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Trends in the Human Appropriation of Net Primary Production for Ethiopia between 1961 and 2013 and their Impacts from a National and Local Perspective

MASTER THESIS

submitted in fulfilment of the requirements for the degree of

Master of Science

Studium:
Masterstudium Sozial- und Humanökologie

Alpen-Adria-Universität Klagenfurt

Evaluator:

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Vienna, March 2017

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I am grateful to all who made this thesis possible!

Special thanks go out to Anja and my family for their support, patience and encouragement in the process of writing.

I am indebted to Caritas Austria/Diocese of Feldkirch and especially Martin Hagleitner-Huber who made it possible for me to set time aside for my studies.

Many thanks to the SILVR team, especially Tesfaye Fetenu and Dr Abdelghani Souirji who collected and prepared the field data from Siraro, and Dr Samuel Ledermann from Biovision for motivating me in many ways.

Finally, a word of appreciation to the evaluator of this thesis, Dr Karlheinz Erb, for his support and guidance and to the team of the Institute of Social Ecology in Vienna!

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Abstract

In 2015, the population of Ethiopia reached the 100 million mark, and about 80 million people subsisted on agricultural production. The average household farm size had by then shrunk to less than 1 ha while cereal production yields remain low. Likewise, the country's livestock population often exceeds the carrying capacity of the grazing land, while its productivity is minimal. About half of the cattle are held for ploughing, still total traction capacity is below the demand. 90% of the total energy demand of Ethiopia is covered from biomass sources. With enormous topsoil losses reported, soil erosion has become and major concern. Thus, deforestation, erosion and land degradation has been linked to decreasing soil fertility and its impact on agricultural livelihoods and food security.

This study shows trends in biomass extraction with the help of the Human Appropriation Net Primary Production (HANPP) methodology as a socio-ecological indicator set. It demonstrates long-term trajectories of biomass flows and dynamics of land use change between 1961 and 2013 for Ethiopia and triangulates these with results from a local household livelihood survey to discover their representation in a real-life setting.

Study findings reveal that the total HANPP in % of NPPpot of Ethiopia for all land use categories increases from 30% in 1961 to 63% by 2013. Cropland HANPPharv per hectare almost triples and the cropland HANPPharv:HANPPluc ratio increases fourfold to 61%. On grazing land, HANPP per ha increases by 58%, accompanied by a rise in HANPPluc per ha of 78%. For grazing land, the modelled land degradation impact is the most significant contributing factor. However, no data are available to reliably validate this result, pointing to a massive research gap. Forest and woodland HANPP in 2013 stands at 53% of NPPpot. Locally in Siraro, 87% of the respondents report food shortage months in normal years. Low agricultural production is attributed to decreasing rainfall amounts, reduced soil fertility and a reduction in available farmland. Land degradation is a challenge raised by 92% of the farmers. Moreover, for 77% of the respondents biomass supply for livestock is not sufficient. 77% use fuel wood as their main source of energy, 13% also use crop residues.

Ethiopian HANPP rates reach more than three times the African average by 2005. In cropland production, efficiency gains seem to be a strong driver for these increases. In fact, for cropland this study finds a discrepancy between soil degradation stipulated widely in research and HANPP per ha results, which do not reflect such yield declines. It seems possible that agricultural intensification and cropland expansion may hide degradation losses.

Nevertheless, high levels of biomass utilization, especially in the form of animal feed and for energy consumption occur in the ecologically sensitive mountainous highlands. Ethiopia's grazing intensity is among the highest observed globally. Soil degradation and erosion have reached unsustainable levels and are identified as a major challenge locally and nationally. Keeping stocking rates below the carrying capacity of the land, improving feed and water management and quality seem vital to increase the productivity of the livestock subsystem while reducing its impact on natural resources. Such measures should contribute to creating conditions for a more sustainable yet also more productive agricultural system that would foster food security.

Zusammenfassung

2015 erreichte Äthiopien die Marke von 100 Millionen Einwohnern, 80 Millionen von ihnen lebten von Subsistenzlandwirtschaft. Die durchschnittliche Landwirtschaftsfläche pro bäuerlichem Haushalt sank auf unter 1 ha. Hektarerträge für Getreide verharren auf niedrigem Niveau. Der Viehbestand des Landes übersteigt vielerorts die Belastbarkeitsgrenzen der Weideflächen, aber die Produktivität bleibt niedrig. Etwa die Hälfte der Rinder wird zum Pflügen gehalten, dennoch reicht deren Kapazität nicht aus um die Nachfrage nach tierischer Zugkraft zu decken. 90% des gesamten Energiebedarfes wird durch Biomasse gedeckt. Forschungsergebnisse berichten von enormen Verlusten an Oberboden. Bodenerosion ist zu einer wesentlichen Herausforderung geworden. Entwaldung, Bodenerosion und Bodenverarmung scheinen damit direkt verbunden mit verminderter Bodenfruchtbarkeit und deren Auswirkung auf landwirtschaftliches Einkommen und Ernährungssicherheit.

Diese Studie zeigt Trends der Entnahme von Biomasse mit Hilfe der HANPP Methode (Human Appropriation of Net Primary Production) auf und verwendet damit eine Auswahl von sozioökologischen Indikatoren. Längerfristige Bewegungskurven von Biomasseflüssen und Dynamiken des Landnutzungswandels von Äthiopien zwischen 1961 und 2013 werden beschrieben und mit Ergebnissen einer lokalen Studie zu Wirtschaftsweisen von bäuerlichen Haushalten trianguliert, um Entsprechungen im realen Leben zu entdecken.

Die Resultate der Studie zeigen, dass die gesamte HANPP in % der NPPpot für Äthiopien über alle Landnutzungskategorien von 30% im Jahr 1960 auf 63% im Jahr 2013 gestiegen ist. HANPPharv pro Hektar Ackerland verdreifachte sich nahezu und das Verhältnis HANPPharv:HANPPluc stieg um das Vierfache auf 61%. Für Weideland erhöht sich HANPP um 58%, während HANPPluc gleichzeitig um 78% anstieg. Hierbei ist das zugrunde gelegte Degradationsmodell der wichtigste Einflussfaktor. Allerdings erlaubt die derzeitige Datenlage nicht, über eine Annäherung des Effekts hinaus zu gehen. Die erzielten Ergebnisse deuten nachdrücklich auf einen erhöhten Forschungsbedarf zur Degradation und ihrer Effekte in Äthiopien hin. HANPP von Wäldern und Baumbeständen betrug 2013 53% der NPPpot. Auf lokaler Ebene in Siraro berichteten 87% der Befragten von Monaten mit Nahrungsmittelengpässen auch in normalen Jahren. Die geringe landwirtschaftliche Produktion wird mit verminderten Regenfällen, reduzierter Bodenfruchtbarkeit und mit einem Mangel an Ackerland begründet. Bodendegradierung wird von 92% der Bauern als Problem erkannt. Für 77% der Befragten ist die verfügbare Biomasse nicht ausreichend, um ihre Tiere zu ernähren. 77% verwenden Holz als Hauptenergiequelle, 13% verwenden dafür auch Erntereste.

Die äthiopischen HANPP-Raten sind etwa dreimal so hoch wie die des Durchschnittes aller afrikanischen Länder. Für Ackerland zeigen sich markante Effizienzsteigerungen. Damit stehen die Resultate dieser Studie für HANPP pro Flächeneinheit wissenschaftlichen Erkenntnissen entgegen, die weiträumige Bodendegradation aufzeigen. Für HANPP pro Hektar Ackerland können jedoch keine Ertragseinbußen nachgewiesen werden. Es scheint möglich, dass die landwirtschaftliche Intensivierung und die Ausweitung der Landwirtschaftsflächen hier Degradationsverluste verdecken.

Trotzdem muss festgehalten werden, dass große Mengen an Biomasse entnommen wird. Dies gilt speziell für die Tierernährung und für die Energiebereitstellung und geschieht im ökologisch sensiblen gebirgigen Hochland Äthiopiens. Die Beweidungsintensität des Landes ist eine der höchsten weltweit. Bodendegradation und Bodenerosion befinden sich auf einem Niveau, das nicht nachhaltig ist und das eine große lokale und nationale Herausforderung darstellt.

Es scheint unbedingt notwendig, den Viehbestand unter die Kapazitätsgrenzen des Weidelandes zu senken, Futterqualität und Wasserzugang zu verbessern und die Produktivität der Viehhaltung insgesamt zu heben. Damit sollte es möglich sein, die negativen Auswirkungen auf die natürlichen Ressourcen zu reduzieren und Voraussetzungen für eine nachhaltigere, produktivere Landwirtschaft zu schaffen, die die Ernährungssicherheit verbessern kann.

1. Introduction

1.1. Biomass extraction and HANPP in the context of Ethiopia

In 2015, the population of Ethiopia touched the 100 million mark. The share of urban population has increased steadily within the last 30 years and stood at 19.5% of the total population in 2015. Hence, 80.5 % or about 80 Million Ethiopians live in a rural environment. In parallel, almost 80% of all Ethiopians subsist on agricultural production (FAO 2016) and about 40% of the Ethiopian GDP in 2015 was derived from agriculture (World Bank 2016).

In the main crop producing area of Ethiopia, the highlands, which account for a bit over 50% of the total land area, the average household farm size has shrunk to less than 1 ha in an inverse correlation with population growth (Hurni 2010). The average cereal production yields per hectare remains limited and reach maxima of only 1.5 tonnes. Despite major progress made in safeguarding human lives during times of drought, Ethiopia remains a country challenged by widespread food insecurity (Webb, Braun 1994; Josephson et al. 2014).

Ethiopia's livestock population on a regional scale frequently exceeds the carrying capacity of the grazing land (Hurni 2010) while its productivity in terms of carcass weight or milk and egg yields must be considered as low even if only compared regionally within East Africa (FAO 2016). In spite of high draught animal numbers held for ploughing, their total capacity is still beyond the traction labour required, especially during certain peak demand periods during the agricultural campaign (Hurni 2010).

In 2015, only about 27% of the population had access to electricity. Less than 6% of the total energy consumed was derived from fossil energy carriers (World Bank 2016). It is not surprising, then, that almost 90% of the total energy demand of Ethiopia is covered from biomass sources such as fuelwood/charcoal, crop residues and animal dung (Berhanu et al. 2016).

Deforestation, land degradation and their impact on agricultural livelihoods have been a major research and policy concern at least since the early 1990s (FAO 1986). Hurni (2010) points out that 90% of the Ethiopian highlands were once forested. In 2010 only 20% of this area was covered by trees, and less than 4% remained forested. Erosion from cropland is estimated at an average of 20 to 40 tons per hectare per year, 10 to 100 times the potential annual rate of regeneration, if farmland is fallowed. Land degradation has been linked to decreasing soil fertility and falling farm income from agricultural production and may thus have direct impacts on the food security situation in Ethiopia (WBISPP 2004; Josephson et al. 2014; Lal 1995).

From these statistical cornerstones it seems clear that the majority of the Ethiopian population is directly dependent on biomass extraction for their immediate livelihood. This dependency is based on the high importance of agricultural activities to cover basic needs in terms of food, feed and fuel in the form of crop and livestock production and fuelwood to safeguard the most basic energy needs. Disquietingly, current land use and biomass extraction patterns may lead to the depletion of soils, erosion and may result in reduced biomass production.

This study intends to highlight some of the general developments of the crucial role of biomass extraction with the help of a well-established socio-ecological indicator set and by applying the corresponding methodology to available data. The Human Appropriation Net Primary Production (HANPP) methodology has developed into a standard indicator set for measuring biomass extraction, the related backflows and the concurrent effects of land use changes (Krausmann et al. 2012; Haberl et al. 2007).

This study therefore intends to demonstrate long-term trajectories of biomass flows for Ethiopia and to reveal the socio-ecological sustainability of the land use practises which inform their basis. In a second step, findings of this HANPP study for Ethiopia are triangulated with a local household economy study to evaluate to what extend general trends discovered with the HANPP indicator set find their representation on the ground in a real-life setting.

It will be argued that human population, livestock pressures as well as the socio-economic and cultural practises have complex impacts on land use and the utilization patterns of biomass and that, through the excessive and unsustainable use of land and biomass, Ethiopians are likely to undermine their natural resource base which provides them with vital organic materials to cover their basic needs.

1.2. Relevance of the HANPP indicator in the Ethiopian context

Within the study timeframe, the Ethiopian land use systems and its ecosystems have undergone massive changes. The HANPP indicator set allows us to chart, abstract and analyse these natural and socio-economic transitions for five crucial decades of the Ethiopian recent past. HANPP as an indicator set and as a methodology lends itself to the systematic analysis of the changes in land use systems, their influence on ecosystems, and thus the utilization of trophic energy within ecosystems (Haberl et al. 2007). It incorporates natural ecosystem productivity based on climate, soil fertility and hydrological data and relates these to biomass extraction. Changes in the flows of biomass reveal linkages of natural with socio-economic developments. The HANPP indicator set therefore can be used to delineate crucial transitions within natural or colonized ecosystems, and hints at challenges that might result from the identified trends (Haberl et al. 2007; Krausmann et al. 2008; Zika, Erb 2009).

1.3. Research questions

Significant increases in the human population of Ethiopia between 1961 and 2013 from 22 to 95 Million inhabitants (World Bank 2016) have led to an increased demand for food for human consumption. Similarly, soaring livestock numbers have led to a substantial increase in the demand for animal feed (FAO 2016). As livestock is most frequently kept in free grazing arrangements, grazing pressure has shown rapid increments (Alemayehu et al. 2013; Gebremedhin et al. 2004). Additionally, biomass extraction as fuel for households form the basis of the Ethiopian energy regime (Guta 2014). In combination, these three extractive land use practices have had major impacts on the biomass flows of the country and have been linked to serious degradation tendencies in its natural resources (Bane et al. 2007; Bezuayehu et al. 2002; Biazin, Sterk 2013; Hurni 2010; Hurni et al. 2015; Kassa et al. 2016; Lal 1995; Nyssen et al. 2003). The study at hand, therefore, endeavours to respond to the following research questions:

- What dynamics and drivers of land use change can be observed for Ethiopia between 1961 and 2013?

- Which long-term trajectories of the Human Appropriation of Net Primary Production (HANPP) can be observed for Ethiopia between 1961 and 2013?
- Are current patterns of land use and biomass extraction sustainable?
- To what degree do trends delineated by the HANPP for Ethiopia reflect ground realities within rural villages in the district of Siraro?

1.4. Roadmap through this study

The following section (1.5) gives a brief introduction to the context in which this study was conducted. First, relevant characteristics of Ethiopia are presented with a focus on agricultural production. Second, related attributes of the district of Siraro are identified. In Chapter 2, data, methodologies and scope of the study at hand and limitations thereof are explained in detail. Chapter 3 outlines the results of the study: major land use dynamics of Ethiopia for the period under examination are explained, HANPP indicators are reported for the most important land use categories, and land use as well as biomass appropriation patterns are described for three villages in the rural district of Siraro. In Chapter 4 the trends of the national HANPP study are discussed and an attempt is made to come to a synthesis of the national HANPP developments with local outcomes for the three Siraro villages. Finally, a concluding remark draws together the most salient research findings and gives an outlook on identified additional research needs.

