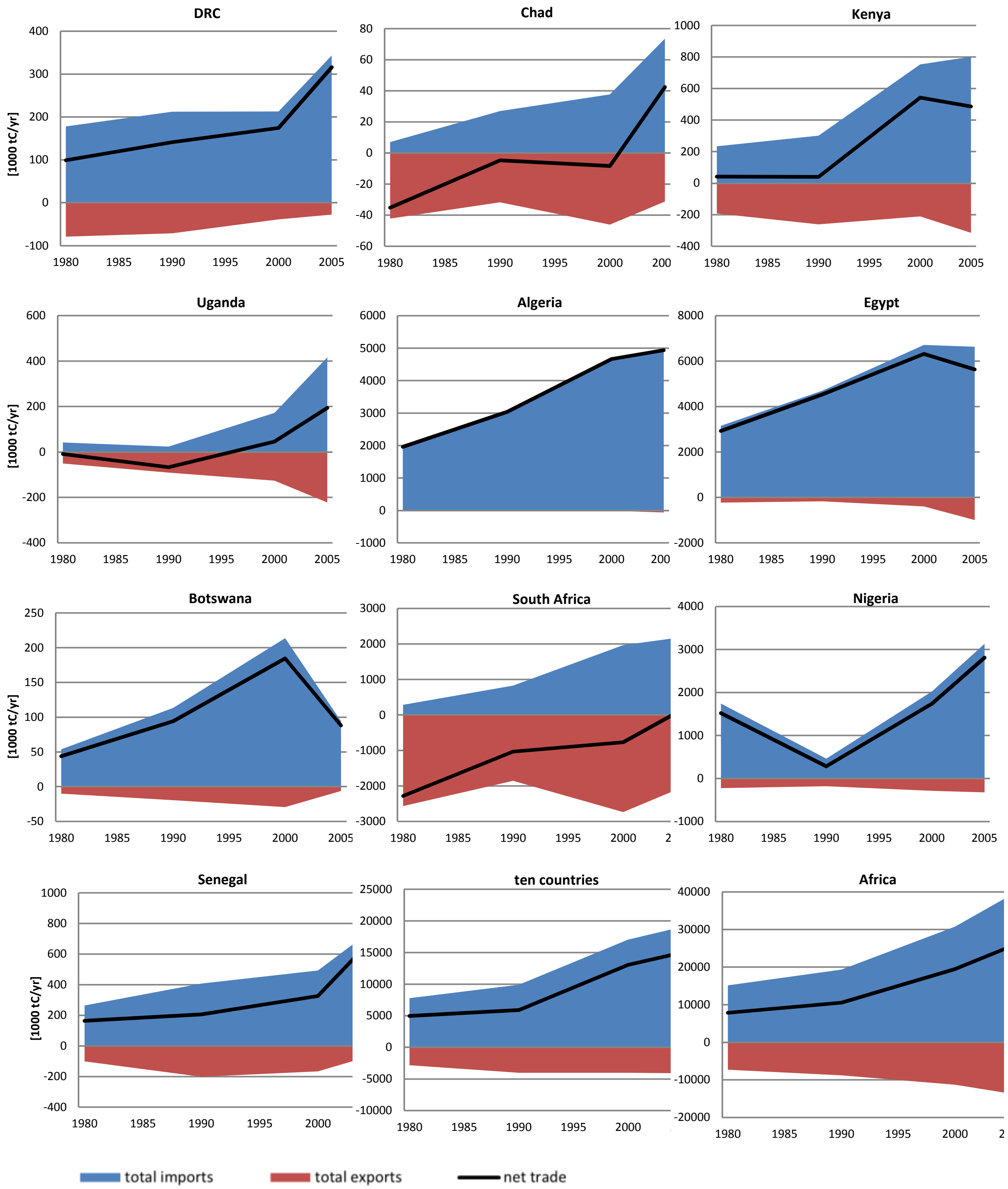

Fig 17 Development of net trade, imports and exports of biomass. Sources: FAO statistical database, own calculations

5.Summary and conclusion

HANPP in African countries is mostly rather low. Exceptions are Rwanda, Uganda, Burundi, Nigeria, Togo and Côte d'Ivoire. The high level of HANPP in these countries is likely to result from high population densities. Population grew almost 2 fold in the period between 1980 and 2005 and countries with a high population density, however, usually have low levels of HANPP per capita such as it is the case in Nigeria. This can be explained by low availability of biomass and hence a strong pressure towards either low consumption levels or efficient use of biomass in countries with little resource endowment in terms of low availability of fertile land per capita of human population (Haberl et al. 2012). The proportion of land use induced productivity losses (ΔNPP_{LC}) to total HANPP is relatively high in Central African countries such as Angola, Madagascar, Congo, Zambia, the Democratic Republic of Congo, and Gabon. Also some Western African countries like Cameroon, Togo and Côte d'Ivoire have high levels of ΔNPP_{LC}. Reasons for this have to be evaluated for every country separately, but it seems likely that they result in many cases from land cover change (replacement of highly productive natural vegetation with less productive agro-ecosystems) and hence from inefficiencies in agricultural systems. Losses due to dryland degradation discussed in chapter 3, however, are not clearly visible in ΔNPP_{LC} values as these are restricted to dryland areas, whereas the ratio ΔNPP_{LC}/HANPP as shown in Fig 6 relates to the total productive country area. Most other countries show a relatively high share of harvest on total HANPP, indicating either an efficient agricultural system (like in South Africa) or a low status of land conversion from natural vegetation cover into other land uses (as expected to be the case in Somalia).

When looking at the development of HANPP between 1980 and 2005 a generally increasing trend is evident. Total HANPP increased in all African regions with West Africa having experienced the strongest growth about almost 84% of its value in the 1980´s. The lowest growth of HANPP was observed in Southern Africa. Increasing HANPP is likely to reflect an expansion of the agricultural land through land conversion (e. g. replacement of forests by pasture or cropland).

Looking at the development of HANPP compared to the potential net primary productivity (NPP_0) is crucial for understanding the relation between human appropriated biomass and the potential productivity of a country's ecosystems. HANPP as % of NPP_0 increased in almost all parts, with the exception of South Africa. West and East Africa experienced the strongest growth with a plus of 65% and 48% respectively. Despite that the total appropriation is highest in North Africa where 43% of the total NPP was appropriated in 2000. Kleidon (2006) argues that high levels of appropriation possibly result in a reduction of vegetative growth. Based on this Moriarty and Honnery (2009) interpret levels higher than 40% as self-defeating. However, higher levels of HANPP generally indicate increasing pressure through human appropriation of NPP on natural ecosystems.

The results of the analysis on human induced degradation in drylands (Erb et al. 2009a) suggest a considerable contribution of NPP losses to total HANPP through degradation in these areas. These average losses range between 18% and 50% of the total potential NPP per hectare of affected land, whereat maximum losses can range up to 67% of the total NPP. As dryland areas are particularly vulnerable this can substantially undermine the livelihood of people living in such areas. As discussed in chapter 3 Degradation the underlying processes causing degradation are complex and various. Some of the related processes are population growth, deforestation, and degradation resulting from a combination of different underlying socio-economic obstacles for agricultural performance amongst smallholders, such as an insecure legal framework for land owners, the difficult access to capital, a lack of infrastructure, poverty, and inappropriate land use techniques.

Trade patterns

The study on embodied HANPP considers inter- and intraregional transfer of (trade-related) HANPP and shows net consuming and net producing areas. Consumption of embodied HANPP is highest in strongly populated areas. All North African countries are pointed out as not being self-sufficient, thus relying upon imports of HANPP to cover their own demand. Most other countries are net exporters of embodied HANPP as their production exceeds their consumption. However, these values only describe the global patterns of eHANPP split into producing and consuming areas and do not imply that African countries are self-sufficient regarding all agricultural commodities. In fact, many African countries are still dependent on large amounts of biomass imports. With regard to the global transfer of trade related HANPP African countries account for up to 11.4% of total imports and 4.2% of exports. The bulk of exports from African countries (91%) result from low population density developing countries covering 34% of the total population. Dominant importing countries in Africa are low density developing countries which make up for 89% of the total imports and are clearly dominated by North African states. However, importing countries cover almost 55% of the total land area and 66% of the total population. In conclusion the African role in the global transfer of eHANPP is rather minor and certainly dominated by imports of which the bulk is targeted towards North African desert countries.

HANPP time series

Trajectories of HANPP for the ten African case countries from 1980 to 2005 reveal increases in HANPP, except for South Africa and Botswana, were HANPP followed different patterns. HANPP increases can mainly be attributed to rising HANPP on cropland and grazing land, reflecting the growing demand for biomass caused by population growth, rising livestock numbers and accelerating losses of productivity caused by land transformation and degradation. Anyway, when looking at absolute HANPP figures the effects of country size have to be taken into consideration. With regard to the comparability of HANPP figures it is crucial analyzing HANPP as a percentage of the potential productivity (NPP_0). Here HANPP levels correlate positively with population density. High population densities go hand in hand with higher levels of HANPP as % to NPP_0, which was the case for Nigeria and Uganda in particular. In contrast, scarcely populated DRC, the Chad and Botswana show lower levels of HANPP. Additionally analyzing trajectories of HANPP reveals much about a country's land system state. Unlike many European countries, which were able to increase the fraction of harvest to HANPP over the last decades, while decreasing the fraction of ΔNPP_{LC} through advanced agricultural production means, many African countries exhibit high fractions of ΔNPP_{LC} to total HANPP, which either only slightly decreased, or rather stagnated over time. This was particularly true for the DRC and the eastern and western African countries discussed here. ΔNPP_{LC} made up for 80% of HANPP in 2005 in the DRC and around 50% in the other countries mentioned before. However, also other African countries exhibit high ΔNPP_{LC} values, except for South Africa and Egypt, where agriculture was optimized by introducing modern cultivation techniques in the last decades. High indirect losses of ΔNPP_{LC} are often attributed to insufficient agricultural systems, lacking access to productive land, advanced cultivation techniques and lack of agricultural expertise. Relations to economic recession and armed conflicts in this matter are obvious; however, they cannot be discussed in detail here. On the other hand an increasing dependency on agricultural imports has been recorded in order to meet the population’s biomass demand. This trend is alarming, particularly in the light of worldwide trends towards higher biomass consumption rates and rising demand for bioenergy. Therefore increasing yields by enhancing a more productive agricultural system is a prerequisite for establishing food security on the African continent.

Ecological Footprint and HANPP

When looking at the development and patterns of HANPP it is also of interest to compare the findings with other prominent indicators such as the Ecological Footprint (EF). However, there are fundamental differences in the calculation and results between HANPP and the EF calculation. The EF indicator focuses on the total consumption and all related resources in a country whereas HANPP accounts for biomass related extraction of NPP within a defined area, e.g. within the country borders of a nation. The calculation of embodied HANPP is an enhancement of the HANPP analysis such as it accounts for trade flows of biomass between regions and countries. According to Wiedmann and Barrett (2010) the EF calculation is missing strong links to agriculture, land use practices, and biodiversity. Approaches to calculate bio productivity based on the concept of Net Primary Production (NPP) are regarded as useful in context with the above mentioned missing links (Wiedmann and Barrett 2010). The HANPP indicator, however, is based on the concept of NPP and is therefore strongly interlinked with ecosystem intactness by tracing the provision of energy to ecosystems, food webs and ecosystem services. By altering the energy available to ecosystems, HANPP also strongly influences biodiversity (Krausmann 2009). The strength of HANPP, however, is to relate the impact of human land use practices to the potential conditions of the natural ecosystems.

When looking at the development of EF and HANPP in Africa several differences in the development over the last decades appear. The Ecological Footprint in Africa at a glance rose from 1.0 global hectares (gha) per person in 1961 to 1.1 gha in 2003 (WWF 2008), whereas HANPP per person decreased by about 37% in the time between 1980 and 2005. As the EF demonstrates biomass consumption pattern, while HANPP focuses on biomass extraction in between a defined area, these findings are not contradictious. While the results for EF per person exhibits increasing biomass consumption per head over time, declining HANPP per capita rather mirrors the drastic African population growth, which by far outgrew the HANPP increase. Moreover there has been observed a general shift from biomass export to biomass import oriented economies, which in addition indicates increasing biomass consumption patterns. Likewise the continent's bio-capacity declined from 3.0 gha per person in 1961 to 1.3 gha per person in 2003, which reflects the population increase in the case of the EF approach. In general the EF as well as the HANPP approach trace human impacts on earth's biosphere, however, through different means. The trend detected by analyzing HANPP is well in line with the findings from the footprint calculation indicating an increasing exhaustion of biomass resources mainly through the expansion of land, inappropriate land use practices (related to strong population growth and increasing poverty), and human induced degradation in drylands. As both concepts exhibit strengths and shortcomings, integrating the findings of both approaches can be useful for gaining an integrated picture of patterns of the human domination on Earth's ecosystems.

Policy implications

The results presented here show that there is high demand for policy improvements in many fields. Many problems the continent is currently facing are strongly interwoven, and therefore need to be addressed by an integrated, systematic approach covering all related policy fields. Priority issues include poverty, human induced degradation in drylands and high population growth (particularly in urban areas). All of these factors can be directly attributed to failed states, armed conflicts, corruption and restrictive land tenure systems prevailing in many of these countries. Policy reforms and governance strategies aimed at stabilizing and subsidizing agricultural performance are regarded central in order to guarantee returns of agricultural investment of many small scale producers and are crucial for warranting future food security. Comparing patterns of biophysical biomass trade of the ten case countries discussed in chapter 4 of this report (cf. chapter 4 Trajectories of HANPP; Fig. 18) to patterns of trade related HANPP (eHANPP; cf. chapter 4) reveals that while in the eHANPP approach most sub-Saharan countries appear as net exporters of HANPP, they appear as net biomass importers when considering only biophysical biomass trade (e.g. as reported in the FAOSTAT). This hints to the fact that despite exports from sub-Saharan Africa are moderate (as most countries are net importers of biomass), these exports are associated with a high HANPP rucksack and thus cause high productivity losses (ΔNPP_{LC}) in the African regions of biomass production. North African countries however appear as net importers of biophysical biomass as well as of eHANPP. As a conclusion the eHANPP results highlight the fact that trade is not the solution to problems, rather policies should focus on the establishment of a productive agricultural system by enhancing agricultural efficiency and reducing indirect productivity losses (ΔNPP_{LC}). Knowledge transfer and the advancement of adequate infrastructure are central for mitigating food shortages and enhancing small scale farming in the developing world. In the past years Africa, particularly sub-Saharan Africa, experienced a tendency towards the acquirement of agricultural land at large scale by high populated countries such as China and India. Leasing foreign land for agricultural production is often considered an alternative for purchasing food or biofuels from the world market by these countries which are likely to experience food shortages in the coming decades. This issue, widely known as *'land grabbing'* became particularly important in the Sudan, Ethiopia, Madagascar and Mozambique, where almost 2.5 Mio hectares of land have been leased by foreign companies since 2004 (Cotula et al. 2009). If this trend is to be continued and foreign nations continue to establish intensive agricultural systems in these countries, future HANPP levels will change dramatically and system boundaries will have to be redefined. However, this development often goes on the cost of the local population, i.e. by restricting the access to land and resources. Harvested biomass products often are exported and the profit achieved does not add up to increasing wealth of the local population. Rather the depletion of the natural resources goes on cost of the local population and international companies gain profit out of it (Cotula et al. 2009).

However, the reasons for agricultural underperformance are often to be found in a country's political history. Sub-Saharan agricultural policies in the 1980 and 1990s were characterized by market liberalizations and the reduction or removal of subsidies and taxes. Diagana (2003) states that these reductions have led to a rise in input prices, whereas at the same time investments in infrastructure were decreasing. Also investments into natural assets such as the conservation of soil and water declined following these changes. Since the mid 1990's, new policy approaches such as good governance (bottom-up processes), increasing democratization and community based approaches have gained attention as means for improving living standards for many African citizens. There have been attempts to establish a focus on the encouragement of knowledge (schools and research), and better access to capital. However, policy changes are absolutely necessary, particularly in low income countries and countries facing a food deficit (FAO 2011b) given that in order to keep pace with the rapid population growth, some 4% of annual growth in productivity would be necessary. In fact, agricultural productivity grew around 2% between 1965 and 1980 and about 1.4% in the 1990's (UNDP/UNECA Report, cited in Diagana 2003), reflecting the need for change.

Additionally the FAO (2011b) identifies high taxes on crops, a lack of research in the agricultural sector, and a lack of investments into infrastructure as the most important issues hindering high agricultural performance. However, these obstacles have to be addressed thoroughly in the future, as the agricultural sector is the main source of income for many and makes up for 1/3 of the total GDP and ¾ of employment (FAO 2011b). Different factors such as strong population growth, restrictive land tenure rights, political instability, and failures to incorporate local knowledge were blamed for the problems Africa is currently facing (Koning et al. 2001). In order to tackle future challenges, a combination of technological and policy approaches is necessary. Several policy areas such as input and output markets, credit systems, infrastructure, and institutional support need to be reviewed (Dregne and Chou 1992; Diagana 2003). A successful approach towards improving current situation should attempt to include all fields related to the triple bottom line approach, focusing on economic, social, and environmental issues.

In the light of the results of this report we recommend, based upon other authors, policy actions in the following areas:

- Introduction of an efficient legal framework which allows adequate management of land use rights (Koning et al. 2001)

- Ensure local communities profit from the policy changes. Fighting poverty is one of the key elements when fighting against the exhaustion of land resources. Poor households should be able to compete for resources with wealthy households (UNU/INRA 1998). Community based organizations and projects promote the transfer of knowledge between individuals and places (Sanchez 2002).
- Investments into infrastructure (transport in particular) are crucial as these lower input costs for famers (Koning et al. 2001).
- Implementing crop rotation would result in higher yields, higher soil fertility, and a reduction of soil erosion (Gebremedhin and Schwab 1998).
- Restoring degraded areas is economically viable, as the seemingly high input costs earn benefits 2.5 times higher than the emerging costs (Dregne and Chou 1992). This requires, however, an underlying policy system which supports farmers in doing so.
- The overvaluation of currencies and taxes on exports are another problem, as this keeps prices below world market values and result in low income for farmers. Establishing regional tariff unions which are accepted by the World Bank and the IMF could strengthen local farmers' position on the world market (Koning et al. 2001).
- Lowering prices for agricultural assets is a prerequisite for enhancing high agricultural performance of small scale farmers, since high prices for seeds and other necessary inputs keep farmers trapped in a vicious cycle of poverty. Sanchez (2002) also recommends promoting an enhanced availability of input products such as seeds and fertilizers, although in combination with increased knowledge.

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Appendix A - Tables

Table 6 Degradation in drylands; Source (Erb et al. 2009a)

Country	Total area	Dryland area	Degraded area	NPP dryland	Min NPP loss	Max NPP loss	NPP loss min	NPP loss max	Share Agriculture GDP in 2000
	['000 sqkm]	['000 sqkm]	['000 sqkm]	[Mio t C/yr]	[Mio t C/yr]	[Mio t C/yr]	in % of NPP_0	% of NPP_0	
Algeria	2.321	485	104	23	3,54	7,30	16	32	8,9%
Angola	1.252	242	2	1	0,26	0,50	24	45	5,7%
Benin	117	101	16	11	1,46	3,22	13	30	36,5%
Botswana	580	580	48	18	5,07	9,06	28	50	2,7%
Burkina Faso	274	274	115	64	19,10	33,19	30	52	29%
Burundi	Na	Na	Na	Na	Na	Na	Na	Na	Na
Cameroon	466	60	16	9	2,90	5,03	31	55	22,1%
Central African Rep.	621	125	2	1	0,09	0,20	9	21	53,1%
Chad	1.275	869	224	59	6,25	14,56	11	25	42,3%
Comoros	Na	Na	Na	Na	Na	Na	Na	Na	Na
Congo, Rep.	345	1	0	0	0,01	0,03	18	38	5,3%
Congo, DRC	2.305	10	2	1	0,25	0,52	18	38	50%
Côte d'Ivoire	322	124	7	6	0,35	0,95	6	17	24,2%
Djibouti	21	15	3	1	0,09	0,20	9	21	3,5%
Egypt	991	73	10	0	0,06	0,13	17	36	16,7%

Country	Total area ['000 sqkm]	Dryland area ['000 sqkm]	Degraded area ['000 sqkm]	NPP dryland [Mio t C/yr]	Min NPP loss [Mio t C/yr]	Max NPP loss [Mio t C/yr]	NPP loss min in % of NPP_0	NPP loss max % of NPP_0	Share Agriculture GDP in 2000
Equatorial Guinea	Na	Na	Na	Na	Na	Na	Na	Na	Na
Eritrea	121	100	26	6	2,48	4,14	39	65	15,1
Ethiopia	1.127	654	142	59	13,94	25,74	23	43	49,9%
Gabon	Na	Na	Na	Na	Na	Na	Na	Na	Na
Ghana	233	152	20	13	3,05	5,64	23	43	39,4%
Gambia	10	10	1	1	0,05	0,13	8	20	35,8%
Guinea	245	35	1	1	0,05	0,14	5	15	20,25%
Guinea-Bissau	32	2	0	0	0,02	0,03	17	36	56,4%
Kenya	571	407	49	29	5,62	10,66	19	36	32,4%
Libyan Arab Jamah.	1.619	368	179	15	0,99	2,66	7	18	5,2% (2002)
Lesotho	Na	Na	Na	Na	Na	Na	Na	Na	Na
Liberia	Na	Na	Na	Na	Na	Na	Na	Na	Na
Madagascar	593	138	54	48	16,01	27,29	34	57	29,2%
Malawi	Na	Na	Na	Na	Na	Na	Na	Na	Na
Mali	1.255	1.005	279	81	11,87	25,56	15	32	41,6%
Mauritania	1.040	474	187	35	4,68	10,25	13	29	27,6%
Morocco	402	371	38	9	1,31	2,79	15	31	14,9%

Country	Total area ['000 sqkm]	Dryland area ['000 sqkm]	Degraded area ['000 sqkm]	NPP dryland [Mio t C/yr]	Min NPP loss [Mio t C/yr]	Max NPP loss [Mio t C/yr]	NPP loss min in % of NPP_0	NPP loss max % of NPP_0	Share Agriculture GDP in 2000
Mozambique	779	294	24	16	1,24	3,14	8	19	24%
Namibia	824	748	64	9	1,56	3,28	18	37	11,8%
Niger	1.186	736	342	90	14,28	30,04	16	33	37,8%
Nigeria	911	529	86	45	8,66	17,45	19	39	48,5% (2002)
Rwanda	Na	Na	Na	Na	Na	Na	Na	Na	Na
Senegal	197	185	46	22	6,15	10,74	29	50	19,4%
Somalia	636	510	97	10	2,11	3,94	20	38	Na
South Africa	1.218	809	208	48	6,29	13,40	13	28	3,3%
Sudan	2.495	1.679	475	159	24,84	51,97	16	33	41,7%
Swaziland	18	9	0	0	0,05	0,09	38	63	12,5%
Togo	57	19	6	4	1,23	2,18	30	52	34,2%
Tunisia	155	145	85	14	1,20	2,96	9	22	12,3%
Uganda	206	9	3	2	0,97	1,61	40	67	29,4%
United Rep.Tanzania	882	96	17	14	3,18	6,05	23	44	33,5%
Zambia	742	121	10	7	1,21	2,47	18	38	22,3%
Zimbabwe	388	260	23	13	2,50	5,12	19	39	18,5%