1.5. Ethiopian agriculture in the national and local research context

Ethiopia - including Eritrea - until 1993 covered 1.22 Million km2 but shrunk to 1.1 Million km2 after the Eritrean secession. Ethiopia today is host to nearly 100 Million inhabitants, the vast majority of whom (about 84% in 2007) reside in the mountains and plateaus known as the highlands between 1,000 and 3,800 meters above sea level. These highlands are separated into two distinct parts by the Great Rift Valley, which divides the country from North-East to South-West, from the Danakil depression to Lake Turkana on Ethiopia's border with Kenya (Ofcansky, LaVerle 1993; Hurni 2010). Above 3,800 meters sea level and up to Ethiopia's highest mountain peaks, crop agriculture is not possible for temperature reasons while below 800 to 1,200 meters sea level, cropping becomes prohibitively difficult because of a lack of precipitation (Hurni 2010).

Present-day Ethiopia spans from 15° Northern latitude to 4° close to the equator, and from its 33° Eastern longitude border with South Sudan to 47° E in the middle of the Somali desert. Ethiopia boasts an impressive variety of climates, from dry desert to humid tropical climate regions and from hot lowlands with annual mean temperatures of 25 to 30° C to the highland cropping zones with average mean temperatures between 15 and 20° C (McSweeney et al. 2010), to afro-alpine permafrost. Ethiopia's seasonal rainfall patterns are dependent on the Inter-Tropical Convergence Zone (ITCZ). Most parts of the country have one wet season, named *Kiremt* or *Meher*, from June to September, while some regions in the Northern and central highlands experience a second, shorter and less intense rainy season called *Belg*, and some Southern parts receive the *Bega* short rains (McSweeney et al. 2010).

To accommodate for this huge range of possible agricultural subclimates, most scientific literature follows the nomenclature of the Ethiopian agro-ecological belts or zones developed by Hurni (1998), as depicted in Figure 1 below.

Altitude in metres above sea level (m asl)	Less than 900	900 to 1400	More than 1400
More than 3700		**MOIST WURCH** A: None but wildlife C: None S: Black, shallow T: Hypericum quartinianum, Hypericum roeperianum	**WET WURCH** A: None (frost limit) C: None S: Black soils, little disturbed T: Mountain grassland
3700 to 3200		**MOIST HIGH DEGA** A: Only barley, 1 cropping season per year C: Drainage rare S: Black soils, degraded T: Erica Hypericum	**WET HIGH DEGA** A: Only barley, 2 cropping seasons per year C: Widespread drainage ditches S: Black soils, highly degraded T: Erica Hypericum
3200 to 2300	**DRY DEGA** A: Barley, wheat, pulses C: Traditional moisture conservation measures S: Grey-brownish grey T: Olea europaea, Maytenus undata, M. senegalensis	**MOIST DEGA** A: Barley, wheat and pulses, 1 cropping season per year C: Some trad. terracing S: Brown clay soils T: Juniperus, Hagenia, Podocarpus	**WET DEGA** A: Barley, wheat, nug, pulses, 2 cropping season per year C: Widespread drainage ditches S: Dark brown clay soils T: Juniperus, Hagenia, Podocarpus, Bamboo
2300 to 1500	**DRY WEYNA DEGA** A: Wheat, tef, rarely maize C: Terracing widespread S: Light brown to yellow soils T: Acacia trees	**MOIST WEYNA DEGA** A: Maize, sorghum, tef, inset rare, wheat, nug, daguss, barley C: Trad. terracing S: Red-brown soils T: Acacia, Cordia, Ficus	**WET WEYNA DEGA** A: Tef, maize, inset in W parts nug, barley C: Drainage widespread S: Red clay soils, deeply weathered, gullies frequent T: Many varieties, Ficus, Cordia, Acacia, Bamboo
1500 to 500	**DRY KOLLA** A: Sorghum rare, tef C: Water retention terraces S: Yellow sandy soils T: Acacia bushes and trees	**MOIST KOLLA** A: Sorghum, rarely tef, nug, dagussa, groundnut C: Terracing widespread S: Yellow silty soils T: Acacia, Erythrina, Cordia, Ficus	**WET KOLLA** A: Mango, taro, sugarcane maize, coffee, citrus C: Ditches frequent S: Red clay, highly oxidized T: Milicia excelsa, Cyathea manniana
Below 500	**DRY BERHA** A: None (except irrigation areas) C: None S: Yellow sandy soils T: Acaciabushes	**MOIST BERHA** A: Seasonal rainfed agriculture possible C: Burning grasses common, no wind erosion S: Silty and clayey, mainly black T: Ziziphus pubescens, Antiaris toxicaria, Erythroxylum fischeri	

Annual rainfall (millimetres)

Figure 1: Ethiopia's agro-ecological zones according to FAO 1986; Hurni 1998. Illustration taken from Hurni 1998

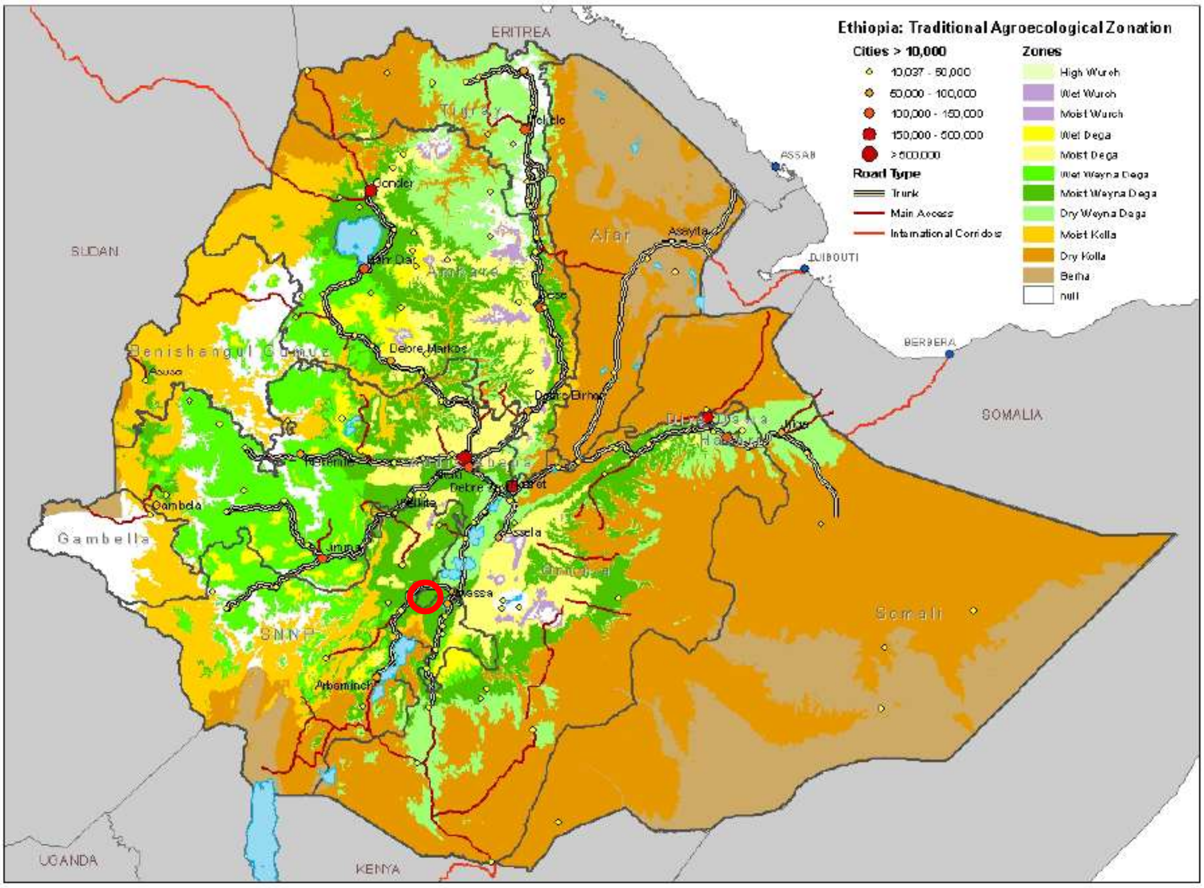

Figure 2: Agro-ecological zone map of Ethiopia (in its boundaries from 1993) following Hurni 1998, adapted from Chamberlin J., Schmidt (2011). The red circle indicates the position of the district of Siraro, which forms part of the research area of this study.

The vast majority of Ethiopian farm households practise mixed crop-livestock farming systems. The components and crops that make up these systems will depend on altitude (that is, temperature), the length of growing period and other socio-economic and cultural conditions. Except for certain areas with favourable circumstances or for products with relatively high profit margins, almost all crop production in Ethiopia is rain-fed agriculture. Most crop farming is dependent on animal draught power for ploughing (FAO 1986). Ploughing is still frequently done with a traditional *maresha* plough which does not invert the soil. Seedbed preparation is often lengthy and labour-intense as up to 6 passes have to be made with the plough team. Often draught power at peak periods is in high demand and therefore limits potential production (FAO 1986; Gryseels, Goe 1984). Major crops include teff (*Eragrostis tef*), the preferred staple food in the country and basis for the national sourdough flatbread *injera,* maize, wheat, sorghum and barley. Enset or false banana (*Ensete ventricosum*) is another speciality crop of Ethiopia and important to food security in parts of the Southern Ethiopian highlands. Coffee, oilseeds, vegetables and cut flowers are agricultural goods that are produced for international markets and have national economic relevance (FAO 2016). Double cropping is possible in some parts of the country that have two rainfall seasons. Here, short-maturing varieties of pulses may be planted in the first rainy season while longer-maturing cereals may be planted to benefit from the longer rainy season. Crop rotation of cereals with pulses has become quite common but fallowing is less and less practised due to a shortage of cropland (FAO 1986).

Livestock forms an important part of the Ethiopian mixed farming system. The supply of sufficient animal traction is a crucial aspect of the livestock subsystem (Gryseels, Goe 1984) and breeding and maintenance of draught animal stocks may form the basis for 50% of the Ethiopian cattle population, as will be shown in Chapter 3. But livestock may be kept and bred for a number of other reasons such as transport, as a form of capital substitute for insurance and savings purposes, or to supply manure for fuel. Interestingly, the production of milk or meat has much less importance within the cropping areas (FAO 1986).

Ethiopia boasts the highest livestock population in absolute numbers of all African countries and had 54 Mill. cattle, 28 Mill. goats and 26 Mill. sheep in 2013 (see Figure 15) . The majority of these animals, with the exception of camels and goats, is home to the intensely cropped highlands (Leta, Mesele 2014). Nevertheless, pastoralism and agro-pastoralism still forms the basis of the livelihood for 12% of the Ethiopian population living in pastoral areas of Ethiopia (SOS Sahel). In contrast to crop farming practised in the highlands, the major source of food of pastoralists stems from livestock, in the form of milk, meat and eggs.

The district of Siraro had a total rural population of 140,477, of which 69,059 were male and 71,418 were female. 27,480 households were registered in the district, according to the government census data of 2007 (Central Statistical Agency 2007). Hence, the average Siraro household has 5.1 members on average, according to government statistics. Nevertheless, within the survey area that forms part of this study, households appear to be considerably larger. Siraro is located in the West Arsi administrative zone in the regional state of Oromia. Its altitude above sea level ranges between 1,500 and 2,075 meters. The district extends over an area of 675 km2. A part of the district is set aside to form the Senkelle Wildlife Sanctuary for the protection of the rare Swayne's Hartebeest. Nevertheless, this wildlife retreat is also frequently grazed by cattle.

The only perennial river within the district is the Bilate. It forms the border to the neighbouring SNNPR regional state to the West of the district (GoE 2010). Due to altitudinal differences and rainfall patterns, the district has areas with moist to dry *Weyna Dega* and some lower-lying *Kolla* areas close to river Bilate. Rainfall estimates vary but are in the range of 800 to 1,500 mm per year (FEG 2008; GoE 2010). The most-commonly practised agricultural livelihood is centred around maize and bean cropping, while the lower-lying *Kolla* areas belong to an agro-pastoral livelihood zone with its main focus on animal husbandry. The three kebeles that form part of this study, Alemtena Sirbo, Nuna Raba and Loke Hada are situated in the center of the district (see Figure 3) and belong to the predominantly crop producing livelihood zone (FEG 2008). The district is considered food insecure and prone to drought (FEG 2008; FEWSNET 2015)

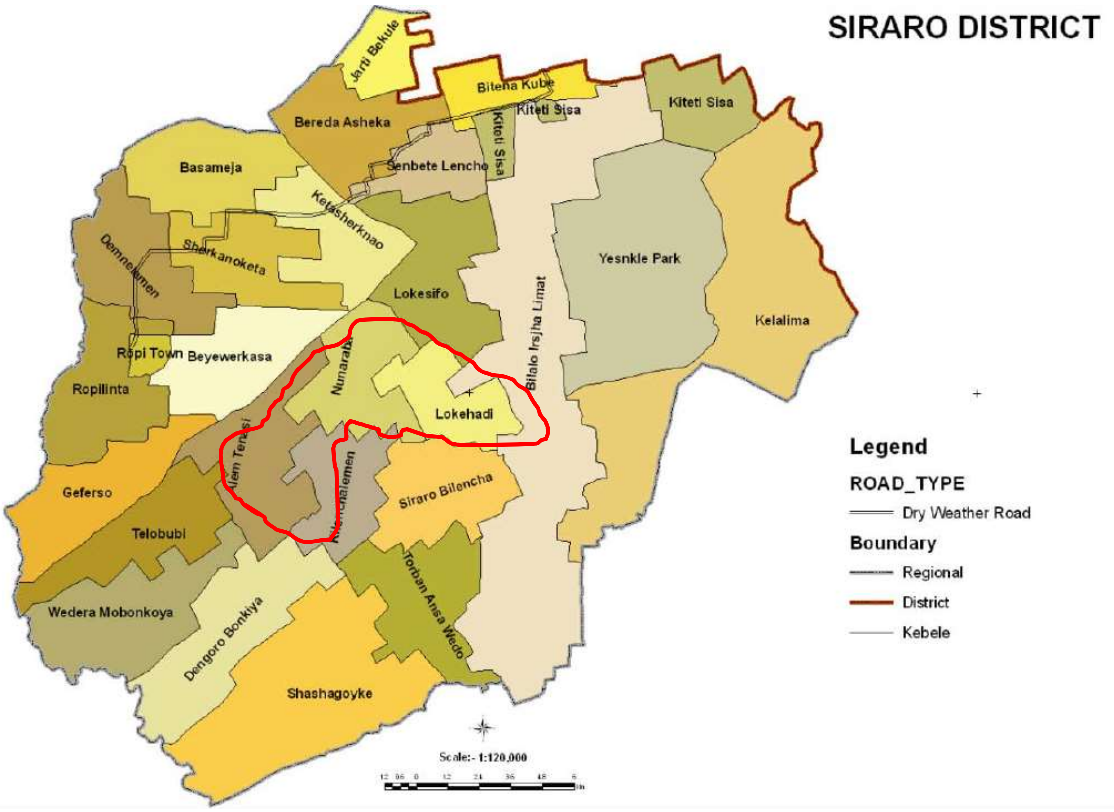

Figure 3: Map of the district of Siraro (adapted from GoE 2010). The kebeles (villages) under scrutiny in this study are in the heart of the map marked in red. Due to widely divergent transcriptions from Oromo to English they are marked as Alem Tenasi, Nunaraba and Lokehadi in this depiction.

2. Data, methodology, scope and limitations

2.1. Sources of primary and secondary data utilized

For the analysis of HANPP on the Ethiopian national level, the majority of data underlying this study was extracted from FAO data sources (FAO 2016). For the detailed analysis how the HANPP indicator set is reflected on local scales, data from a household survey in the district of Siraro conducted in 2014 was used.