Table 7 Comparison of HANPP and its components in Africa and globally

	North Africa	Eastern Africa	Central Africa	Western Africa	Southern Africa	Total Africa	Northern Africa and Western Asia	Sub-Saharan Africa	Central Asia and Russian Federation	Eastern Asia	Southern Asia	South-Eastern Asia	Northern America	Latin America & the Carribean	Western Europe	Eastern & South-Eastern Europe	Oceania and Australia	World
NPP_0				[Mio. t C/yr]									[Mio. t C/yr]					
1990	184	4.392	4.539	1.948	499	11.562	527	11.701	7.713	4.141	2.056	4.223	7.225	15.304	1.762	589	2.208	57.451
2000	136	4.663	4.723	2.011	625	12.157	474	12.359	7.912	4.109	1.994	4.482	7.348	15.736	1.856	625	2.755	59.650
2005	196	4.712	4.768	2.142	553	12.370	530	12.509	8.076	4.242	2.155	4.448	7.811	15.419	1.682	642	2.319	59.833
% Change	27%	5%	0%	11%	13%	5%	12%	7%	10%	12%	7%	9%	11%	3%	-4%	11%	11%	7%
NPPact				[Mio. t C/yr]									[Mio. t C/yr]					
1980	179	4.128	4.473	1.674	474	10.927	480	10.749	6.508	3.843	1.556	3.442	6.665	14.104	1.527	489	2.049	51.412
1990	218	3.991	4.259	1.654	475	10.598	555	10.686	6.960	4.161	1.729	3.507	6.831	14.272	1.639	512	2.120	52.969
2000	178	4.174	4.421	1.686	590	11.050	517	11.192	7.257	4.022	1.820	3.740	7.034	14.678	1.714	514	2.668	55.157
2005	237	4.130	4.448	1.710	528	11.052	586	11.133	7.487	4.257	1.935	3.728	7.496	14.365	1.580	550	2.223	55.341
% Change	32%	0%	-1%	2%	11%	1%	22%	4%	15%	11%	24%	8%	12%	2%	3%	13%	9%	8%
HANPP				**[Mio t C/yr]**									**[Mio t C/yr]**					
1980	53	682	343	424	116	1.617	187	1.564	1.440	840	1.348	1.110	1.443	1.880	806	344	215	11.177
1990	62	760	364	520	123	1.828	189	1.785	1.471	1.149	1.417	1.260	1.484	2.155	794	342	286	12.332
2000	58	908	407	621	133	2.128	176	2.089	1.082	1.356	1.408	1.324	1.454	2.386	837	315	301	12.729
2005	79	1.058	434	781	127	2.479	199	2.421	1.059	1.430	1.481	1.380	1.568	2.564	806	330	292	13.531
% Change	50%	55%	27%	84%	10%	53%	6%	55%	-26%	70%	10%	24%	9%	36%	0%	-4%	35%	21%

	North Africa	Eastern Africa	Central Africa	Western Africa	Southern Africa	Total Africa	Northern Africa and Western Asia	Sub-Saharan Africa	Central Asia and Russian Federation	Eastern Asia	Southern Asia	South-Eastern Asia	Northern America	Latin America & the Carribean	Western Europe	Eastern & South-Eastern Europe	Oceania and Australia	World
NPPh				[Mio t C/yr]								[Mio t C/yr]						
1980	77	314	68	175	99	733	192	656	605	895	883	465	1.066	965	581	256	167	6.733
1990	96	358	84	226	99	864	216	770	719	1.169	1.090	544	1.090	1.122	671	264	197	7.850
2000	101	419	106	296	98	1.020	219	922	426	1.269	1.235	582	1.140	1.329	695	204	215	8.236
2005	119	476	114	349	102	1.161	255	1.045	471	1.446	1.261	660	1.253	1.510	704	238	196	9.038
% Change	56%	52%	69%	99%	4%	58%	33%	59%	-22%	62%	43%	42%	18%	56%	21%	-7%	17%	34%
ΔNPP_{LC}				[Mio t C/yr]								[Mio t C/yr]						
1980	-24	367	275	248	17	884	-5	908	835	-55	464	644	377	915	225	87	48	4.444
1990	-34	401	280	294	24	964	-27	1.015	752	-19	327	716	394	1.033	124	77	89	4.482
2000	-42	489	302	325	35	1.107	-42	1.167	655	87	174	742	313	1.057	142	111	87	4.494
2005	-41	582	320	432	25	1.318	-56	1.376	588	-16	220	720	316	1.054	102	92	96	4.492
% Change	69%	58%	16%	74%	44%	49%	953%	52%	-30%	-71%	-53%	12%	-16%	15%	-55%	6%	100%	1%
HANPP in % of NPP_0																		
1980	34%	15%	7%	22%	24%	14%	39%	13%	20%	22%	67%	27%	20%	13%	46%	60%	10%	20%
1990	34%	17%	8%	27%	25%	16%	36%	15%	19%	28%	69%	30%	21%	14%	45%	58%	13%	21%
2000	43%	19%	9%	31%	21%	18%	37%	17%	14%	33%	71%	30%	20%	15%	45%	50%	11%	21%
2005	40%	22%	9%	36%	23%	20%	38%	19%	13%	34%	69%	31%	20%	17%	48%	51%	13%	23%
% Change	18%	48%	26%	65%	-3%	46%	-5%	44%	-33%	52%	3%	14%	-2%	33%	4%	-14%	22%	13%

	North Africa	Eastern Africa	Central Africa	Western Africa	Southern Africa	Total Africa	Northern Africa and Western Asia	Sub-Saharan Africa	Central Asia and Russian Federation	Eastern Asia	Southern Asia	South-Eastern Asia	Northern America	Latin America & the Carribean	Western Europe	Eastern & South-Eastern Europe	Oceania and Australia	World
ΔNPP_{LC} in % of NPP_0																		
1980	-15%	8%	6%	13%	4%	7%	-1%	8%	11%	-1%	23%	16%	5%	6%	13%	15%	2%	8%
1990	-19%	9%	6%	15%	5%	8%	-5%	9%	10%	0%	16%	17%	5%	7%	7%	13%	4%	8%
2000	-31%	10%	6%	16%	6%	9%	-9%	9%	8%	2%	9%	17%	4%	7%	8%	18%	3%	8%
2005	-21%	12%	7%	20%	5%	11%	-11%	11%	7%	0%	10%	16%	4%	7%	6%	14%	4%	8%
Change in %	34%	51%	16%	56%	28%	42%	843%	41%	-36%	-74%	-56%	3%	-25%	12%	-53%	-5%	81%	-6%
ΔNPP_{LC} in % of HANPP																		
1980	-46%	54%	80%	59%	15%	55%	-3%	58%	58%	-7%	34%	58%	26%	49%	28%	25%	22%	40%
1990	-55%	53%	77%	57%	19%	53%	-14%	57%	51%	-2%	23%	57%	27%	48%	16%	23%	31%	36%
2000	-73%	54%	74%	52%	26%	52%	-24%	56%	61%	6%	12%	56%	22%	44%	17%	35%	29%	35%
2005	-52%	55%	74%	55%	20%	53%	-28%	57%	56%	-1%	15%	52%	20%	41%	13%	28%	33%	33%
Change in %	13%	2%	-8%	-6%	32%	-3%	889%	-2%	-4%	-83%	-57%	-10%	-23%	-16%	-55%	10%	48%	-17%
Harvest in % of HANPP																		
1980	146%	46%	20%	41%	85%	45%	103%	42%	42%	107%	66%	42%	74%	51%	72%	75%	78%	60%
1990	155%	47%	23%	43%	81%	47%	114%	43%	49%	102%	77%	43%	73%	52%	84%	77%	69%	64%
2000	173%	46%	26%	48%	74%	48%	124%	44%	39%	94%	88%	44%	78%	56%	83%	65%	71%	65%
2005	152%	45%	26%	45%	80%	47%	128%	43%	44%	101%	85%	48%	80%	59%	87%	72%	67%	67%
Change in %	4%	-2%	33%	8%	-6%	3%	25%	3%	6%	-5%	30%	14%	8%	15%	21%	-3%	-14%	11%

This table presents the summary statistics for HANPP related to domestic consumption and trade. HANPPdc is the amount of HANPP consumed within the territory of a country, tHANPP is the total HANPP produced in each country`s territory and Balance depicts the balance which provides information on the consumption patterns of a country. Negative balance values thus mean that these countries are net-consuming countries which rely upon biomass imports in order to meet their domestic demand (e.g. Algeria). Finally HANPPdc/cap provides information on the share of total HANPP consumption per person. The column self-sufficiency shows the extent to which a country can cover its demand for embodied HANPP by national HANPP. The column share trade/HANPPdc shows the ratio of total traded biomass to the total domestic consumption of HANPP. Finally the last column provides information on each countries share on the globally transferred embodied HANPP of 1.7 PgC/year.

Table 8 HANPP domestic consumption and trade related biomass; Source: Erb et al. (2009).

Country	Population ['000 head]	Area ['000 sqkm]	HANPPdc [Mt C/yr]	tHANPP [Mt C/yr]	Balance [Mt C/yr]	HANPPdc/cap [t C/ha/yr]	Selfsufficiency in %	Share trade/HANPPdc	Share on global trade
Algeria	27.459	2.321	81,1	39,4	-41,6	3,0	-51%	49%	2,46%
Angola	11.527	1.252	83,8	83,8	-0,1	7,3	-4%	96%	0,18%
Benin	5.175	117	20,5	22,3	1,8	4,0	9%	109%	-0,10%
Botswana	1.447	580	13,2	11,1	-2,1	9,1	-2%	98%	0,02%
Burkina Faso	10.165	273	51,2	52,4	1,2	5,0	2%	102%	-0,07%
Burundi	6.011	27	18,3	15,9	-2,4	3,0	1%	101%	-0,01%
Cameroon	13.218	467	78,3	82,8	4,6	5,9	6%	106%	-0,26%

Country	Population ['000 head]	Area ['000 sqkm]	HANPPdc [Mt C/yr]	tHANPP [Mt C/yr]	Balance [Mt C/yr]	HANPPdc/cap [t C/ha/yr]	Selfsufficiency in %	Share trade/HANPPdc	Share on global trade
Central African	3.150	621	21,6	22,0	0,4	6,9	2%	102%	-0,02%
Chad	6.309	1.276	41,9	43,6	1,8	6,6	4%	104%	-0,10%
Comoros	635	2	0,1	1,1	1,0	0,2	-39%	0%	0,00%
Congo	2.318	346	17,6	16,7	-0,9	7,6	-2%	98%	0,02%
Congo, DRC	41.026	2.337	167,3	169,9	2,6	4,1	-1%	99%	0,06%
Cote d'Ivoire	13.499	323	60,2	79,7	19,5	4,5	32%	132%	-1,10%
Djibouti	451	22	1,4	0,9	-0,5	3,2	-33%	67%	0,03%
Egypt	56.133	1.000	75,9	-5,8	-81,8	1,4	-75%	25%	3,35%
Equatorial Guinea	386	27	2,3	2,5	0,2	5,0	9%	109%	0,01%
Eritrea	3.662	121	9,5	8,2	-1,2	2,6	-13%	87%	0,07%
Ethiopia	53.143	1.132	225,2	220,7	-4,5	4,2	-3%	0%	0,09%
Gabon	1.561	262	7,9	6,6	-1,3	5,1	16%	116%	-0,07%
Ghana	16.698	240	58,0	58,6	0,6	3,5	1%	101%	-0,04%
The Gambia	936	11	3,0	2,0	-1,1	3,2	-35%	65%	0,06%
Guinea	62.420	246	29,2	27,8	-1,4	0,5	-5%	95%	0,08%
Guinea-Bissau	1.086	33	3,6	3,7	0,1	3,3	5%	105%	-0,01%
Kenya	25.835	584	91,4	91,0	-0,4	3,5	-3%	97%	0,14%

Country	Population ['000 head]	Area ['000 sqkm]	HANPPdc [Mt C/yr]	tHANPP [Mt C/yr]	Balance [Mt C/yr]	HANPPdc/cap [t C/ha/yr]	Selfsufficiency in %	Share trade/ HANPPdc	Share on global trade
Lesotho	1.928	31	9,2	0,0	0,0	4,8	-11%	89%	0,06%
Liberia	2.902	96	10,8	10,4	-0,3	3,7	-3%	97%	0,02%
Libya	5.246	1.620	20,0	7,4	-12,6	3,8	-62%	38%	0,73%
Mauritius	1.097	2	1,2	na	na	na	-31%	0%	0,02%
Mauritania	2.204	1.041	21,1	18,8	-2,3	9,6	-9%	91%	0,11%
Morocco	27.768	404	75,1	44,8	-30,4	2,7	-40%	60%	1,80%
Mozambique	16.605	789	56,4	54,8	-1,6	3,4	-3%	97%	0,10%
Namibia	1.576	827	10,4	0,0	0,0	6,6	-18%	82%	0,11%
Niger	8.798	1.186	54,4	53,8	-0,7	6,2	-1%	99%	0,04%
Nigeria	97.229	912	306,0	291,9	-14,2	3,1	-5%	95%	0,85%
Rwanda	7.934	25	19,7	21,0	1,3	2,5	-2%	98%	0,02%
Sao Tome and Principe	Na	Na	Na	Na	Na	Na	Na	Na	Na
Senegal	8.117	197	28,0	28,6	0,7	3,4	-5%	95%	0,09%
Sierra Leone	4.552	73	11,2	10,3	-0,9	2,5			0,05%
Somalia	9.952	639	32,1	31,1	-1,0	3,2	0%	100%	0,00%
South Africa	40.634	1.222	168,3	0,0	0,0	4,1	9%	109%	-0,87%

Country	Population ['000 head]	Area ['000 sqkm]	HANPPdc [Mt C/yr]	tHANPP [Mt C/yr]	Balance [Mt C/yr]	HANPPdc/cap [t C/ha/yr]	Selfsufficiency in %	Share trade/HANPPdc	Share on global trade
Sudan	27.713	2.496	187,7	197,1	9,4	6,8	5%	105%	-0,54%
Swaziland	843	17	1,9	17,3	15,4	2,2	38%	138%	0,00%
Togo	4.048	57	18,2	19,2	1,0	4,5	6%	106%	-0,06%
Tunisia	8.620	155	30,2	16,0	-14,3	3,5	-43%	57%	0,77%
Uganda	18.144	243	114,4	114,2	-0,3	6,3	2%	102%	-0,13%
United Rep. Tanzania	28.386	945	100,0	99,1	-0,9	3,5	1%	101%	-0,04%
Western Sahara	223	270	0,2	0,0	-0,2	1,0	Na	94%	0,00%
Zambia	8.779	755	45,5	45,2	-0,3	5,2	6%	106%	-0,15%
Zimbabwe	11.107	391	30,7	29,0	-1,7	2,8	24%	124%	-0,42%

Table 9 Constituents of HANPP; Source: (Haberl et al. 2007). Please note: different underlying model runs for the calculation of the potential NPP may result in inconsistencies between the data provided. The effects of this are of minor importance as the general pattern is not affected by this.

Country	HANPP [capita/yr]	HANPP [t C/ha/yr]	Harvest [t C/ha/yr]	ΔNPP_{LC} [tC/ha/yr]	Used Extraction [% of HANPP]	Harvest [% of HANPP]	ΔNPP_{LC} [% of HANPP]
Algeria	1,32	1,11	0,38	0,74	49%	65%	35%
Angola	6,02	0,65	0,09	0,57	10%	12%	88%
Benin	3,11	1,91	0,80	1,11	27%	41%	59%
Botswana	7,37	0,22	0,07	0,16	50%	53%	47%
Burkina Faso	4,65	1,91	0,68	1,24	37%	48%	52%
Burundi	2,65	6,20	1,12	5,09	24%	33%	67%
Cameroon	5,62	1,77	0,45	1,32	24%	33%	67%
Cape Verde	Na	Na	Na	Na	58%	77%	23%
Central African Republic	5,80	0,35	0,13	0,23	39%	46%	54%
Chad	5,31	0,53	0,20	0,34	52%	63%	37%
Comoros	0,00	0,00	0,00	0,00	27%	37%	63%
Congo	5,32	0,49	0,07	0,43	15%	24%	76%
Congo, DRC	3,39	0,71	0,21	0,50	6%	11%	89%
Cote d'Ivoire	4,89	2,46	0,59	1,88	16%	24%	76%
Djibouti	1,63	0,43	0,29	0,15	92%	102%	-2%
Egypt	-0,09	-0,51	2,76	-3,27	4473%	7147%	-7047%
Equatorial Guinea	7,21	0,85	0,22	0,64	16%	32%	68%

Country	HANPP [capita/yr]	HANPP [t C/ha/yr]	Harvest [t C/ha/yr]	ΔNPPLC [tC/ha/yr]	Used Extraction [% of HANPP]	Harvest [% of HANPP]	ΔNPPLC [% of HANPP]
Eritrea	2,34	0,73	0,40	0,33	Na	Na	Na
Ethiopia	3,23	1,94	0,81	1,14	41%	50%	50%
Gabon	10,67	0,35	0,10	0,25	14%	28%	72%
Ghana	3,03	2,44	0,99	1,45	27%	42%	58%
Gambia, The	2,32	1,81	1,12	0,70	51%	68%	32%
Guinea	3,43	1,13	0,50	0,63	27%	39%	61%
Guinea-Bissau	3,04	1,09	0,41	0,69	27%	35%	65%
Kenya	2,97	1,52	0,61	0,91	39%	50%	50%
Lesotho	4,34	2,48	0,54	1,95	30%	35%	65%
Liberia	4,02	1,08	0,35	0,73	18%	31%	69%
Libya	1,47	0,42	0,12	0,30	114%	132%	-32%
Madagascar	8,24	2,20	0,37	1,84	16%	19%	81%
Malawi	1,73	1,62	0,89	0,74	38%	55%	45%
Mali	5,15	0,70	0,24	0,47	52%	63%	37%
Mauritius	Na	Na	Na	Na	Na	Na	Na
Mauritania	7,74	0,53	0,19	0,34	79%	82%	18%
Morocco	1,58	1,34	0,52	0,83	64%	76%	24%
Mozambique	3,13	0,69	0,22	0,47	20%	31%	69%
Namibia	4,52	0,15	0,11	0,05	75%	78%	22%

Country	HANPP [capita/yr]	HANPP in [t C/ha/yr]	Harvest [t C/ha/yr]	ΔNPP_{LC} [tC/ha/yr]	Used Extraction [% of HANPP]	Harvest [% of HANPP]	ΔNPP_{LC} [% of HANPP]
Niger	4,56	0,94	0,25	0,70	54%	66%	34%
Nigeria	2,50	3,19	1,58	1,62	39%	54%	46%
Rwanda	2,37	7,42	2,38	5,04	29%	39%	61%
Senegal	3,28	1,45	0,60	0,86	50%	62%	38%
Sierra Leone	2,50	1,41	0,54	0,88	23%	35%	65%
Somalia	4,84	0,61	0,53	0,09	84%	89%	11%
South Africa	4,09	1,61	0,73	0,88	57%	77%	23%
Sudan	6,02	1,12	0,47	0,66	54%	62%	38%
Swaziland	2,55	1,51	1,58	-0,07	78%	105%	-5%
Togo	3,69	3,35	1,06	2,29	25%	39%	61%
Tunisia	1,80	1,90	0,52	1,39	42%	53%	47%
Uganda	4,90	4,79	1,65	3,14	27%	40%	60%
United Rep. Tanzania	3,10	1,07	0,45	0,62	36%	47%	53%
Western Sahara	Na	Na	Na	Na	Na	Na	Na
Zambia	4,49	0,63	0,13	0,50	20%	27%	73%
Zimbabwe	3,04	0,97	0,52	0,45	56%	71%	29%

Table 10 Timeseries - constituents of HANPP in % of NPP_0; Source: Haberl et al. 2007

	1980	1990	2000	2005	1980	1990	2000	2005	1980	1990	2000	2005
	HANPP				Harvest				ΔNPP_{LC}			
					[% of NPP_0]							
Algeria	27,3	26,6	34,4	28,5	14,8	15,4	22,2	18,9	12,5	11,2	12,2	9,6
Angola	8,8	9,0	9,6	10,0	0,9	0,8	1,1	1,3	8,0	8,2	8,5	8,7
Benin	18,6	22,6	27,8	30,5	7,4	8,7	11,4	12,8	11,2	13,8	16,4	17,7
Botswana	12,0	11,0	7,1	8,1	6,5	6,1	3,8	4,4	5,5	5,0	3,4	3,7
Burkina Faso	18,2	25,3	27,8	39,5	8,1	11,6	13,3	16,9	10,1	13,7	14,5	22,5
Burundi	63,1	68,0	64,4	72,0	18,1	21,3	21,0	23,7	45,1	46,7	43,3	48,3
Cameroon	13,2	14,6	15,9	17,9	3,7	4,7	5,2	5,4	9,5	9,9	10,7	12,6
Cape Verde	na	na	na	na	na	na	na	na	na	na	na	na
Central African Republic	2,7	2,5	3,2	3,2	0,9	1,1	1,4	1,5	1,8	1,5	1,7	1,7
Chad	7,8	9,8	11,0	12,0	4,7	6,0	6,9	7,5	3,0	3,7	4,1	4,5
Comoros	na	na	na	na	na	na	na	na	na	na	na	na
Congo	5,4	5,8	5,9	6,3	0,5	0,7	0,7	0,9	4,9	5,1	5,2	5,4
Congo, DRC	7,2	8,1	8,4	8,7	1,3	1,7	2,0	2,1	6,0	6,4	6,4	6,6
Côte d'Ivoire	19,1	24,8	31,4	29,3	3,0	3,9	7,6	6,2	16,1	21,0	23,8	23,0
Djibouti	58,3	52,2	59,9	53,1	61,6	54,4	61,2	52,3	-3,3	-2,3	-1,2	0,8
Egypt	-147	-44	66	116	2818	2006	4717	3828	-2965	-2050	-4651	-3711
Equatorial Guinea	7,4	8,3	9,5	7,9	1,2	1,7	3,0	2,2	6,2	6,6	6,5	5,7
Eritrea	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na
Ethiopia	24,6	27,0	30,9	37,6	12,2	13,7	15,3	18,9	12,4	13,3	15,6	18,6
Gabon	3,0	3,5	3,8	4,2	0,6	0,8	1,1	1,4	2,4	2,7	2,8	2,8