2.1.1. The HANPP data sets

As the state of Eritrea officially separated from what is now called Federal Democratic Republic of Ethiopia in 1993, two different data sets are used to calculate all HANPP related indicators:

- Data set ETPDR (Ethiopia including Eritrea): one distinct dataset for Ethiopia including Eritrea (covering the late years of the Ethiopian Empire which included Eritrea during its federal affiliation with and its ensuing annexation by the Empire), with the FAO area code 62 and calculations carrying the identifier "ETPDR".
- Data set ET (Ethiopia excluding Eritrea): one distinct dataset for Ethiopia in its present-day boundaries, the Federal Democratic Republic of Ethiopia, thus excluding landmass, production and consumption data of Eritrea, with the FAO area code 238 and calculations carrying the identifier "ET".

These two distinct data sets and, indeed, the results of the two separate HANPP calculations derived from them, are combined in this study to highlight trends across the timeframe 1961 to 2013. In all graphs the discontinuity of the two distinct datasets is highlighted and, where appropriate, marked with a visible blank area separating the two data sets or a red vertical line.

The study thus adheres to the historic and geographic reference nomenclature by denoting Ethiopia as a distinct political and economic entity before and after the secession of Eritrea. This decision also has the advantage that historical land use data can be applied from various sources that do not explicitly distinguish between the two different state entities. In such cases, data was attributed according to the time coordinate of a given data point. In Chapter 3, study results will in many cases be presented in relative values (results per hectare and year (t dm/ha/yr) or per capita and year (t dm/cap/yr) to reflect developments of HANPP over time.

The two HANPP calculations presented in this study incorporate data from FAO sources (FAO 2016). This study used the following information from this database: for cropland HANPP calculations, crop harvest quantities and areas harvested; for grazing demand calculations and grazing land HANPP, animal stocks, livestock primary production quantities for beef, pig meat, poultry meat, eggs and milk yield, as well as commodity balances (primary equivalents) for plant-based, livestock- and fish-based feedstuffs; for forestry production quantities coniferous/non-coniferous wood fuel and industrial roundwood; and total population figures.

2.1.2. The Siraro household survey data set

A third data set is used for a "drill-down" analysis that compares trends for HANPP of Ethiopia with local ground realities in three villages of the district of Siraro. The data set of this drill-down analysis of land use and natural resource usage is based on household survey data that was collected in 2015 for a social development project entitled "Siraro Integrated Livelihood Vulnerability Reduction Project (SILVR)". The project is, at the time of writing of this thesis in 2016/17, implemented by the Ethiopian Catholic Church, Social Development Coordination Office of Meki (ECC-SDCOM) with funding from the donor organisations Biovision (Switzerland) and Caritas Austria[1].

The SILVR baseline survey was conducted with the aid of a structured questionnaire. The SILVR project manager and two project experts as supervisors, each supervising 5 survey enumerators, took charge of the survey data collection. The supervisors also took the GPS position of each surveyed households. Data processing was done with Microsoft Excel.

According to survey findings of the three villages analysed, 23% of the households are led by women. Consistent with the average household size of the representative sample of 172

[1] The author of this study is an employee of Caritas Austria. The author confirms that no conflict of interest related to this study exists which may be caused by his affiliation to Caritas Austria, the project SILVR or to the usage of the data set.

households (see Table 2), the total population can be extrapolated at 24,820 inhabitants. 2/3 of the respondents see their households as resource poor (see Table 1).

Respondents	**Alemtena Sirbo**		**Nuna Raba**		**Loke Hada**		**Total**	
	HHs	**% of total**	**HHs**	**% of total**	**HHs**	**% of total**	**HHs**	**%**
Number of HHs	51	30%	50	29%	71	41%	**172**	**100%**
Male-led HHs	40	78%	40	80%	52	73%	**132**	**77%**
Female-led HHs	11	22%	10	20%	19	27%	**40**	**23%**
HH socio-economic status (self-assessment)								
Poor	37	73%	30	60%	48	68%	**115**	67%
Moderately poor	12	24%	18	36%	22	31%	**52**	30%
Better off	2	4%	2	4%	1	1%	**5**	3%
HH with cellphone	4	8%	0	0%	8	11%	**12**	7%

Table 1: Composition of survey interviewees and some general socio-economic metrics for the three kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey.

The sum total of all household members represented amounts to 1,256 individuals of which 49.9% or 627 are female and 50.1% or 629 are male. As stated above, the average household has 7.3 members. Disaggregation by age reveals that 23.2% of respondents' household members and, by extension, of the three kebeles are under 5 years of age. 36.8% fall into the 5-18 year age bracket, 39.6% are aged between 19-65 years and only 0.5% are above 65 years of age (see Table 2).

Age group	Gender	Number	% Age group	% Total
<5 years	Male	140	48,1%	23,2%
	Female	151	51,9%	
5-18 years	Male	248	53,7%	36,8%
	Female	214	46,3%	
19-65 years	Male	237	47,7%	39,6%
	Female	260	52,3%	
>65 years	Male	2	33,3%	0,5%
	Female	4	66,7%	
all age groups	Male	627	49,9%	
	Female	629	50,1%	
Total		1256		100%

Table 2: Disaggregation of total household members by age groups for the three kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey.

2.2. The HANPP methodology

The Human Appropriation of Net Primary Production (HANPP) as a scientific concept is rooted in a continuing discourse of linking processes of nature with impacts of human endeavours on natural ecosystems (Haberl et al. 2007; Haberl et al. 2014). Net Primary Production (NPP) is mainly seen a product of photosynthesis[2], in which solar energy is transformed and stored as organic compounds with the help of inorganic elements, Carbon taken from the atmosphere as $CO2$ and water (Fetzel et al. 2012). These organic compounds represent the basis on which all heterotrophic food webs rely for sustenance. Human activities alter the environment in the process of colonization to control and thereby alter Net Primary Productivity (Haberl et al. 2014). The HANPP indicator, in its most basic form, therefore consists of its two components, HANPPluc and HANPPharv. HANPPluc entails the difference between the potential NPP (NPPpot) of a given land area that has been altered by human activities and its current, actual productivity (NPPact). HANPPharv denotes the fraction of NPPact that is actually extracted from the environment either to be used as food, feed, fuel, fiber or any other human purpose (Used Extraction) or to flow back to nature (in case of Unused Extraction). NPP remaining in the ecosystem after human interventions is labelled NPPeco (see Figure 4).

[2] Chemosynthesis plays a subordinate role in this context.

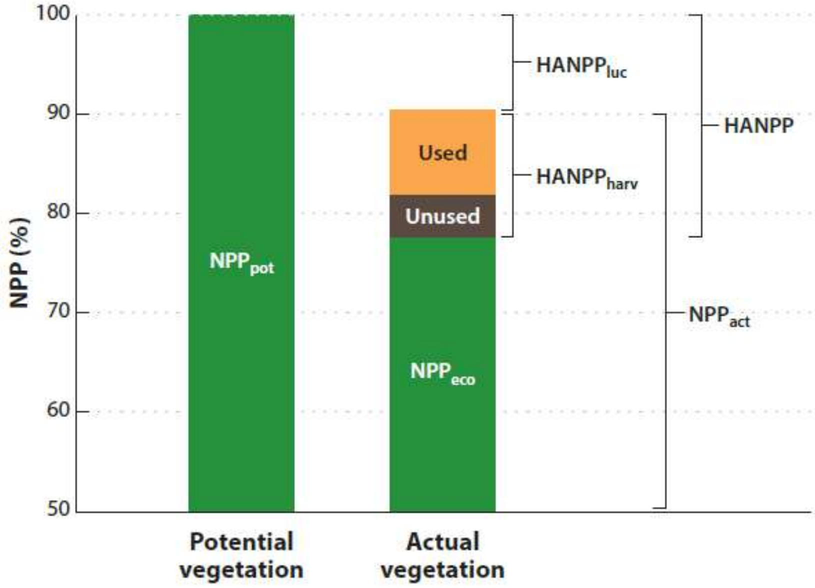

Figure 4: The definition of HANPP and its main sub-indicators HANPPluc and HANPPharv. Illustration taken from Haberl et al. (2014).

2.2.1. NPP, NPPpot and NPP calculations

The potential net primary productivity (NPPpot) of a given land area can be understood as the productivity of all natural vegetation without colonization impacts of humans on the environment. This study considers both above- and belowground NPP. NPPpot is derived from time series data generated with the Lund-Potsdam-Jena Global Vegetation Model with improvements in the representation of hydrology (Gerten et al. 2004). The NPPpot data set for Ethiopia of Krausmann et al. (2008) was used for this study. The dataset comprises modelled NPPpot values for Ethiopia from 1890 to 2006. For ET calculations, spanning 1993 to 2013, the gap in NPPpot data was bridged by modelling a linear trend for the years 2007 to 2013 on data values for the timespan from 1990 to 2006 taken from this NPPpot dataset. The same NPPpot data set, adjusted for the larger land area of Ethiopia including Eritrea by relation, was used for the calculation of NPPpot for ETPDR, i.e. Ethiopia including Eritrea.

From these two total NPPpot time series data sets, an average value of NPPpot per hectare of land area was calculated for the two separate HANPP calculations. The average per hectare NPPpot value thus arrived at was attributed to the five different land use categories utilized in this study by weighting factors to differentiate between differing net primary productivities assumed for land areas under specific uses (see Table 3). The weighting factors were taken from Krausmann et al. (2008), where the total NPPpot is disaggregated into the corresponding five different land cover classes.

Weighting factors for NPPpot allocation	**% of average NPPpot**
Cropland	130%
Forest and woodland	116%
Infrastructure area	129%
Wilderness	87%
Grazing land	95%

Table 3: Weighting factors for the allocation of the average NPPpot for Ethiopia to the five different land use categories.

Using these weighting factors, the total sum of NPP for all land cover categories was calculated and related to the annual NPPpot time series data as the NPP ceiling value. Finally, yearly NPPpot values for all land use categories were averaged over 5-year timeframes to smoothen out effects of outlying NPP values thus arriving at final average annual NPPpot values per hectare per land use category.

2.2.2. Land cover classes and land cover data used

To account for the most relevant land use categories, this study distinguishes between five different land cover classes: cropland, grazing land, forest land, settlements and built-up area, and wilderness. To some extent, degraded land is also considered in the study in the grazing land category. It is not calculated as a land cover class *per se* given the notorious difficulties in attaining reliable data on degradation and erosion, especially in dryland areas which cover large parts of the Ethiopian ecosystems (Zika, Erb 2009).

It must be acknowledged that land cover does not always fully coincide with land use. While this fact has been taken into account to some extent for settled/built-up areas, for practical reasons this study assumes that land use determines land cover. To some extent, grazing land may be seen as an exception here, because of how the grazing land area has been calculated for this study. As HANPP calculations rely on grazing demand calculated on a production or consumption basis, it may thus include grazing from other land use categories.

Cropland data for arable land and permanent crops was taken from FAO land cover data for Ethiopia and Eritrea.

Grazing land was calculated according on the basis of a closed budget approach, i.e. all land not allocated to any of the other land cover classes cropland, forest land, built-up land and wilderness is considered grazing land in this study (Erb et al. 2009).

Data for forest land from the FAO for Ethiopia exist only from 1990. Land cover was therefore extrapolated from three FAO-based data points at the beginning of the 1990s and literature review and synthesis (FAO 1986; Bane et al. 2007), which leads to the assumption that total forest cover (including woodlands and dense shrublands not suitable for grazing) may still have covered 25% of the Ethiopian land area in the late 1950s.

Infrastructure data for Ethiopia was extrapolated to annual values from 11 distinct data points for the timespan 1910 to 2005 taken from (Krausmann et al. 2008). Implicitly it is assumed that data points of this data set before 1993 reflect Ethiopia including Eritrea.

Land cover that is considered in the land use category wilderness was taken from Global Environment Facility data (GEF 2007) which reflects all areas currently under protection as national parks or wildlife sanctuaries, wildlife reserve areas and controlled hunting areas, regardless of when these protected areas were established. In this study, 25% of the land area of the demarcated total protected area is attributed to the wilderness land cover class throughout its timeframe, so for both ET and ETPDR HANPP calculations.

2.2.3. Cropland production data and calculations

The main indicator for cropland, HANPPharv, was calculated as the sum total in dry matter (dm) of all annual and perennial crops harvested, all crop residues (both used and unused fractions) and crop roots killed in the course of harvesting, following the definitions of Haberl et al. (2007). Crop production reported in fresh weight by FAO was converted into dry matter weight by using crop-specific water content (see Table 4 below) factors derived from Krausmann et al. (2008).

FAO Code	FAO Name	Water content (%)	Used Extraction multipliers
176	Beans, dry	10%	0,21
181	Broad beans, horse beans, dry	10%	0,21
108	Cereals, nes (*for Ethiopia Teff*)	14%	2,10
656	Coffee, green	10%	0,00
201	Lentils	11%	0,21
333	Linseed	10%	0,00
56	Maize	14%	3,19
79	Millet	12%	3,19
75	Oats	14%	2,10
339	Oilseeds nes	10%	0,00
187	Peas, dry	11%	0,21
116	Potatoes	78%	0,75
211	Pulses, nes	10%	0,21
149	Roots and tubers, nes	75%	0,75
289	Sesame seed	6%	0,00
83	Sorghum	11%	3,19
236	Soybeans	10%	1,35
156	Sugar cane	83%	0,60
122	Sweet potatoes	70%	0,75
388	Tomatoes	94%	0,00
463	Vegetables, fresh nes	95%	0,00
15	Wheat	14%	2,10

Table 4: A selection of crops and their water content factor (in Column 1) which is applied on FAO-reported fresh weight data. Column 2 reflects the multipliers per crop used to calculate Used Extractions. All factors taken from Krausmann et al. (2008).

Similarly, allocation factors derived from crop-specific harvest factors were taken to calculate residues from crop production and allocate crop residues to the fractions of used and unused extraction of biomass (see Table 4 for examples of Used Extraction multipliers applied). The sum of crop production and crop residues representing the total aboveground NPP of cropland denotes the basis for the calculation of the total root dry matter by applying a general shoot to root NPP factor of 15% on the aboveground biomass in dry matter. This factor is again derived from Krausmann et al. (2008).

To compute HANPPluc, HANPP and NPP values for cropland, losses in net primary production (so called pre-harvest losses) from planting to harvesting were calculated by applying a loss expansion factor of 36% to HANPPharv (based on Krausmann et al. 2008). Land under fallow during a specific year was calculated by comparing the total cropland area (as stated by FAO) with the total cropland area harvested for the sum total of all crops per year. No fallowing was assumed to occur if the value for cropland harvested exceeded total cropland area. Such negative values (where the area under crops is larger than the total of all cropland area) are attributed to multiple harvest per year per unit area. In the context of Ethiopia the potential for multiple harvests exists in some parts of the major cropping areas so that about 10% of the national cropland may potentially be harvested twice in one year (Taffesse et al. 2011).

The NPPact of fallowed land was assumed to be 80% of potential NPP, with HANPPluc of land under fallow therefore assumed at a constant 20% of NPPpot to account for conversion and other productivity losses. The total NPPact of all cropland was calculated as the sum of HANPPharv, pre-harvest losses (multiplied by a loss extension factor of 1.36 for least developed countries) and NPPact of fallowed land per year, in accordance with the HANPP method described in Krausmann et al. (2008). To calculate cropland HANPPluc, the total cropland NPPact was deduced from the total cropland NPPpot for each year. The HANPP for cropland represents the sum of HANPPharv and HANPPluc. The NPP remaining on cropland, NPPeco, the sums of HANPPharv and HANPPluc for cropland are deducted from cropland NPPpot.