	1980	1990	2000	2005	1980	1990	2000	2005	1980	1990	2000	2005
	HANPP				**Harvest**				ΔNPP_{LC}			
	[% of NPP_0]											
Gambia	23,1	28,9	32,2	40,3	14,1	19,9	21,8	22,2	9,0	9,0	10,4	18,1
Ghana	23,5	24,1	37,7	43,3	7,1	8,5	15,7	14,9	16,4	15,6	21,9	28,4
Guinea	12,6	13,8	15,8	20,5	4,4	4,9	6,2	7,7	8,3	8,9	9,6	12,8
Guinea-Bissau	11,6	11,6	17,4	17,9	4,2	5,9	6,0	6,8	7,4	5,7	11,4	11,1
Kenya	16,9	21,9	21,1	26,0	8,7	11,6	10,6	13,2	8,2	10,4	10,5	12,8
Lesotho	26,7	27,3	24,9	29,1	10,4	9,8	8,7	10,0	16,3	17,5	16,1	19,1
Liberia	11,1	11,3	11,9	12,6	2,9	3,4	3,8	3,9	8,2	7,9	8,2	8,7
Libya	25,6	18,5	18,2	10,8	28,7	23,5	24,1	13,4	-3,1	-5,0	-5,9	-2,6
Madagascar	18,4	19,1	20,3	18,8	3,4	3,9	3,9	3,9	15,0	15,3	16,4	14,9
Malawi	20,4	25,1	26,6	37,6	10,6	13,4	14,7	15,6	9,8	11,7	11,9	22,1
Mali	10,3	9,4	14,2	15,9	6,8	7,7	9,0	9,5	3,5	1,8	5,3	6,4
Mauritania	41,0	41,5	40,0	27,8	34,0	35,3	32,9	22,2	7,1	6,3	7,1	5,5
Mauritius	na	na	na	na	na	na	na	na	na	na	na	na
Morocco	40,9	38,5	47,2	39,6	36,4	35,7	35,7	29,6	4,4	2,8	11,5	10,0
Mozambique	8,4	9,6	8,7	10,1	2,1	2,6	2,7	3,2	6,2	7,0	6,0	6,9
Sudan	10,8	11,4	19,1	21,4	8,4	8,1	11,9	14,1	2,4	3,4	7,2	7,4
Western Sahara	na	na	na	na	na	na	na	na	na	na	na	na
Namibia	7,2	6,9	7,4	7,1	6,1	5,9	5,8	5,5	1,1	1,0	1,6	1,7
Niger	30,7	23,8	26,8	79,3	17,2	15,8	17,6	31,9	13,5	8,0	9,1	47,5
Nigeria	33,2	43,9	47,1	53,4	14,7	20,4	25,3	28,2	18,4	23,5	21,8	25,2
Rwanda	57,9	64,7	66,8	80,9	22,2	22,6	26,0	26,7	35,7	42,0	40,9	54,2

	HANPP 1980	HANPP 1990	HANPP 2000	HANPP 2005	Harvest 1980	Harvest 1990	Harvest 2000	Harvest 2005	ΔNPP_{LC} 1980	ΔNPP_{LC} 1990	ΔNPP_{LC} 2000	ΔNPP_{LC} 2005
	[% of NPP_0]											
Sao Tome and Principe	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na
Senegal	19,4	21,3	23,0	22,3	11,0	14,0	14,3	13,8	8,3	7,3	8,7	8,5
Sierra Leone	15,5	17,7	18,8	23,8	6,6	7,2	6,6	8,6	8,9	10,5	12,1	15,2
Somalia	37,6	38,9	35,8	39,9	34,5	36,9	31,9	35,2	3,2	2,0	4,0	4,7
South Africa	31,5	32,8	28,6	33,7	28,6	27,7	22,0	28,6	2,8	5,1	6,7	5,1
Sudan	10,8	11,4	19,1	21,4	8,4%	8,1%	11,9%	14,1%	2,4%	3,4%	7,2%	7,4%
Swaziland	32,8	31,6	23,4	24,6	34,6	36,9	24,5	29,2	-1,8	-5,3	-1,1	-4,6
Togo	24,8	31,4	39,0	39,7	9,5	11,9	15,0	14,9	15,4	19,5	24,0	24,9
Tunisia	58,0	61,0	77,0	98,0	24,5%	29,5	29,5% 41,1	41,1% 28,9	34	31,2	35,8	69,9
Uganda	32,7	38,2	45,8	51,5	13,8	15,1	18,5	20,0	18,9	23,1	27,3	31,4
Tanzania, United Rep.	11,0	12,0	13,9	19,2	4,8	5,8	6,5	6,5	6,2	6,2	7,4	12,7
Western Sahara	na	na	na	na	na	na	na	na	na	na	na	na
Seychelles	na	na	na	na	na	na	na	na	na	na	na	na
Zambia	5,2	6,2	6,6	6,7	1,4	2,0	1,8	2,2	3,8	4,2	4,8	4,6
Zimbabwe	10,5	15,3	16,8	17,1	8,5	13,7	11,9	10,5	2,1	1,6	4,9	6,6

.2% 35,8%

Appendix B – Maps

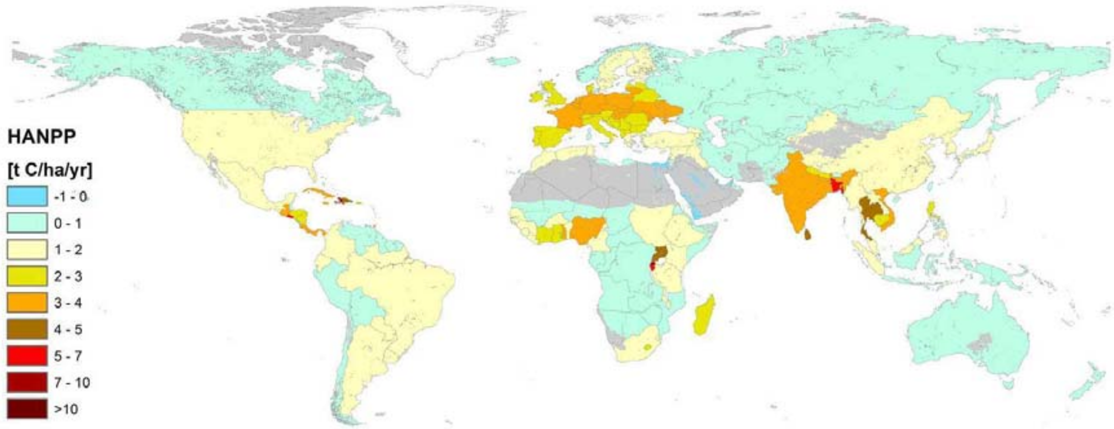


Fig 18 Total HANPP in t C/ha/yr exclusive non-productive area (grey color)

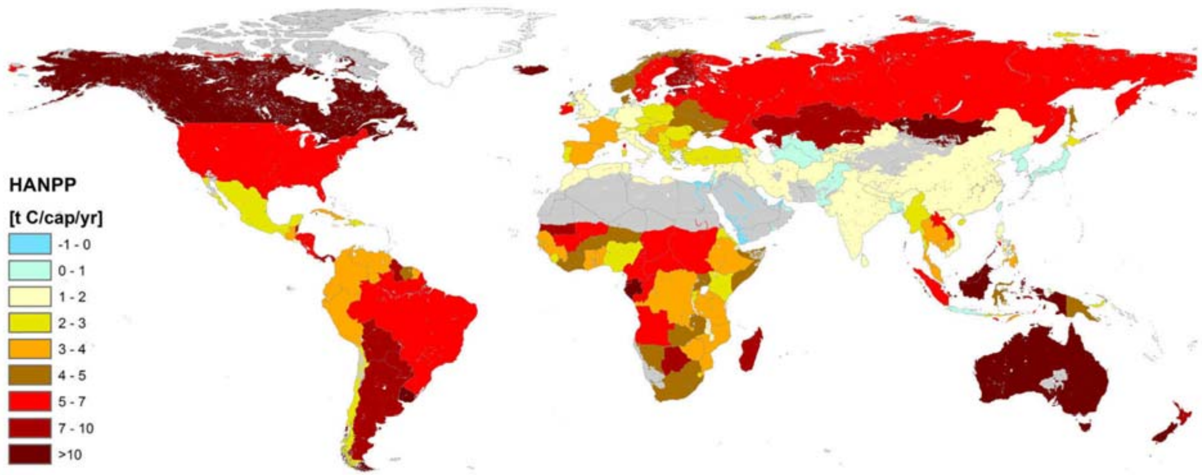


Fig 19 HANPP per capita exclusive non-productive area (grey color)

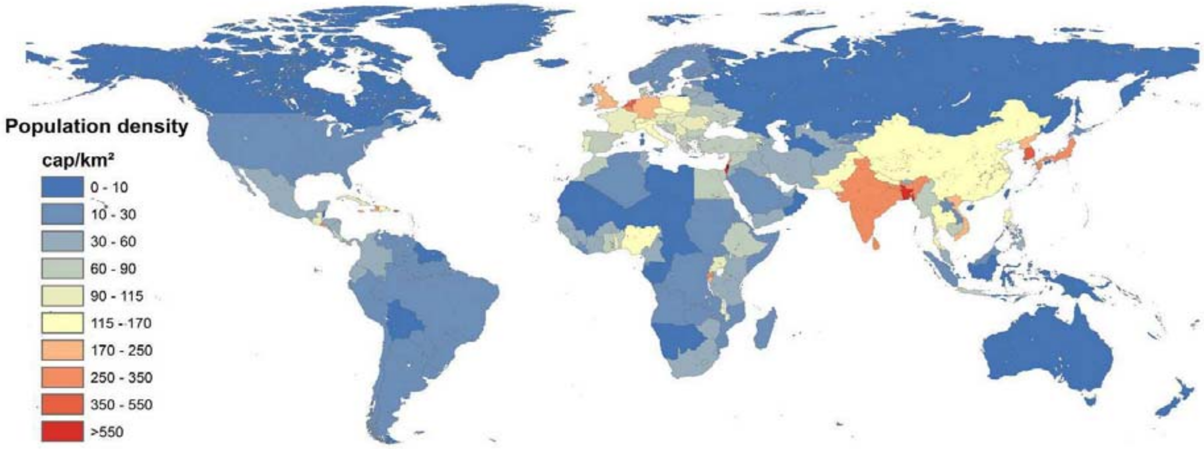


Fig 20 Population density in cap/km²

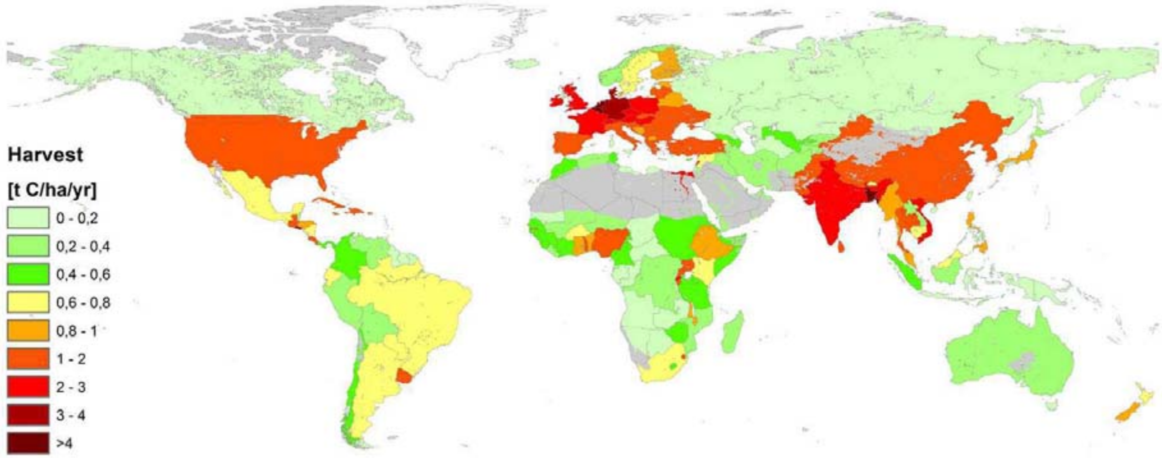


Fig 21 Harvest in t C/ha/yr exclusive non-productive area (grey color)

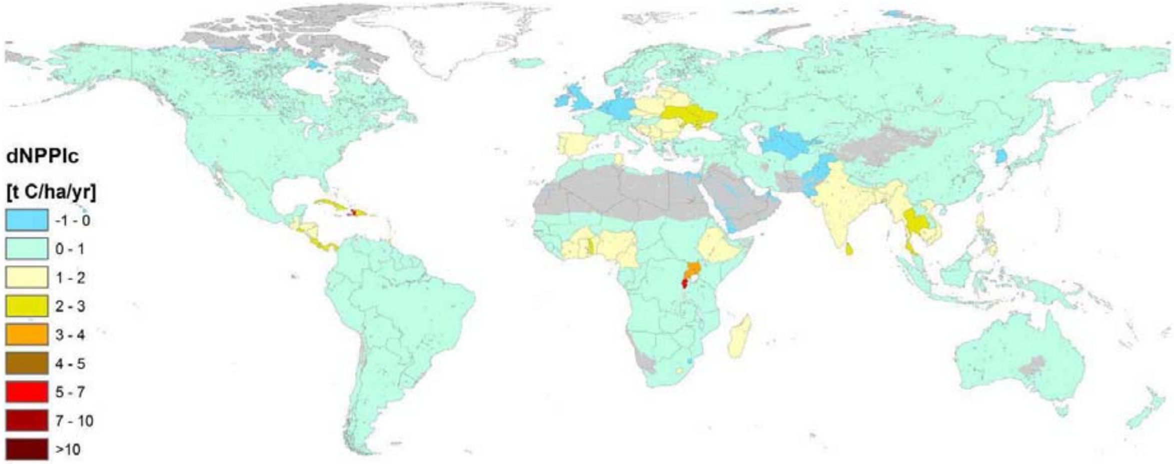


Fig 22 ΔNPP_{LC} in t C/ha/yr exclusive non-productive area (grey color)

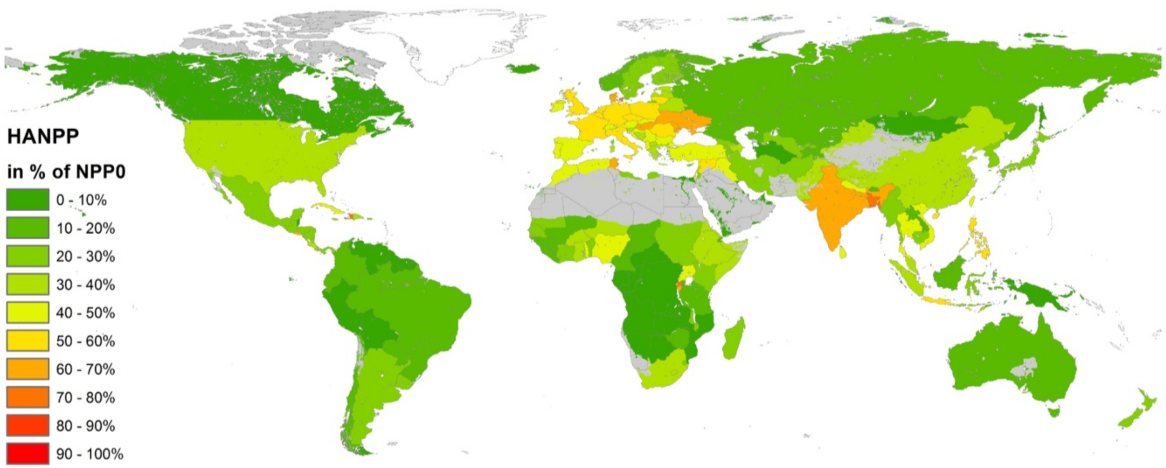


Fig 23 HANPP in % of NPP0 exclusive non-productive area (grey color)

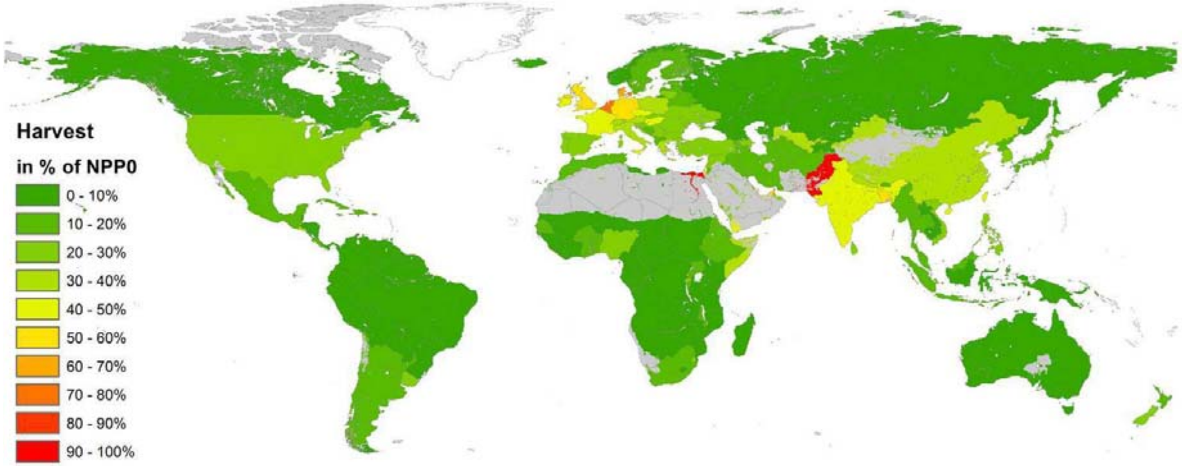


Fig 24 Harvest in %of NPP0 exclusive non-productive area (grey color)

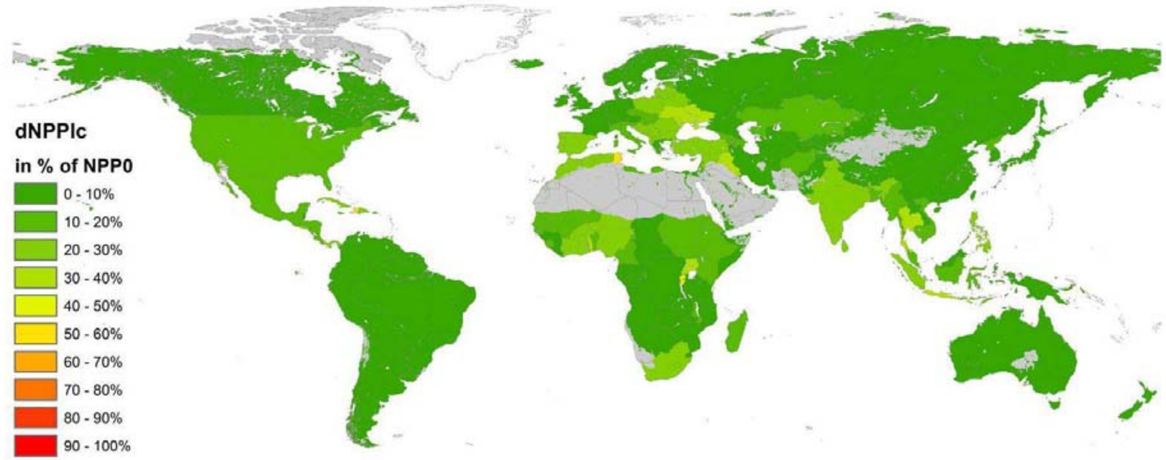


Fig 25 ∆NPPLC in % of NPP0 exclusive non-productive area (grey color)

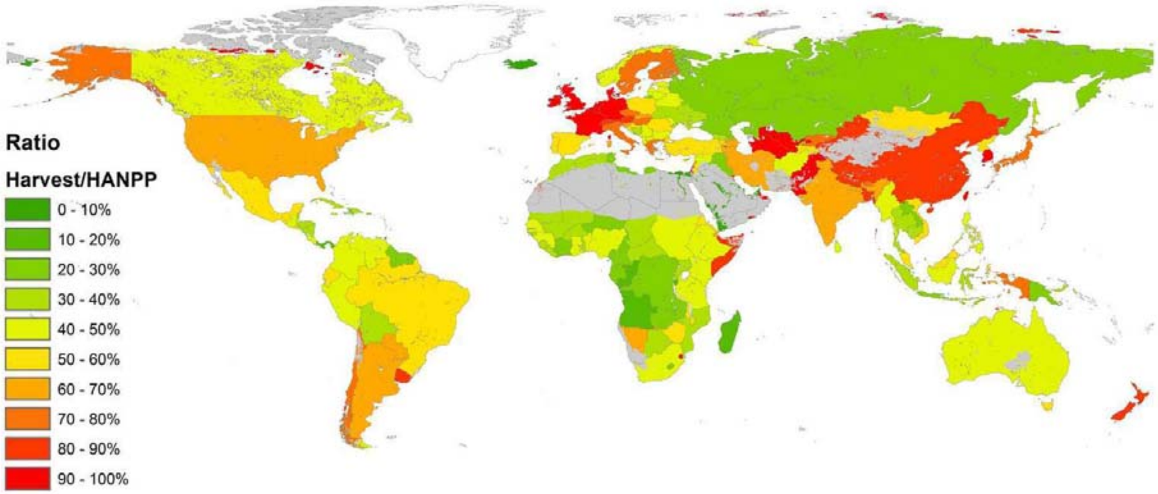


Fig 26 Ratio Harvest/total HANPP exclusive non-productive area (grey color)