2.2.4. Livestock production data and calculations

In the FAO data framework, permanent pasture is defined as land used for at least five years for herbaceous forage crops. Thus, existing FAO data on permanent pastures do not fully reveal the total land available for grazing which in the context of Ethiopia may for example cover the bush- and shrublands of the South and East that are not permanently or exclusively used for pasture purposes. Therefore, in this study, grazing land for Ethiopia is calculated following a closed budget approach (Erb et al. 2009). Total grazing land is defined in this study as all land that does not fall under the land use categories cropland, forest land, built-up land/infrastructure and wilderness.

For all ruminants, except for cattle, feed demand in dry mater was calculated on a per ruminant category and per head basis. Daily feed demands based on Krausmann et al. (2008) were taken to calculate average annual feed intake (see Table 5).

Animal	kg dm/head/day
Sheep	1,0
Goats	1,0
Horses	10,0
Asses	6,0
Mules	6,0
Camels	10,0
Rabbits	0,1
Other Rodents	0,1
Other Camelids	10,0

Table 5: Feed demand of selected animals used for the study taken from Krausmann et al. (2008)

To calculate cattle feed demand, two specific linear feed demand models (see Figure 5) were applied to FAO data on beef versus milk production. The higher feed demand value (in dry matter) was then used for further computation (Krausmann et al. 2008).

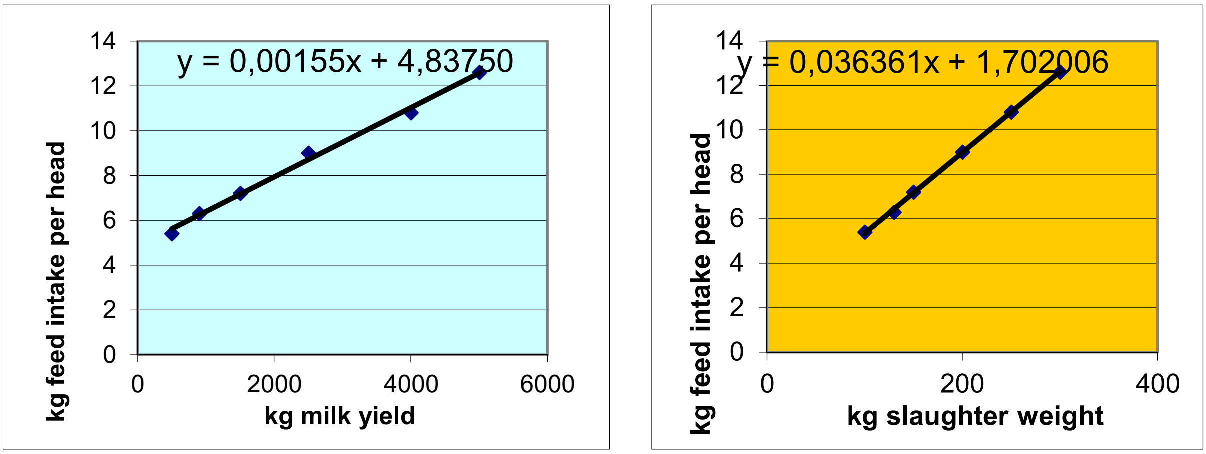

Figure 5: Linear functions utilized to calculate cattle feed demand. Both the feed demand calculated on FAO beef production data and on FAO milk production data was calculated, with the higher value reflecting cattle feed demand.

For pigs and poultry, FAO production data for pig meat, poultry meat and egg production and corresponding feed demand factors were applied according to Krausmann et al. (2008) to arrive at dry matter values (see Table 6). In order to account for commercial plant-based and animal/protein-based feed supply dry matter values were computed for FAO livestock feed commodity balance data sets.

Feed demand		Sub-saharan Africa value
Poultry - eggs	kg feed/kg eggs	4,00
Poultry - meat	kg feed/kg meat	5,50
Pigs - meat	kg feed DM/kg meat FW	8,50

Table 6: Feed demand factors for poultry and pigs by product, based on Krausmann et al. (2008)

The total grazing/feed demand was calculated by using the "grazing gap approach" as described in (Krausmann et al. 2008): from the basis of the total feed demand of ruminants, remaining commercial livestock feed after monogastric consumption and crop residues (assumed to be used 90% as fodder) were subtracted. In this study the computed grazing demand represents HANPPharv on grazing land.

For the purpose of this study, NPPact of grazing land is assumed to remain constant at 80% of NPPpot. The reduction by 20% takes into account changes in vegetation due to normal grazing and trampling effects (Steinfeld et al. 2006; Haberl et al. 2014). NPP losses due to land degradation (see 2.2.7) were assessed separately.

Finally, HANPPluc of grazing land was calculated by subtracting NPPact from NPPpot, HANPP of grazing land was calculated as HANPPluc plus HANPPharv, and NPPeco was calculated by subtracting HANPP from NPPpot.

2.2.5. Forest extraction data and forest calculations

For wood consumption, in this study HANPP of forest land is defined as HANPPharv, HANPPluc is therefore assumed to be zero. Total wood dry matter values were calculated from FAO-reported fresh weight values for coniferous and non-coniferous wood fuel and industrial roundwood data by applying wood density factors (see Table 7), according to Krausmann et al. (2013). As FAO reports wood under bark, bark extraction is accounted for by applying bark factors (see Table 7).

Factor	Coniferous Wood	Non-Coniferous Wood
Wood density for fresh weight to dry matter conversion	0,432	0,58
Bark factor: FAO reports wood under bark so that 100 % represents total dm biomass incl. bark)	90%	90%
Factor	**Wood Fuel**	**Industrial Roundwood**
Applied wood recovery rate	100%	95%
Belowground phytomass (shoot to root) factor	0,28	

Table 7: Conversion factors used in different stages of calculating HANPP of forest and woodlands, according to Krausmann et al. (2008)

Aboveground HANPPharv was calculated by accounting for felling losses using wood recovery factors of Table 7. Finally, killed root biomass of extracted wood was calculated by applying a belowground phytomass factor (Krausmann et al. 2008) to the aboveground forest HANPPharv (see Table 7). The HANPP of forest land equals this sum of wood roots killed during extraction and aboveground HANPPharv. NPPpot and NPPact are assumed to be the same on forest land, therefore NPPeco can be calculated by subtracting HANPP from NPPpot.

2.2.6. Settlement/built-up area calculations

For the calculation of built-up area HANPPluc, it was assumed that 2/3 of the built-up land has a net primary productivity of 0 and is barren. On 1/3 of the built-up land (for which the NPPpot value for cropland is allocated) NPPpot is assumed to be extracted at a rate of 50%, reflecting for example the biomass extraction from urban gardens or by roadside grazing. The total HANPP of built-up land again comprises HANPPluc and HANPPharv, with NPPeco reflecting the remaining 50% NPPpot on 1/3 infrastructure land. These figures are in line with global studies on HANPP (Krausmann et al. 2013) which may not fully mirror realities in the Ethiopian context. Nevertheless, as the built-up area land cover class represents a very small fraction of the total land cover (between 0.3 to 0.5% of the total land area), impacts on the results here presented are negligible.

2.2.7. Land degradation

Due to the extent and severity of soil degradation in Ethiopia (Nyssen et al. 2003; Hailu et al. 2015; Hurni et al. 2015; Lal 1995; Haberl et al. 2014), and the accumulative effects over time that will impact especially on grazing land, in this study an NPP reduction factor or degradation coefficient is developed, in order to take this fact into account. Land degradation and soil erosion and its suppressive effects on net primary production are therefore included in the HANPP calculations by the assumption of this NPP reduction factor, or degradation coefficient. Degradation from other land use classes, especially cropland, are considered in this study in so far as NPPact is derived from harvest data. In the context of land degradation it is assumed that eroded cropland not productive for farming will be reflected in the grazing land category. Nevertheless, it must be acknowledged that erosion effects on cropland and infrastructure land may be potentially severe.

Figure 6: Soil degradation and soil erosion have a significant effect on the NPP of Ethiopia: the picture shows cattle grazing on severely eroded communal land that was once used as cropland (picture taken by the author Harald Grabher on Aug 24, 2016 in Dugda district, Ethiopia)

The degradation coefficient used in this study assumes an exponential degradation development between 1961 and 1992, reducing the NPPact of grazing land by 5% in 1961 up to 34% in 1992, and remains constant at 35% from 1993. The degradation coefficient is calculated on the total grazing land area and hence assumes an even distribution of erosion over all grazing land. The loss of NPPact in % of NPPpot due to degradation assumed in this study therefore rises from 4 to 12% in the 1960s and 1970s, increases further to 23% by 1989 and peaks and levels off at 28% from 1992. The degradation coefficient is based on research findings that underline the severity of degradation in Ethiopia (Baudron et al. 2015; Bezuayehu et al. 2002; Duncan et al. 2016; Gebremedhin et al. 2004; Hailu et al. 2015; Hurni et al. 2015; Jaleta et al. 2015; Lal 1995; Nyssen et al. 2003; Pimentel et al. 1995; Alemayehu et al. 2013). According to a crop yield reduction model, based on an annual topsoil loss of 17 t/ha (and other factors), Pimentel et al. (1995) calculate a yield decline of -20% over 20 years. Although the study at hand allocates its degradation to grazing land, it is assumed here that this the model can serve as a frame of reference, especially because research finds that soil loss from all land on average in Ethiopia is in excess of the soil loss used by Pimentel et al. (1995) For selected studies reporting on soil loss rates for Ethiopia, please see Table 8.

Still, data on the severity and extent of degradation on grazing land remains fragmented, varied and inconclusive. For this study, the exponential development and the high final level assumed as the degradation coefficient strive to account for various phases of degradation that have taken place at least in parts of the current grazing land: the successive conversion of pristine, original forest cover to cropland which, degraded and eroded, may be abandoned and left to animal grazing, exacerbating existing degradation and erosion. Research data to support this assumption can be found in Table 8 and Table 9. Nevertheless, attention must be drawn to the fact the trajectory and extent of the degradation coefficient remain speculative and cannot be fully substantiated.

Study	Type	Information	Soil Loss
Alemayehu et al. (2013)	Field study	Study on grazing land management	-32 t/ha/yr from open communal grazing land on slopes
Bezuayehu et al. (2002)	Review		-37 t/ha on 9% slope; -16 t/ha on 6% slope
Hailu et al. (2015)	Study, NPP reconstruction	38.9% of current agricultural land area was converted from broadleaved evergreen and deciduous forest	-
Hurni et al. (2015)	Assessment	Ethiopian highlands only; 52.205.748 ha Net erosion - highlands average:	total soil net erosion/ deposition of - 940.893.165 t/year; - 379.255.511 t/yr from cropland; -18 t/ha/yr
		Cropland (net e.)	-20,2 t/ha yr
		Grazing land (net e.)	-12 t/ha/yr to -33 t ha/yr

Table 8: A selection of recent research findings on soil loss for Ethiopia: the high amounts of topsoil loss are undisputed and range between 12 t/ha/yr up to 37 t/ha/yr with an average of 18 t/ha/yr.

	Type	Information	Yield difference
Baudron et al. (2015)	Field study	8 years; open grazing vs. cut & carry	+70% yield (teff) on cut & carry farms (vs open grazing)
Lal (1995)	Review	Yield reduction due to past erosion	-2 to -40 %; -6,2% for SSA in 1995; prediction: - 14.5 by 2020 (SSA)
Pimentel et al. (1995)	Review and modelling	Model based on -17 t soil loss; 75 mm water loss, -2 t SOM loss, -15 kg N loss per ha/yr	-8 % yr/yr; - 20 % over 20 yrs
Tengberg et al. (1997)	Field trials	9 years duration; decrease vs baseline plott; tropical climate, Brazil	-44 to -50% (maize)
Tully et al. (2015)	Review	2 studies from Kenya and Nigeria	see figure 7

Table 9: Selected studies on yield reduction due to degradation that formed the basis for the degradation coefficient assumed in the study at hand.

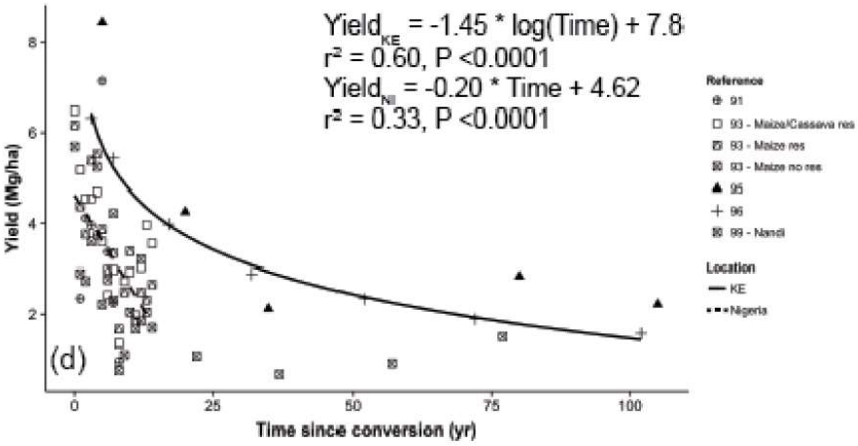

Figure 7: Relationship between land converted to cropland and the consequent degradation impacts presented in the form of yield declines of maize and cassava for two locations in Africa (Kenya and Nigeria). The time scale is given on the x-axis and declining yield trends on the y-axis. Figure taken from Tully et al. (2015)

One major challenge brought forward to counter the soil erosion argument suggests the need report erosion-deposition balances. Based on prior research findings, Nyssen et al. (2003) attempt such balances for three catchment area sizes and show that within 100 km2 catchment area radius, total soil loss may still be as much as 28.1 % or 68,255 t topsoil/year while this balance may even decrease to 7.5% on larger (10,000 km2) catchment scales. Nevertheless, while this argument is valid, and the possibility of relatively lower topsoil losses of 6.8 t/ha/yr must be considered, the accumulated value for soil loss still amount to 360 t/ha on average over the 53 years of this study. This is well beyond sustainable natural reproduction levels of topsoil. Hurni et al. (2015) take up this challenge but still report net soil losses of 18 t/ha/yr on average for the Ethiopian highlands area (see Table 8).

Finally, it also needs to be considered that eroded soil deposits may often be located in flood-prone plains, that such deposits may not be evenly distributed and thus may cover less land functional for cropping and that deposited soil may be compacted and compartmentalized and therefore less fertile than before the erosion process.

2.3. The Siraro baseline survey methodology

For the study part that focuses on three villages of the rural district of Siraro, a baseline survey from a development project was used. The Siraro Integrated Livelihood Vulnerability Reduction Project (SILVR) started its field operations in January 2015. The development project is still ongoing and is funded by Caritas Austria and Biovision of Switzerland. The author of this study is an employee of Caritas Austria. The project is implemented in Ethiopia by the Social Development Coordination office of Meki of the Ethiopian Catholic Church (ECC-SDCOM). The SILVR project baseline study aims at the description of the local situation before the development project started its interventions. In a first step, a household survey questionnaire was prepared, based on the indicators for the success of the project. The household survey questionnaire was then translated from English to Oromo by the project team. The project team tested the questionnaire and the interview process within its team in order to ensure common understanding of the questions, but due to time constraints no formal validation of the questionnaire could be done with interviewees. A representative sample size was drawn from available household data for the 3 selected villages, disaggregated by gender. Based on the population size of 3,399 households, a chosen acceptable error margin of 7.5% and a confidence level of 95% at a sample size of 163 HHs was computed. As the estimated answers rate was 95%, the final sample size was 172 HHs. The sampling intensity is therefore 5%. Finally 172 village inhabitants representing their household responded to a one-on-one interview based on the prepared structured questionnaire. The interviews were conducted under the supervision of project team members by hired survey enumerators in the local language and results were transposed into English. Results were then aggregated and analysed using commercial spreadsheet software.

2.4. Limitations with regard to data

The HANPP data set

Quality and reliability of FAO land use and agricultural production data, especially those spanning a considerable timeframe, bridging major historical disruptions, in regions or countries with limited capacity in data collection, has often been questioned. While data limitations derived from FAO databases must be conceded (Krausmann et al. 2008), these are the only continuous sources of data available for extended timeframes (specifically for 1961 to the 1992) and for the geographical region under scrutiny. Given the aggregate level of data analysis applied here, this study assumes that data quality and reliability is sufficient to depict general trends and developments with regard to the indicator sets derived from the HANPP methodology. Moreover, data from a household survey in Siraro district of Ethiopia is used to verify and triangulate research results arrived at through the HANPP analyses.

There is a fair amount of research on land and soil degradation in Ethiopia and in overall literature on dryland ecology. The study uses a degradation coefficient which is based on research findings that underline the severity of degradation in Ethiopia and beyond (Baudron et al. 2015; Bezuayehu et al. 2002; Duncan et al. 2016; Gebremedhin et al. 2004; Hailu et al. 2015; Hurni et al. 2015; Jaleta et al. 2015; Lal 1995; Nyssen et al. 2003; Pimentel et al. 1995; Alemayehu et al. 2013). Nevertheless, while efforts were made to base the degradation coefficient on research findings (see Table 8 and Table 9) it must be conceded that data on the severity and extent of degradation on grazing land remains inconclusive.

<u>The Siraro household survey data set</u>

For the Siraro drill-down analysis, baseline survey data from a social development project was used. Such data usually describes the situation of a development project area that exists before the start of a development intervention. This data is to be related to changes that are ascribed to take place, at least in part, due to project activities. Such projects are based on an intervention logic or logframe (Coleman 1987), in which project activities are implemented to attain project results which in turn are expected contribute to the fulfilment of the project's objectives. The combined results of a multitude of project activities are supposed to lead to tangible impacts, which are measured against the baseline data.

As a consequence, the research aim behind a baseline survey is structured along and limited to the intervention logic and scope of the project's objectives. The baseline data set of the project SILVR which is used in this study consist of in-depth agricultural and land use information on household level, but also includes more general social data including educational, economical and health statistics. The data set, therefore, lends itself to a socio-economic analysis of how land use and biomass appropriation patterns impact on the lives of the concerned rural population, as perceived at the time of the survey in 2015 by the respondents.

The survey was not intended and therefore cannot be used for a localized HANPP study, as several dimensions to calculate HANPP are not included in the data. Likewise, while degradation is a major concern of the study at hand, the SILVR baseline survey data does not entail in-depth information on degradation. Within the SILVR baseline framework, degradation is most often linked to deforestation. Degradation through grazing was not specifically surveyed and is not reflected in the data set.

3. Results

3.1. Major land use dynamics of Ethiopia between 1961 and 2013

Land use trends in Ethiopia must be seen on the basis of the two distinct HANPP data sets this study is using. With the secession of Eritrea from Ethiopia in 1993, the total land area available decreased from 110 Mha to 100 Mha for all calculations from that year (see Table 10).

Naturally, this change in land area affects all land use classes and renders comparison of land use changes in absolute numbers intricate. By relating area per land use class to the total land area available at that time and by then using the relational value of 1961 as index basis for all following years it is possible to reveal continuous trends in the development of land uses. As can be seen in Figure 8 below, significant changes in land use can be observed in Ethiopia within the analysed timeframe. The cropland area increased by almost 60% relative to the total land area over the basis of 1961: cropland area expanded from 11.5 Mha to 13.8 Mha in the late 1970s before shrinking to 11.3 Mha before secession of Eritrea in 1992. The new Ethiopia remained with 10.5 Mha of area under crops from 1993 until 2002, when a sharp expansion of cropland area set in. Between 2011 and 2013 more than 16 Mha of land were allocated to agriculture (see Table 10).

Hand in hand with the almost fourfold increase of total population of Ethiopia from 24 Mill in 1961 to 95 Mill in 2013 (Table 10) goes a parallel reduction in total available land per capita. Thus, total land available per capita decreased from 4.6 ha/cap in 1961 to 2 ha/cap in 1992 and from 1.9 ha/cap in 1993 to 1.1 ha/cap in 2013. In accordance with population growth, available cropland more than halved in a continuous trend from 0.5 ha/cap in 1961 to 0.2 ha/cap until 1998 and stabilized at this level until 2013, mainly because of cropland expansion.

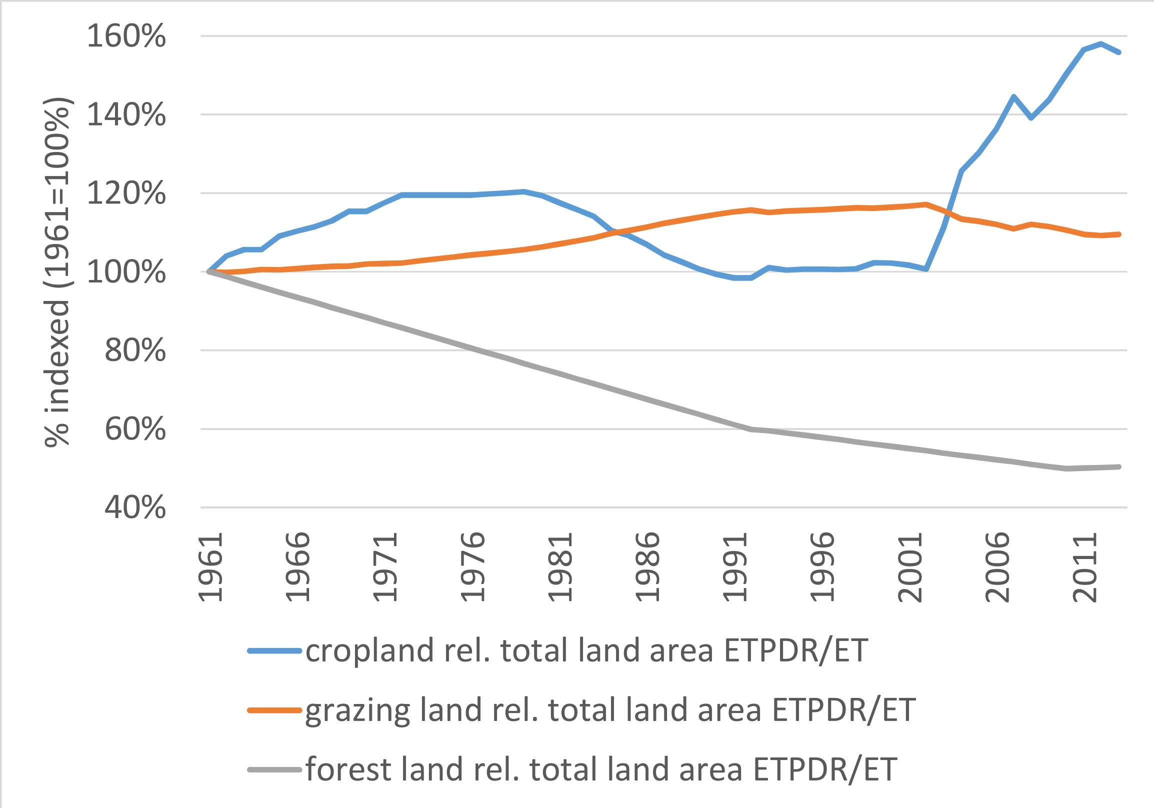

Figure 8: Trends for the development of land uses of the three most important land use categories for Ethiopia between 1961 and 2013. Trends were computed on the basis of different total land areas for both data sets ETPDR and ET, and thereafter plotted based on the index value of the year 1961.

Relative to the total land area, grazing land area expansion peaked in 1992 with an increase of 16% and again in 2001/2002 with an increase of 17% over the 1961 index value and amounted to 80.6 Mha and to 74 Mha respectively.

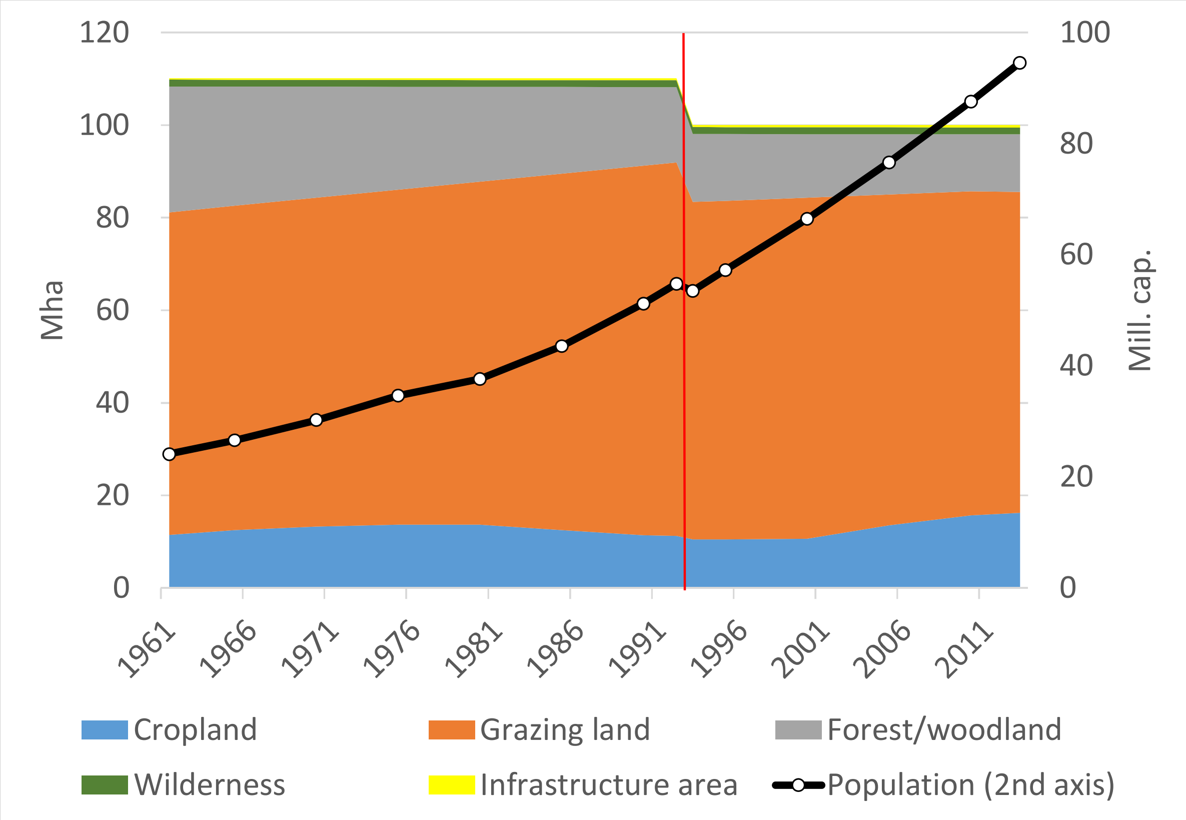

Figure 9: Land use and population trends of Ethiopia between 1961 and 2013 for selected years, structured on data points of Table 10.

		1961	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2013
Population	Mill.	24,1	26,6	30,2	34,6	37,6	43,5	51,2	57,2	66,4	76,6	87,6	94,6
Cropland	Mha	11,5	12,5	13,3	13,7	13,7	12,5	11,4	10,5	10,7	13,6	15,7	16,3
Grazing land	Mha	69,7	70,0	71,0	72,3	74,0	77,0	79,8	73,1	73,7	71,4	70,0	69,3
Forest/woodland	Mha	27,2	25,8	24,0	22,2	20,5	18,7	16,9	14,4	13,7	13,0	12,3	12,4
Wilderness	Mha	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Built-up land	Mha	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,5	0,5	0,5	0,5
Total land area	Mha	110	110	110	110	110	110	110	100	100	100	100	100

Table 10: Land use and population data of Ethiopia between 1961 and 2013 for selected years.

The area under forest (including closed woodlands) decreased significantly by 50% relative to their share of total land area and to 1961. Per capita availability of forest land decreased from around 1 ha in 1961 to 0.1 ha/cap by 2013. Because of the lack of data availability, the low quality of historical forestry and woodland land cover data for Ethiopia and the necessary extrapolations on which the study results rely, these values should be viewed as a general trend indication.

The land use categories wilderness and built-up land, representing only 1.5 to 2% of the land area available in Ethiopia throughout the study period (see Table 10), remain relatively insignificant for the results of this study at historic and current levels and were therefore not included in Figure 8.

3.2. HANPP in Ethiopia from 1961 to 2013

3.2.1. Overall HANPP developments

The general trend observable for Ethiopia between 1961 and 2013 is an increasing human appropriation of net primary productivity (HANPP) in relation to potential NPP. As depicted in Figure 10, the overall HANPP for all land use categories increased from 30% of the total NPPpot in 1961 to 63% in 2013. Therefore, the HANPP in Ethiopia more than doubled within the time span of 50 years.

The amount of biomass extraction that was used in human-related activities almost doubled from 128 Mt dm/yr to 252 Mt dm/yr between 1961 and 2013. On the other hand, NPPeco which denotes the amount of NPP remaining in the ecosystem after human endeavours more than halved from 1050 Mt dm/yr to 435 Mt/dm yr in the same period.

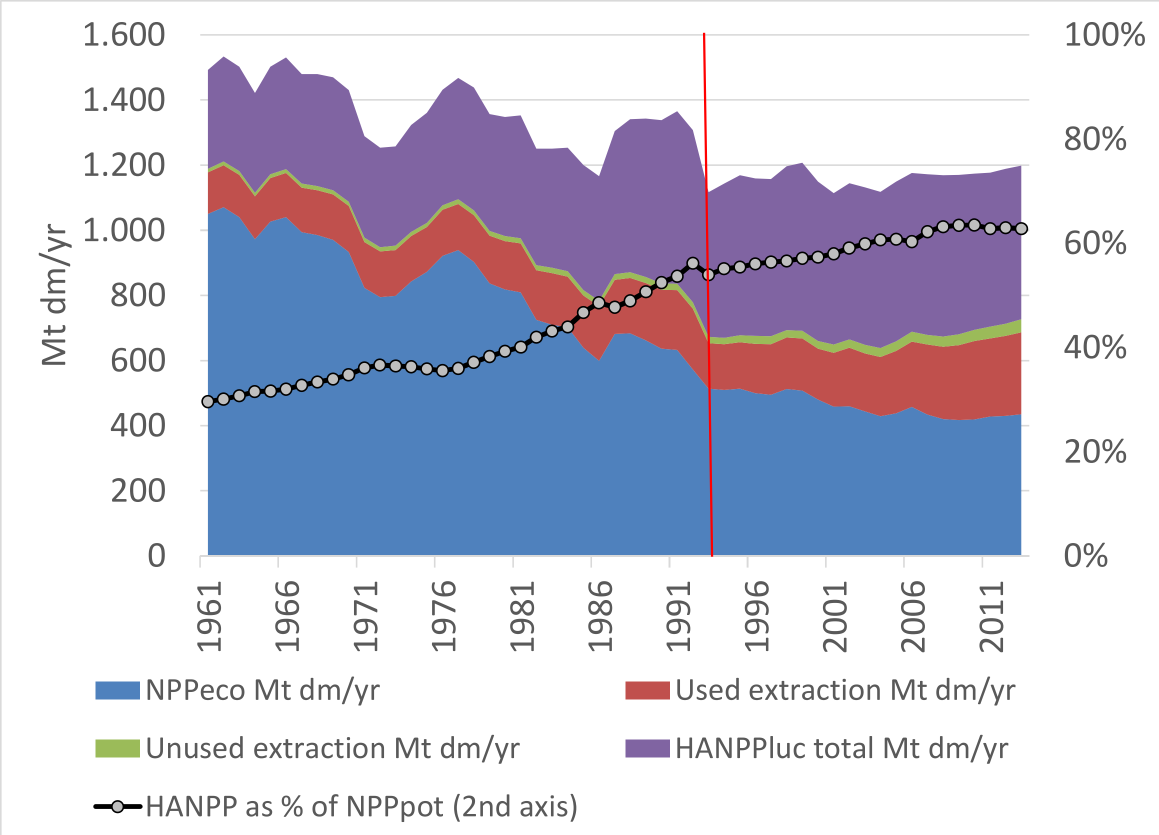

Figure 10: Trends for HANPP in % of NPPpot, the amount of biomass NPP remaining in the ecosystem (NPPeco), used and unused extraction and the NPP forfeit due to land use change (HANPPluc) for Ethiopia between 1961 and 2013. The red line demarcates the secession of Eritrea.