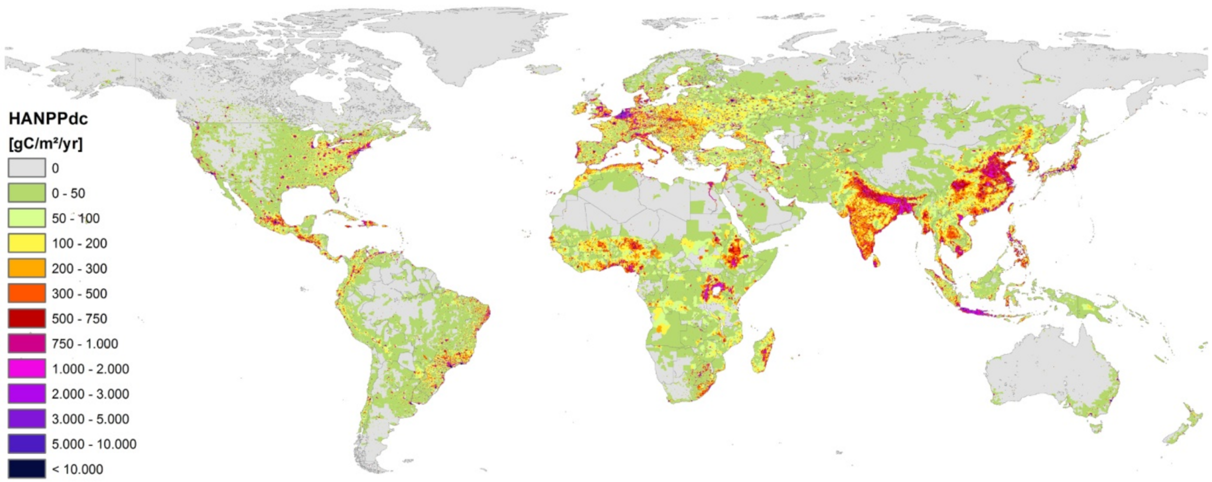


Fig 27 HANPP domestic consumption in g C/m²/yr

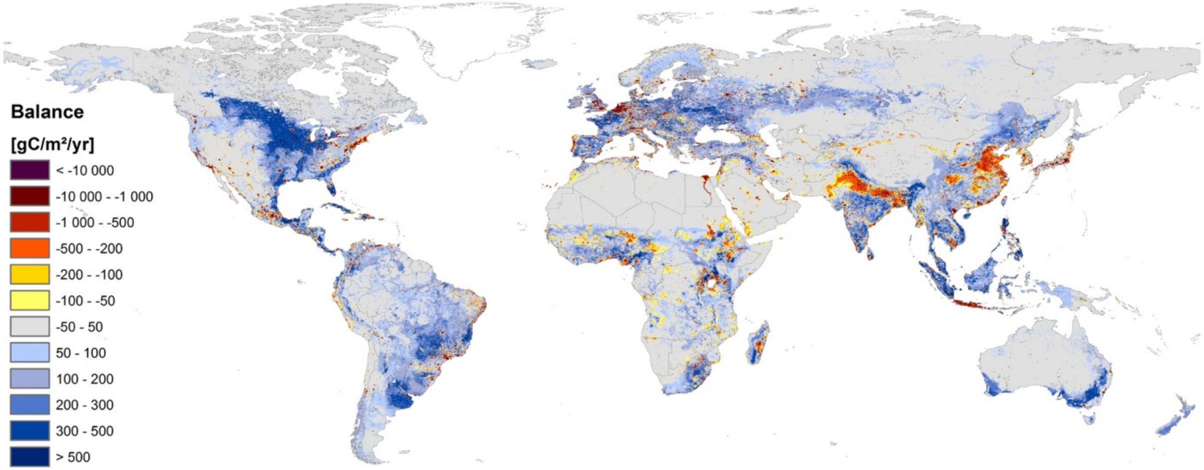


Fig 28 eHANPP balance g C/m²/yr

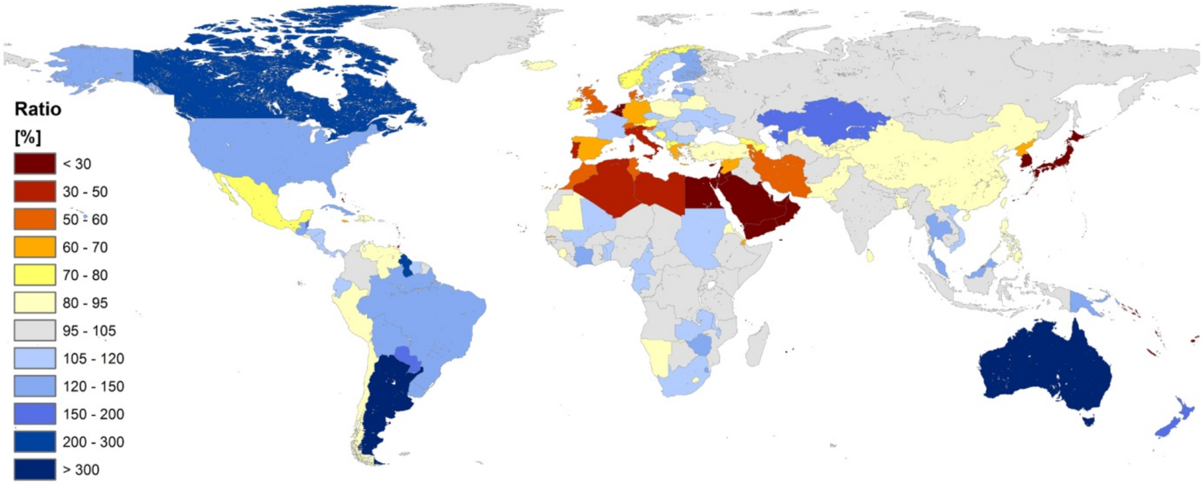
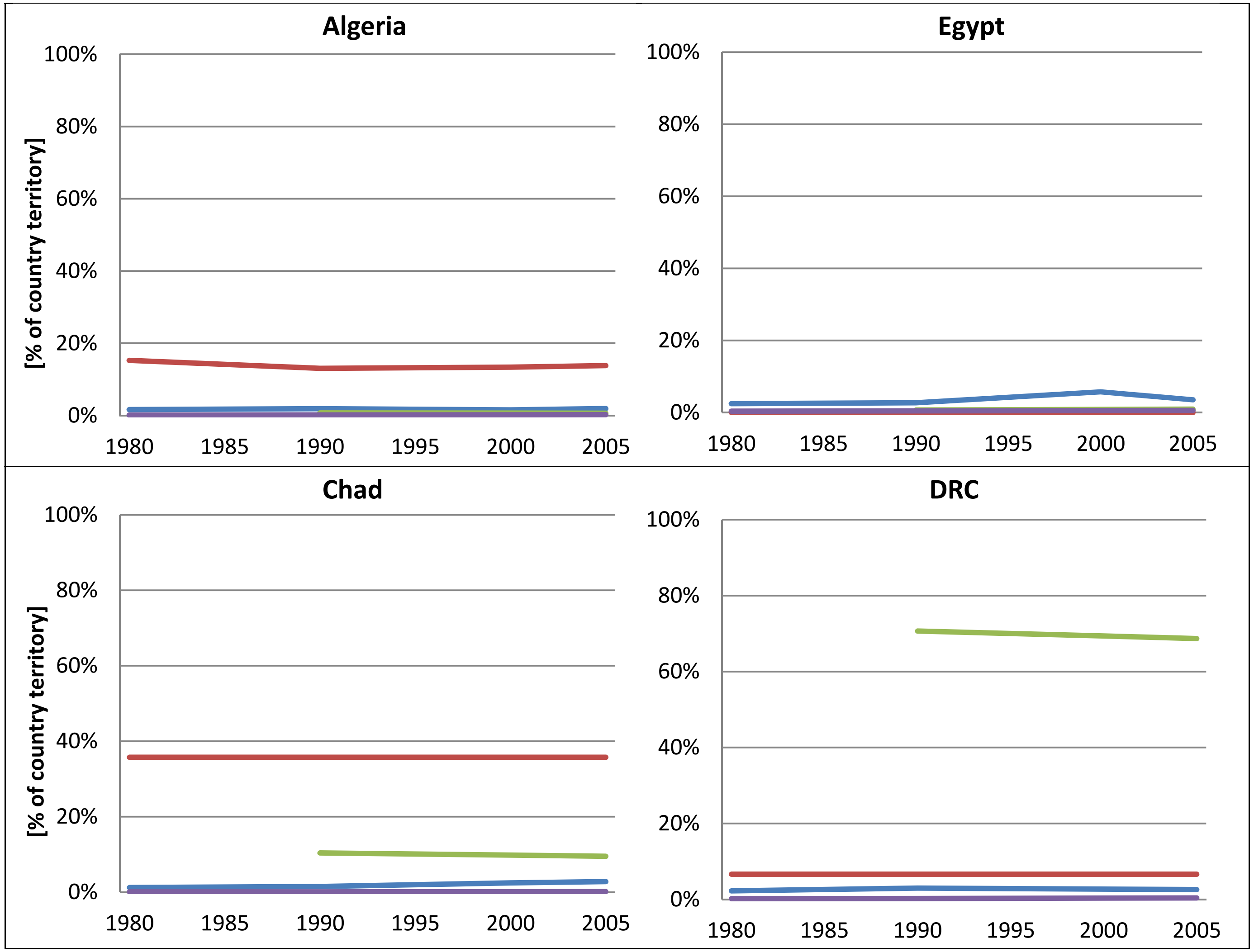
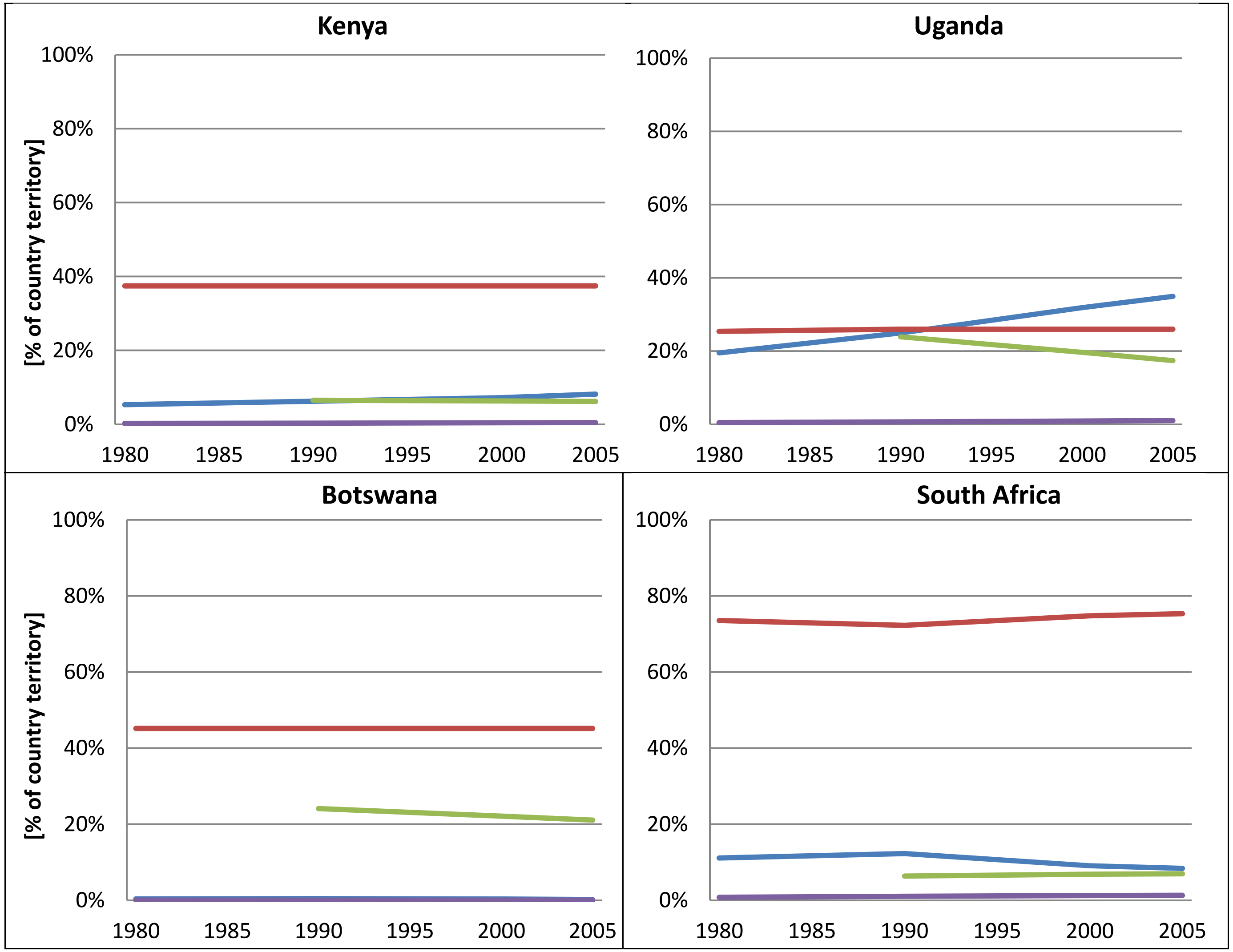


Fig 29 Ratio total HANPP and HANPP domestic consumption

Appendix C – Supplementary material - Time series analysis




Kenya
Uganda
Botswana
South Africa
[% of country territory]
[% of country territory]
100%
80%
60%
40%
20%
0%
1980
1985
1990
1995
2000
2005

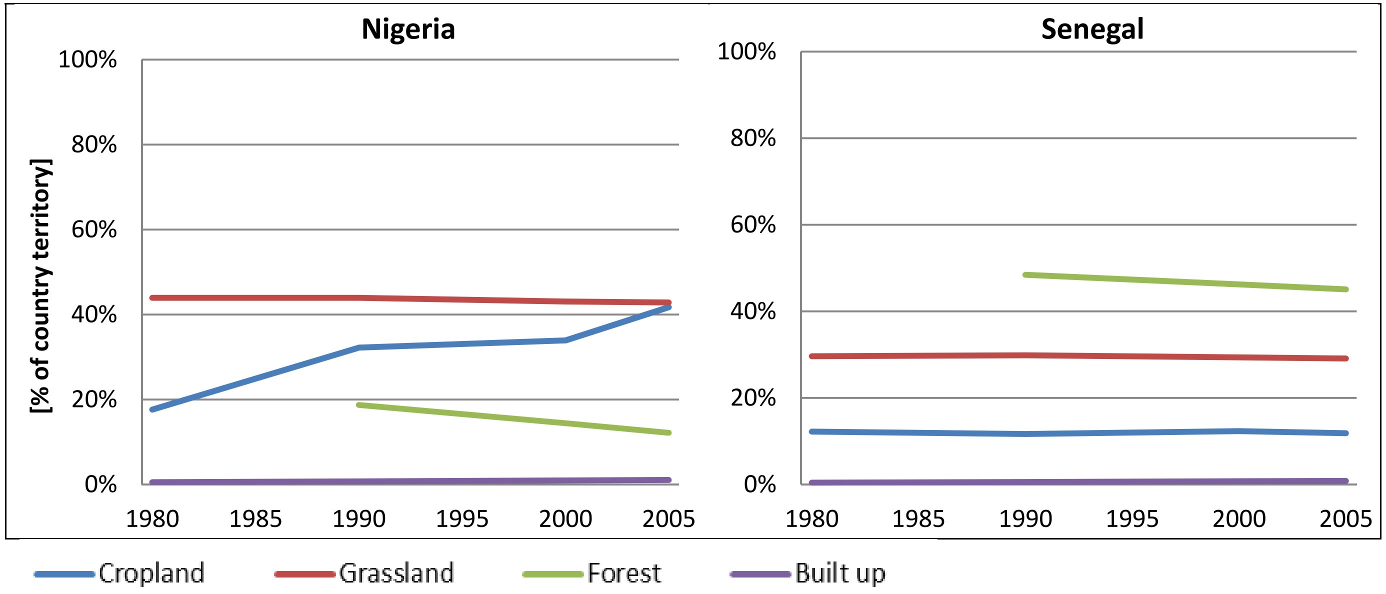


Fig 30 Land cover change in the ten selected case countries, from 1980 to 2005

Table 11 Biomass trade in Africa from 1980 to 2005, net trade (imports minus exports), imports and exports

	Net trade (tC/year)				Imports (tC/year)				Exports (tC/yar)			
Central Africa	**1980**	**1990**	**2000**	**2005**	**1980**	**1990**	**2000**	**2005**	**1980**	**1990**	**2000**	**2005**
Angola	160,229	279,341	335,418	644,647	244,061	282,343	339,020	652,647	83,832	3,002	3,602	8,000
Cameroon	-36,035	-260,913	-326,084	86,968	108,502	222,447	275,319	453,192	144,536	483,360	601,404	366,225
Central African Republic	-2,120	-7,362	-67,272	-64,900	10,779	24,692	20,743	31,293	12,899	32,055	88,015	96,193
Chad	-52,163	-4,027	-8,403	47,264	9,152	27,665	37,689	78,962	61,315	31,692	46,092	31,698
Congo, Dem Republic of	103,087	109,926	174,519	-53,449	182,101	217,732	213,041	203,322	79,013	107,806	38,522	256,771
Equatorial Guinea	-35,635	-30,772	-126,397	-165,673	2,303	7,251	8,044	14,457	37,938	38,023	134,441	180,130
Gabon	-19,203	-295,244	-687,822	-413,734	28,591	42,007	68,941	113,433	47,794	337,251	756,763	527,167
Congo, Republic of	42,071	-191,488	27,098	318,409	44,476	45,644	139,671	345,784	2,405	237,132	112,573	27,375
East Africa												
Sudan	-94,950	35,557	342,165	1,049,405	281,782	345,543	674,854	1,291,402	376,732	309,986	332,689	241,997
Burundi	6,409	-3,418	5,400	29,249	15,798	14,695	19,472	45,235	9,389	18,113	14,072	15,986
Comoros	6,927	16,616	14,393	26,236	7,704	17,214	14,733	29,449	777	598	340	3,213
Djibouti	10,814	38,140	56,081	163,688	24,329	45,331	57,363	178,679	13,515	7,190	1,281	14,991
Kenya	56,397	52,300	542,055	533,089	248,903	315,245	752,967	866,527	192,506	262,944	210,912	333,439
Madagascar	-6,786	-9,684	143,199	250,948	65,814	78,600	187,655	299,128	72,599	88,284	44,457	48,179
Malawi	-98,587	-16,223	-66,889	-5,691	38,813	87,624	47,181	132,508	137,400	103,846	114,070	138,198

East Africa	1980	1990	2000	2005	1980	1990	2000	2005	1980	1990	2000	2005
Mauritius	-259,374	-197,440	1,534	-44,105	111,921	163,408	266,707	296,296	371,295	360,849	265,173	340,401
Mozambique	83,130	249,879	245,924	416,854	184,865	276,851	333,441	557,027	101,735	26,972	87,517	140,174
Rwanda	3,315	6,640	54,020	39,308	17,399	33,059	65,935	57,851	14,084	26,420	11,916	18,544
Réunion	-7,437	30,265	40,588	34,787	100,521	140,860	41,404	35,568	107,958	110,595	816	781
Somalia	275	930	-7,809	292,463	1,300	930	1,902	340,811	1,025	-	9,711	48,348
Tanzania, United Rep of	66,058	-99,322	195,801	166,457	206,975	79,304	411,977	519,010	140,917	178,626	216,176	352,553
Uganda	-7,797	-66,267	45,441	221,497	43,285	24,782	171,803	445,839	51,082	91,049	126,362	224,341
Zambia	238,934	71,787	-17,062	-25,629	249,922	88,162	71,743	174,062	10,988	16,375	88,805	199,691
Zimbabwe	-109,377	-461,033	-363,858	33,499	109,009	87,849	140,909	260,040	218,386	548,882	504,767	226,541
Ethiopia PDR	107,162	263,714	486,973	240,068	193,390	338,675	619,622	555,176	86,227	74,961	132,649	315,108
North Africa												
Algeria	2,189,698	3,368,495	4,666,232	5,526,662	2,222,508	3,375,213	4,677,637	5,593,577	32,810	6,718	11,405	66,915
Egypt	3,494,509	5,197,413	6,316,776	6,551,118	3,719,417	5,364,824	6,714,175	7,571,290	224,908	167,411	397,399	1,020,172
Libyan Arab Jamahiriya	728,745	1,509,856	1,325,715	1,327,276	765,645	1,520,491	1,349,552	1,331,815	36,900	10,635	23,838	4,539
Morocco	1,071,000	1,003,686	3,405,867	3,745,569	1,225,652	1,181,174	3,656,742	4,036,942	154,651	177,488	250,875	291,374
Tunisia	581,458	986,641	1,547,964	1,698,559	629,506	1,069,989	1,756,166	2,010,821	48,048	83,348	208,202	312,262
South Africa												
Botswana	70,285	94,223	184,518	97,194	80,242	113,467	213,757	103,227	9,958	19,244	29,239	6,033
Lesotho	83,776	121,551	121,027	54,513	91,293	130,541	126,748	56,271	7,517	8,990	5,721	1,758
Namibia	-183,372	58,383	257,115	-34,303	53,868	87,346	298,507	-	237,240	28,963	41,392	34,303

South Africa	1980	1990	2000	2005	1980	1990	2000	2005	1980	1990	2000	2005
South Africa	2,106,181	-1,204,094	-767,152	-1,992,143	563,491	980,420	1,968,007	2,616,534	2,669,671	2,184,514	2,735,159	4,608,678
Swaziland	-154,373	-316,026	-494,748	-160,096	36,915	71,038	121,251	156,398	191,289	387,064	615,999	316,494
West Africa												
Benin	569	53,463	-58,461	74,677	37,670	113,393	97,791	254,939	37,101	59,930	156,252	180,261
Burkina Faso	11,705	27,023	83,030	57,847	63,240	80,142	188,155	219,127	51,534	53,119	105,125	161,279
Cape Verde	24,993	41,338	50,336	70,292	40,019	41,787	50,592	70,641	15,026	448	256	349
Côte d'Ivoire	-137,266	-724,414	-876,472	-580,566	304,129	339,067	458,614	632,961	441,395	1,063,481	1,335,085	1,213,527
Gambia	-20,976	50,619	109,774	134,307	33,047	62,677	126,263	164,922	54,023	12,059	16,488	30,615
Ghana	36,035	-26,846	-50,183	300,751	137,023	207,843	339,840	788,314	100,988	234,689	390,022	487,563
Guinea	65,122	121,478	166,741	183,518	76,936	137,016	192,042	219,176	11,814	15,539	25,300	35,658
Guinea-Bissau	-7,335	13,475	9,547	-5,866	11,300	24,366	48,032	41,232	18,635	10,891	38,485	47,099
Liberia	46,459	-133,525	-111,742	132,120	73,118	42,138	125,412	163,172	26,659	175,663	237,155	31,052
Mali	-38,584	-18,390	-7,412	136,647	54,429	64,839	127,044	304,501	93,012	83,230	134,456	167,853
Mauritania	71,750	110,732	248,796	309,928	88,095	125,034	262,922	316,308	16,345	14,303	14,127	6,380
Niger	-11,609	52,673	143,571	266,470	55,358	88,939	170,857	293,495	66,967	36,266	27,287	27,025
Nigeria	1,644,283	319,654	1,737,111	2,955,827	1,868,321	507,987	2,023,554	3,301,106	224,039	188,333	286,443	345,279
Senegal	173,948	237,369	326,555	769,712	274,601	438,596	492,736	824,883	100,653	201,227	166,181	55,171
Sierra Leone	43,544	74,839	103,979	84,750	61,103	82,401	111,199	95,010	17,559	7,562	7,220	10,260
Togo	11,574	13,391	742	69,706	34,877	77,081	72,421	147,731	23,303	63,689	71,679	78,025

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