Similar to the relation of total population to available land (see 3.1), NPPpot available per capita decreased from a decadal average of 55.2 t dm/cap/yr for the first decade to 13.7 t dm/cap/yr for the final decade of the study period, reflecting a decrease by 75%.

Total HANPPharv from all land use categories per capita, comprising Used and Unused Extraction, decreased from 5.7 t dm/cap/yr to 3.1 t dm/cap/yr. Total HANPPluc per capita fell from 12.6 t dm/cap/yr to 4.9 t dm/cap/yr.

Total HANPPharv from all land use categories per hectare increased by 136% from 1.3 t dm/ha/yr to 3.0 t dm/ha/yr between 1961 and 2013. Total HANPPluc per hectare increased from 2.8 t dm/ha/yr to 4.6 t dm/ha/yr, an increase of 68 %.

3.2.2. *HANPP on cropland*

Ethiopia is heavily dependent on farming for the food security of its population. More than 70% of the population worked in agricultural production in 2013, more than 40% of its GDP stems from farming and livestock activities (World Bank 2016). Biomass harvested from cropland has shown a steady increase in the timeframe under scrutiny. Marked efficiency gains in cropland production can be observed but these are counterweighed to a significant extent by an increase in population numbers, as will be discussed further below.

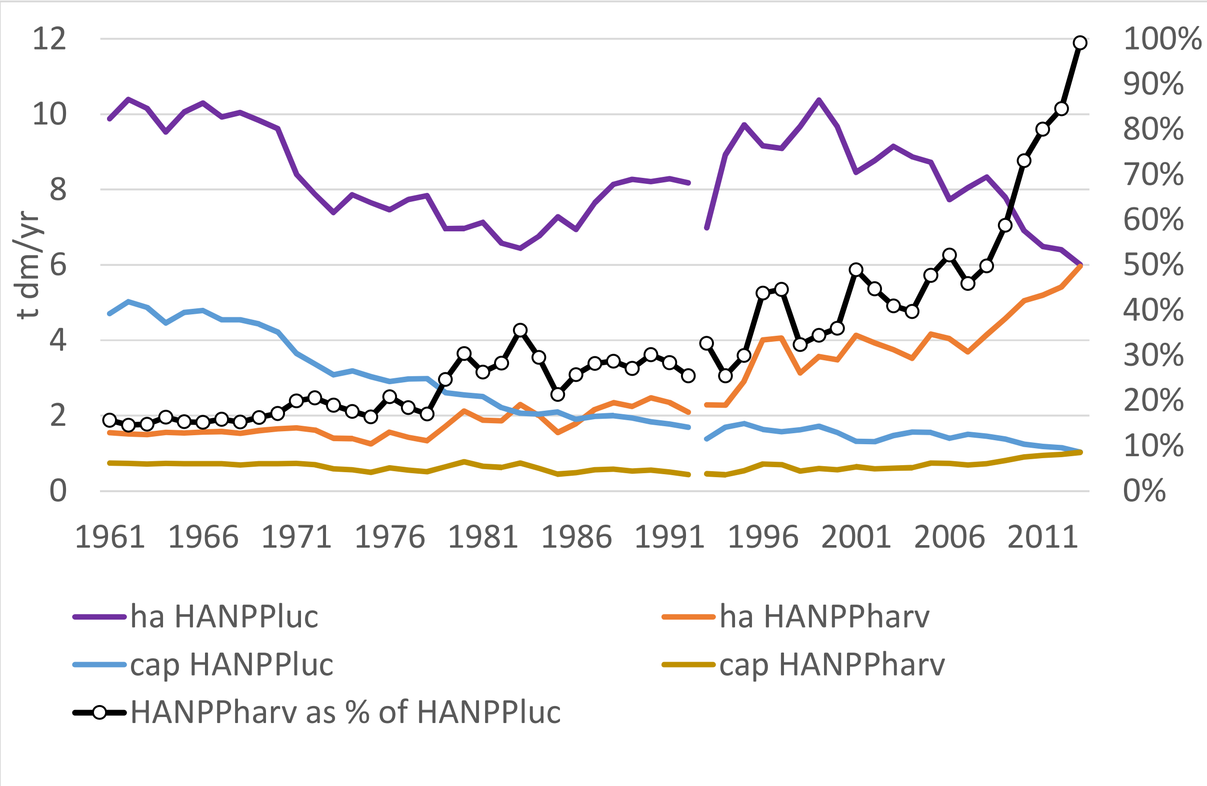

Figure 11: Trends of land use efficiency gains for cropland in Ethiopia between 1961 and 2013 as reflected by the relationship of HANPPluc to HANPPharv. Due to the almost fourfold population increase in Ethiopia, the marked efficiency gains have much less effect on a per capita basis.

HANPP on cropland	Averages in t dm/ha/yr					% Change Decade 1 - Decade 5
	1961-1970	1971-1980	1981-1990	1994-2003	2004-2013	
HANPP	11,5	9,2	9,4	12,8	12,1	5%
NPPpot	15,5	14,6	14,5	14,6	14,6	-6%
NPPact	5,6	7,0	7,1	5,3	7,0	26%
NPPeco	4,0	5,5	5,1	1,8	2,4	-39%
HANPPluc	10,0	7,6	7,3	9,3	7,5	-25%
HANPPharv	1,6	1,5	2,1	3,5	4,6	194%
HANPPharv as % of HANPPlucc	16%	20%	28%	38%	61%	390%
HANPP as % of NPPpot	74%	63%	65%	88%	83%	12%

Table 11: Cropland HANPP (in per ha values) for Ethiopia in a decadal average comparison. % Change values relate Decade 1 (1961-1970) to Decade 5 (2004-2013).

Comparing average results of the first decade of this study (1961-1970) with the final (1994-2013), HANPPharv per hectare of cropland shows an increase of 94% (see Table 11). As shown in Figure 12, cropland HANPPharv almost tripled from the 1960s to around 2010 from a decadal average of 1.6 t dm/ha/yr to 4.6 t dm/ha in the two time spans of comparison. The relation of HANPPharv per ha as % of HANPPluc for cropland extraction serves as an efficiency indicator for land use and reflects the amount of HANPPluc that the agricultural system is able to recover through crop production and harvesting of used and unused fractions per unit area. In this respect, Ethiopia in general shows marked efficiency gains in cropland utilization. The decadal average of cropland HANPPharv as % of HANPPluc the ratio increases almost fourfold from 16% on average between 1961 and 1970 to 61% on average in the final decade of the study, between 2004 and 2013. The trend for HANPPharv per ha shows an increase in absolute values from 1.5 t dm/ha/yr in 1961 to 6.0 t dm/ha/yr in 2013, while in the same timespan HANPPluc per ha decreases from 9.9 t dm/ha/yr to 6.0 dm/ha/yr, resulting in a HANPPluc to HANPPharv ratio of just under 100% for 2013 (see Figure 11), reflecting productivity gains on cropland.

Comparing decadal averages of NPPeco and HANPPluc for the above timeframes, significant drops of -39% (from 4 to 2.4 t dm/ha/yr) and -25% (or from 10 to 7.5 t dm/ha/yr) respectively, can be observed. Total cropland HANPP as % of NPPpot oscillates around the 80% mark (Figure

12), reaching its lowest values in the late 1970 with less than 60% of cropland NPPpot appropriated for human use, while climbing to above 90% around the turn of the millennium.

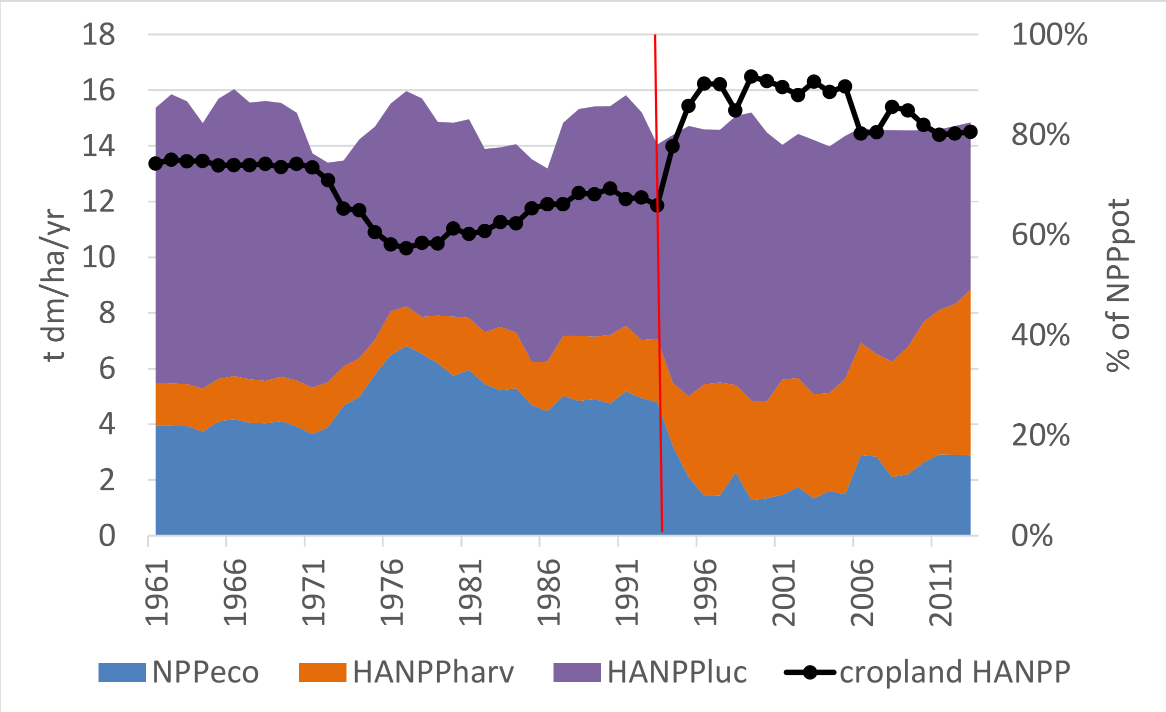

Figure 12: A per hectare view of HANPP on cropland of Ethiopia from 1961 to 2013 shows significant decreases in NPPeco and HANPPluc at the expense of HANPPharv, which almost triples from 1,6 Mt dm/ha/yr to 4,6 Mt dm/ha/yr as the first and last decadal average of the study period. Overall, cropland HANPP as % of NPPpot remains in a bandwidth of 57-92%.

In the time span from 1961 to 1992, thus for Ethiopia including Eritrea, total HANPPharv on cropland increased by one third from 18 Mt dm/yr to 24 Mt dm/yr, whereas from 1993 to 2013 it quadrupled from 24 Mt dm/yr to 97 Mt dm/yr. On the one hand, this steep rise in cropland HANPPharv must be seen against the backdrop of cropland expansion, which saw an increase of 54% from 1993 to 2013, from 10.5 Mha to 16.3 Mha of land under cultivation (as shown in Figure 8). Nevertheless, cropland HANPPharv per hectare increased rapidly from 2.3 t dm/ha/yr to 6.0 t dm/ha/yr between 1993 and 2013. Hence, significant efficiency gains of the Ethiopian agricultural system contribute markedly to the observed increase in available biomass extraction from cropland (see Table 11) and have counterbalanced and thus contributed to the food security situation of a rapidly increasing Ethiopian population, rising from 21.9 Mill. to 94.6 Mill. in 53 years, representing an increase of 292%.

Cereals accounted for the most important crop segment in Ethiopia's main farming system, i.e. smallholder farms with mixed crop-livestock farming. More than 80% of cropland HANPPharv stem from the 5 major cereal crops barley, teff, maize, sorghum and wheat. Their share of cropland HANPPharv remained hovering slightly above 80% for most of the time span analysed. Yet in absolute values the first decadal average (1961-1970) for the cropland HANPPharv amounted to 16.3 Mt dm/yr while the final decadal average (1994-2013) reached 57.4 Mt dm/yr for these 5 cereals (see Figure 13).

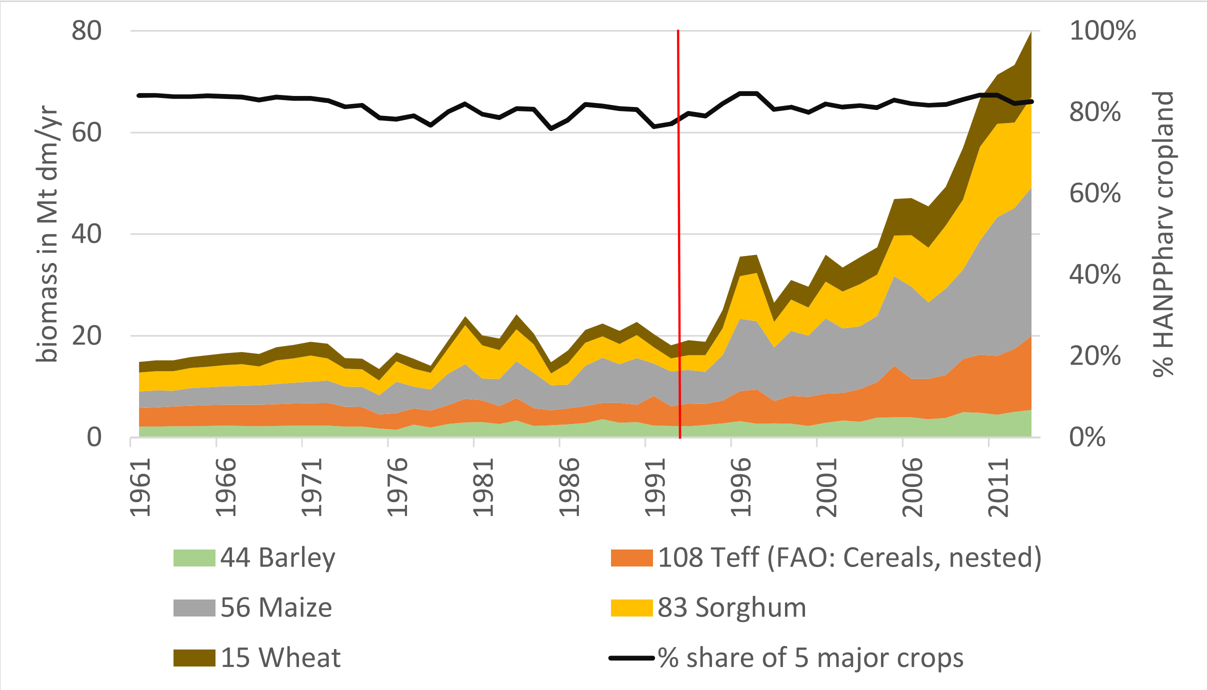

Figure 13: Total biomass appropriated (HANPPharv) for the 5 mayor cereal crops produced in Ethiopia in Mt dm/yr and their share in total cropland HANPPharv between 1961 and 2013.

Nevertheless, on a per capita basis, HANPPharv shows a different picture: it stagnates around 0.7 t dm/cap/year until 1972, hovers between 0.7 and 0.4 t dm/cap/year until 2004, and sees a marked increase only in the last years of the study to reach 1.0 t dm/cap/yr in 2013 (see Figure 11). Hence, while efficiency gains in cropland production amounted to an increase in HANPPharv to HANPPluc ratio of 290% (see Table 11) in a decadal comparison, per capita HANPPharv remained below the level of 1961 for much of the study timeframe, but caught up after 2004 and peaked in 2013 with an increase of 40% over the 1961 value.

3.2.3. HANPP on grazing land

For Ethiopia, grazing land is by far the largest land use category, representing 65-75% of the total land area within the study timeframe. The animal population (converted into tropical livestock units, TLU) increased from 26.6 Mill. TLU in 1961 to 32.7 Mill. TLU before secession in 1992, and almost doubled from 26.1 Mill. TLU in 1993 to 50.2 Mill. TLU in 2013. Livestock density in TLU rose from 24 TLU/km2 to 50 TLU km2 in the study timeframe. Therefore, animal grazing exerts an increasing grazing pressure on sensitive ecosystems and land degradation has become an important factor for consideration in assessing the productivity of the Ethiopian grazing land. It most likely also has direct impacts on food security in Ethiopia. To take the most salient examples, present-day Ethiopia in 2013 was home to 54 Mill. cattle, 28 Mill. goats and 26 Mill. sheep, when expressed in animal heads (see Figure 15).

In tandem with rising animal numbers, animal feed demand increased significantly between 1961 and 2013 (see Figure 14). Thus, HANPPharv of grazing land rose from 88 Mt dm/yr in 1961 to 116 Mt dm/yr by 1992, dropped to 70 Mt dm/yr due to markedly lower animal densities in Ethiopia after secession only to move up sharply to 110 Mt dm/yr by 2013 in correspondence with marked increases in animal numbers.

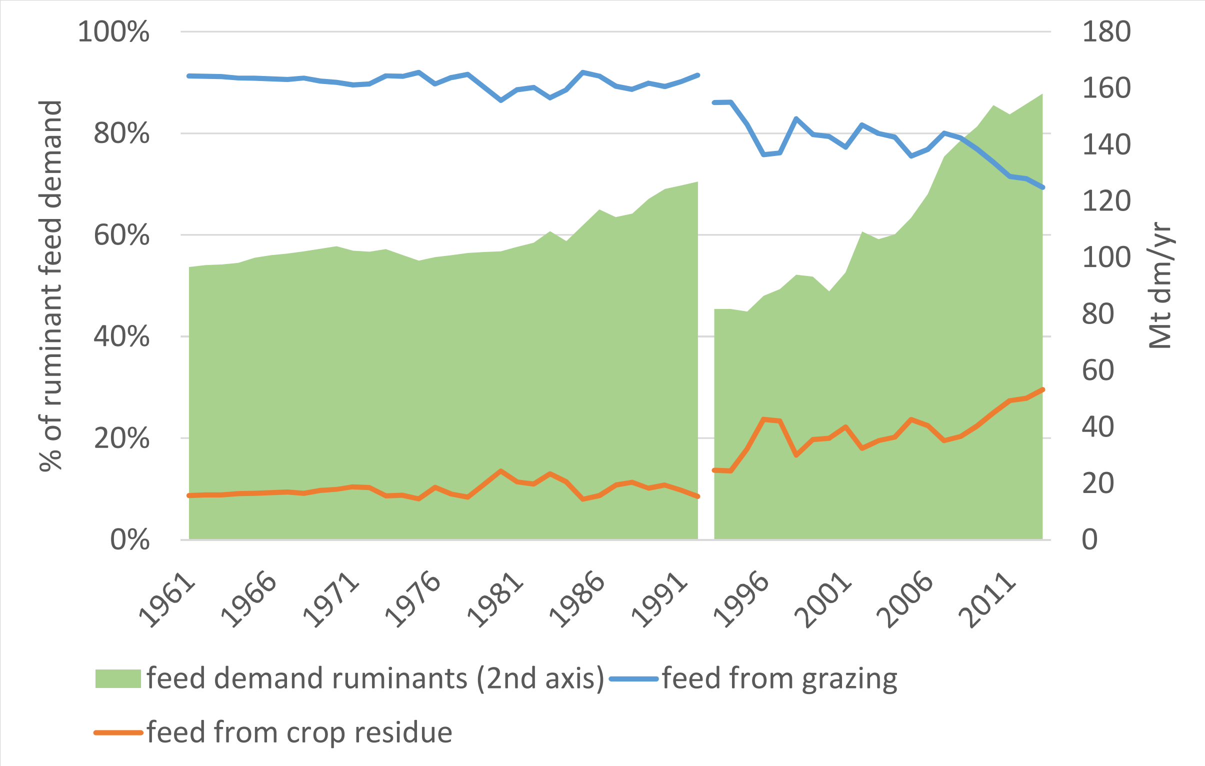

Figure 14: Total ruminant feed demand in dry matter (secondary axis) and feed supply in % of total feed demand covered by grazing and crop residues for Ethiopia between 1961 and 2013. Grazing and crop residues together amount to 99% of the total ruminant feed demand.

Across all ruminant categories, pasture grazing is still the major source of animal feed within the Ethiopian livestock system (see Figure 14). Especially in the dry months in which little vegetation is available in large parts of the country as well as in the intensely cultivated areas of the Ethiopian highlands, the increasing feed demand of the animal stock leads to fodder scarcity (Fetzel et al. 2016). In these areas and times, animal husbandry becomes largely dependent on crop residues for livestock maintenance or more traditional transhumance.

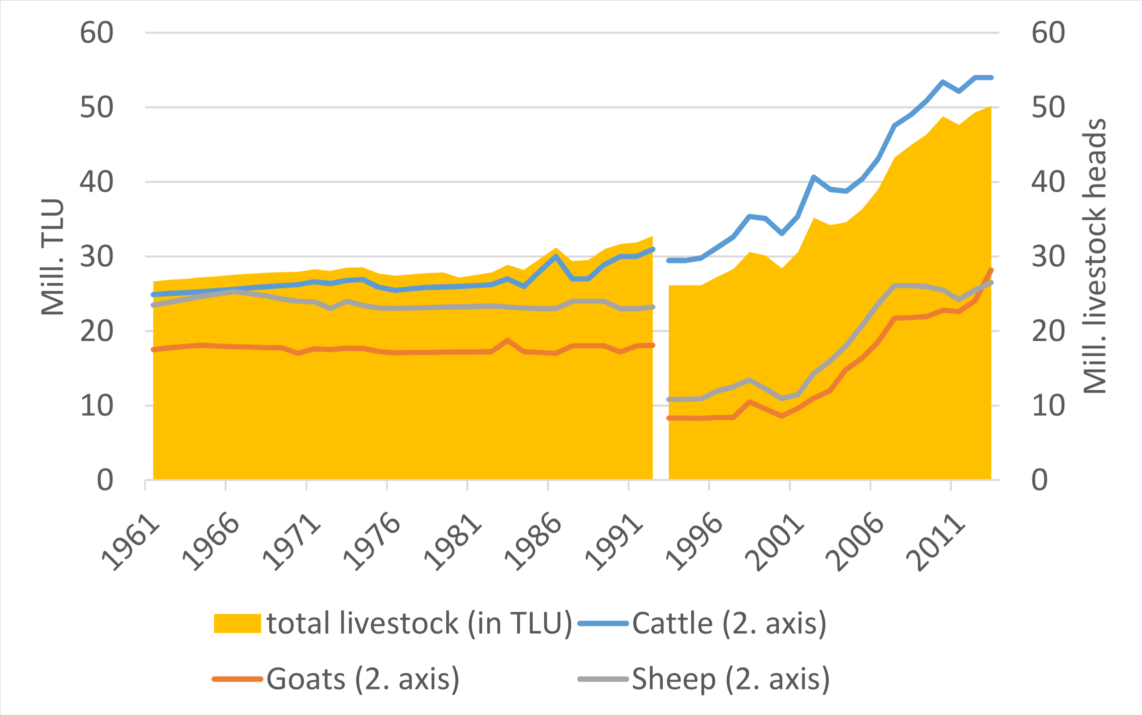

Figure 15: Development of animal numbers in Ethiopia between 1961 and 2013. Total livestock represents all livestock categories converted into Tropical Livestock Units (TLU). On the secondary axis, actual livestock head totals are depicted for the three most important livestock groups. Note that the gap in the diagram reflects the two different datasets ETPDR and ET.

While Ethiopia has thus witnessed massive increases in the livestock population (Figure 15) the intensity of animal rearing for the production of meat or milk has stayed well below regional and international benchmarks (FAO 2016). Average cattle carcass weight has only increased minimally by 2% in the last 50 years and remains low at 109.3 kg per animal. And while milk yields per animal have increased significantly by 163% to 0.68l/animal/day nationally, these are nevertheless extremely low yields compared to production potentials in similarly endowed world regions (see Table 12.)

Product	Unit	1961	1971	1981	1991	2001	2011	%
Beef meat (carcass weight)	kg/anim.	106,8	108	109,5	109,5	108,4	109,3	2%
Milk yield	kg/anim. /yr	97,1	102,2	112,1	120,4	174,9	255,8	163%
Milk yield	l/anim. /day	0,26	0,27	0,30	0,32	0,47	0,68	163%

Table 12: Meat and milk production yields for cattle in Ethiopia for selected years from 1961 to 2011.

On grazing land, the total HANPP per ha increased from 4.2 t dm/ha to 6.6 t dm/ha or by 58% in a comparison of decadal averages of the first and final decade of the study period (see Table 13). As can also be seen from Figure 16, the significant rise in HANPPluc per ha by 78% and, to a lesser extent, an increase in HANPPharv per ha by 14%, contributed to the HANPP development, while NPPeco per ha dropped by 44%. Total HANPP as % of NPPpot increased from 37% to 69%. In the absence of large-scale land use changes for grazing land, the development of HANPPluc per ha corresponds largely to the modelled land degradation. A sensitivity analysis on the assumed degradation coefficient further below will show developments with different model assumptions.

Grazing Land values	**Averages in t dm/ha/yr**					**% Change Decade 1 - Decade 5**
	1961-1970	**1971-1980**	**1981-1990**	**1994-2003**	**2004-2013**	
HANPP	4,2	4,5	5,4	6,1	6,6	58%
NPPpot	11,4	10,7	10,6	10,7	10,6	-6%
NPPact	8,5	7,5	6,4	5,5	5,5	-35%
NPPeco	7,2	6,2	5,1	4,5	4,1	-44%
HANPPluc	2,9	3,2	4,1	5,1	5,1	78%
HANPPharv	1,3	1,3	1,3	1,0	1,5	14%
HANPPharv as % of HANPPluc	45%	39%	32%	20%	29%	64%
HANPP as % of NPPpot	37%	42%	51%	57%	62%	69%

Table 13: Grazing Land HANPP (in per ha values) for Ethiopia in a decadal average comparison. % Change values relate Decade 1 (1961-1970) to Decade 5 (2004-2013).

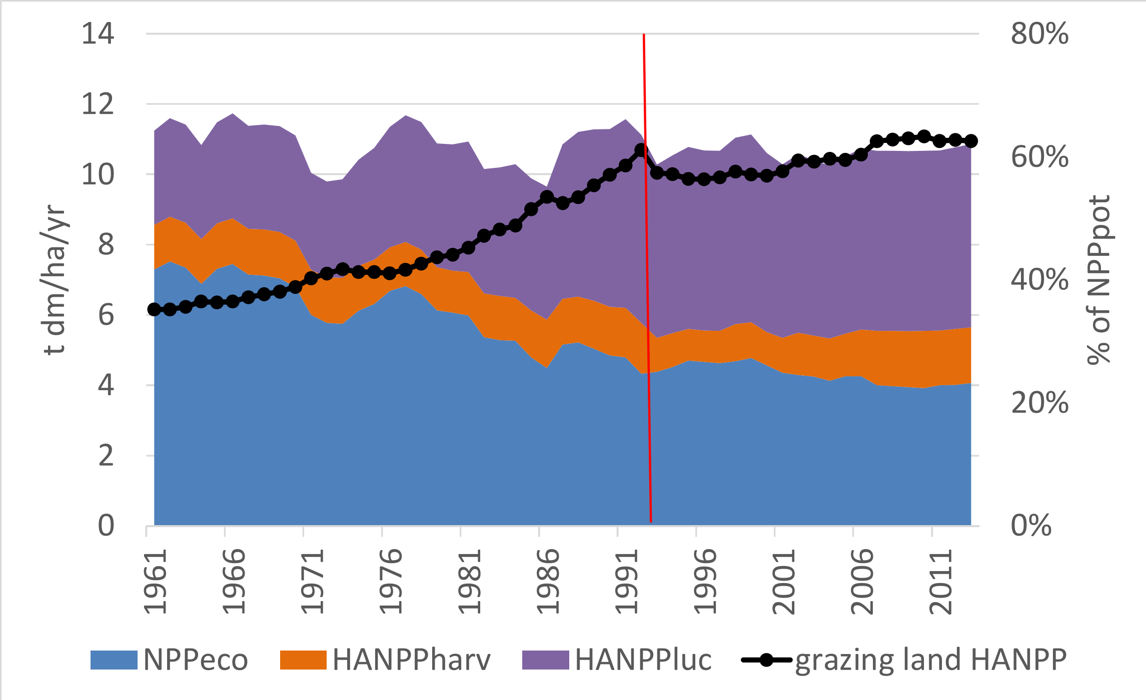

Figure 16: A per hectare view of HANPP on grazing land for Ethiopia between 1961 and 2013 shows significant decreases in NPPeco and corresponding increases in HANPPluc, which can be mainly explained with land degradation and erosion as it is modelled for this study. Due to this, also overall grazing land HANPP as % of NPPpot increases from 35% to 63%.

Land degradation and erosion in this study are the prime contributing factors to the observed reduction in land use efficiency, as expressed by HANPPharv as % of HANPPluc. The ratio may furthermore help to shine a light on the food security situation in Ethiopia. As depicted in Figure 17, per ha HANPPluc in this study steadily increases over time due to land degradation and soil erosion, while overall land use efficiency declines from an average of 45% of HANPPharv as % of HANPPluc in the 1960s to an average 20% between 1994 and 2003, before the ratio recovers to 29% in the final years of the study (see Table 13). Nevertheless it stays well below efficiency levels of the 1960s, which may serve as a sign for the relative inefficiency of the current grazing land production system of Ethiopia. In per capita values, HANPPharv from grazing land drops significantly from 3.6 t dm/yr in 1961 to 1.2 t dm/yr in 2013.

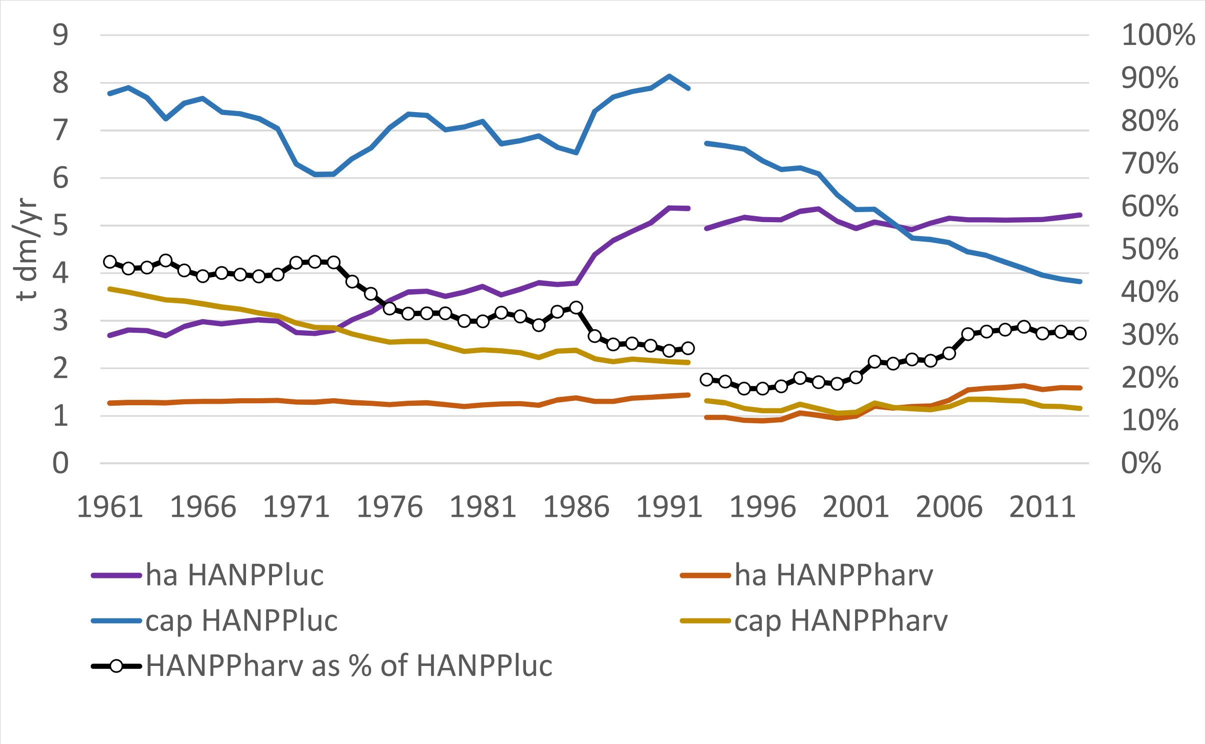

Figure 17: Grassland utilization efficiency between 1961 and 2013 as reflected by the relationship of HANPPharv to HANPPluc. Grazing land utilization efficiency declines to below 20% until the turn of the millennium, then picks up slightly to under 30%. Due to marked population increases, both per capita HANPPluc and HANPPharv on grazing land in dry matter values show overall declines.

3.2.3.1. <u>Sensitivity analysis on the degradation model</u>

As outlined above, the consideration of land degradation in the HANPP calculations for Ethiopia is the most significant contributing factor to the development of HANPP. Degradation in the HANPP model used for this study is assumed to reduce NPPact, and HANPPluc of grazing land is defined as the difference between NPPpot of all available grazing land and its NPPact for any given point in time. Hence, the development of HANPPluc in this study is also directly linked to the modelled land degradation. To clearly show the consequences of the degredation model used in this study, a sensitivity analysis on the degradation coefficient was conducted.

Thus, reducing the degradation coefficient to a value of 0 in the model datasets would lead to a more or less stagnant scenario: total grazing land per ha values of HANPP remain the same (1% increase) for the study period while HANPPluc actually decreases by 6% and HANPPharv increases by 14%. NPPeco decreases by 10% in the same decadal average comparison. In such a scenario, grazing land HANPP as % of NPPpot remains hovering around a level of 30%.

Below in Table 14 and Table 15 the land degradation coefficient in the model has been reduced to 25% and 50% of the actual values used for this study. This means that the degradation coefficient peaks at a reduction of NPPact of grazing land of 8.5% and 17% in 1992, respectively. From 1993 the coefficient again remains on the respective level, as is also the case in the original model. Because of the reduced degradation rates modelled, also HANPPluc in both scenarios decreases. Efficiency as expressed by the HANPPharv to HANPPluc ratio therefore increases in accordance with decreasing HANPPluc values and degradation coefficient levels.

Grazing land decadal comparison			**Degradation coefficient = 25% of study values**			
Variable	**Averages**					**% change decade 1 - decade 5**
	1961-1970	1971-1980	1981-1990	1994-2003	2004-2013	
HANPP	3,7	3,7	3,9	3,9	4,3	17%
NPPpot	11,4	10,7	10,6	10,7	10,6	-6,3%
NPPact	9,0	8,3	8,0	7,8	7,8	-13%
NPPeco	7,7	7,0	6,6	6,8	6,3	-18%
HANPPluc	2,4	2,4	2,6	2,9	2,9	19%
HANPPharv	1,3	1,3	1,3	1,0	1,5	14%
HANPP as % of NPPpot	33%	34%	37%	36%	41%	25%
HANPPharv as % of HANPPluc	54%	53%	50%	35%	52%	96%

Table 14: Sensitivity analysis results on the modelled degradation coefficient. The degradation coefficient values were reduced by 75% to arrive at these results.

Grazing land decadal comparison			**Degradation coefficient = 50% of study values**			
Variable	**Averages**					**% change decade 1 - decade 5**
	1961-1970	1971-1980	1981-1990	1994-2003	2004-2013	
HANPP	3,8	3,9	4,4	4,6	5,1	32%
NPPpot	11,4	10,7	10,6	10,7	10,6	-6,3%
NPPact	8,8	8,1	7,4	7,1	7,1	-20%
NPPeco	7,5	6,8	6,1	6,1	5,6	-26%
HANPPluc	2,5	2,7	3,1	3,6	3,6	41%
HANPPharv	1,3	1,3	1,3	1,0	1,5	14%
HANPP as % of NPPpot	34%	37%	42%	43%	47%	41%
HANPPharv as % of HANPPluc	51%	48%	42%	28%	41%	81%

Table 15: Sensitivity analysis results on the modelled degradation coefficient. The degradation coefficient values were reduced by 50% to arrive at these results.

3.2.4. HANPP on forest land and other land use categories

Forest land HANPP for Ethiopia shows a steady increase from 31 MT dm/yr in 1961 to 88 Mt/dm yr in 2013. The HANPP in % of NPPpot of forests and woodlands increases from 8% in 1961 to 53% in 2013 and thus shows the largest relative increase of all land use categories. Similarly, the Used Extraction of forest biomass (including bark) as wood fuel and, to a much lesser extent, for construction and other commercial purposes rises continuously throughout the study period from 24.5 Mt dm/yr to 68.6 Mt dm/yr. At the same time, per capita Used Extraction drops from about 1 t dm/yr to less 0.7 t dm/yr (see Figure 18 below).

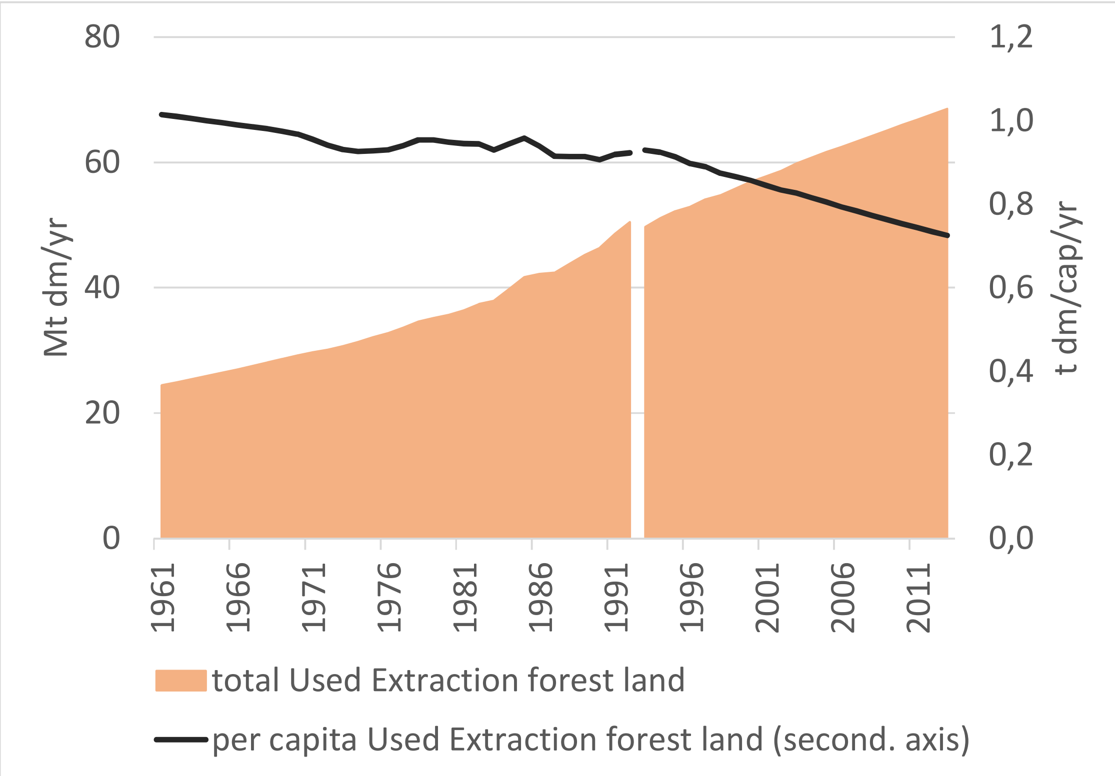

Figure 18: Trends for both total and per capita Used Extraction from Ethiopian forested and wooded land from 1961 to 2013. The gap in the diagram denotes the different data set after the secession of Eritrea.

The HANPP for Ethiopia for land under infrastructure or built-up land remained at a very low absolute level throughout the study period. Although HANPP doubled from 4 Mt dm/yr to 8 Mt/dm yr, its amount is insignificant with regard to other land uses. For wilderness or untouched nature, HANPP does not exist by definition and is therefore assumed to be 0 throughout the study period.

3.3. Local land use and biomass appropriation patterns in Ethiopia as exemplified by three villages in the district of Siraro.

As delineated in 3.2, the trend analysis of the HANPP of Ethiopia describes significant changes in the appropriation of biomass for human purposes between 1961 and 2013. These developments should also bear consequences in everyday life on local scale. The following chapter 3.3 attempts to analyse in how far impacts of these developments can be detected in a very distinct area in a remote and rural setting of Ethiopia, i.e. three *kebeles*[3] sharing two watersheds in the district of Siraro in the rift valley section of regional state of Oromia.

The SILVR baseline survey was conducted in the kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district. The three kebeles and two small watersheds they share are target areas of the project SILVR. Both the district of Siraro as well as the three kebeles presented in this section must be seen in the context of vulnerabilities to external shocks on socio-economic livelihoods common to Ethiopia: drought and, in a more erratic and localized manner, flooding. By Ethiopian standards, the target area is by no means extraordinary with regard to these risks but it does fall into the category of vulnerable districts and is therefore a prioritized area of intervention for the Ethiopian government and aid organizations (FEWSNET 2015). As will be shown, food insecurity levels are dramatic. Obviously, this is one of the reasons why a social development project with a focus on sustainable land management such as SILVR was devised for the area. Findings of the following section therefore may not lend themselves to broad generalizations across an ecologically and climatically diverse country like Ethiopia. Nevertheless, it does exemplify impacts of biomass extraction and ensuing challenges and resource conflicts of many similarly structured districts and areas.

[3] The Amharic term *kebele* designates the smallest, village-level administrative unit of governance in Ethiopia, also called and synonymous with Peasant Association or short, PA.

3.3.1. Cropland utilization

With regard to landholdings, 75% of the survey respondents say that their household owns between 0.5 to 1 hectare of cultivable land, 12.2% of the households own between 1 and 2 hectares, 2.3% of the households own between 2 and 4 hectares. 9.3% of the households own less than half a hectare of cultivable land (between 0,375 and 0,125 hectares) while 1.2% of the households reported having no land of their own (see Table 16).

Land size (ha)	Household reported cultivable landholdings		Net cultivable land per household after lease/sharecrop	
	Number	% of total	Number	% of total
0.000	2	1.2%	10	5,8%
0.125-0.375	16	9.3%	15	8,7%
0.500-1.000	129	75.0%	112	65,1%
1.001-2.000	21	12.2%	29	16,9%
2.001-4.000	4	2.3%	5	2,9%
>4.000	0	0.0%	1	0,6%
total	172	100.0%	172	100,0%

Table 16: Average landholdings per household compared to household net cultivable land considering leasing and sharecropping for the three kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district Ethiopia, as per the 2015 SILVR project baseline survey.

The middle columns in Table 16 which state total cultivable landholdings hide the fact that a considerable amount of land, although farmer households may be officially entitled to its usage, is leased (rented in/out against a lease payment) or sharecropped (rented in/out against a share of the harvest, with 50% of the harvest being the norm) by farmers. Net cultivable land in Table 16 is calculated by considering all owned land per household + leased in + sharecropped in – leased out – sharecropped out land. Adjusted for these land reallocations, a picture of the actual usage of land in the 3 kebeles in Siraro emerges, which is more differentiated and more socially stratified: the share of farmers having no land at their disposal for their own cultivation rises from 1.2 to 5.8%. Farmer households cultivating between 0.5 and 1.0 hectare of land drop by 10% points, from 75.0% to 65.1%. Hence, it is the bigger farmer households which own more than 1.0 hectare of land who increase their cultivable land through sharecropping or leasing in land: Net cultivable land increases from 2.3% to 2.9% in the 2 to 4 hectare landholding group while 1 farmer household (0.6%) has more than 4 hectares of land at its disposal through leasing or sharecropping in land.

3.3.1.1. Food security

The food security situation in all three kebeles is under enormous pressure. 87% of the respondents report that food shortage occurs even in years with normal rainfall. Under normal circumstances, households will experience a period of insufficient nutritional resources after their cereal stocks of the past harvest have been used up. This period usually coincides with the dry season (roughly October to March) and continues into the next rainy periods called Belg and Meher (roughly occurring between March and September normally separated by distinct dry spell). During these months with rain, crops may already grow in the field but are not ready for consumption yet. Thus, 54% of the respondents report an average so-called lean or hunger season for normal rainfall years of 3-4 months peaking between April and July (see Table 17). For years with less than normal rainfall, so in times of drought, almost all respondents (97%) experience insufficient food availability. As shown above, global HANPP figures for Ethiopia allow to draw a somewhat different picture on a national level: it can be shown that efficiency gains on a per hectare basis in cropland production amounted to significant production increases (see Table 11 and Figure 11) between 1961 and 2013. Nevertheless, while HANPPharv on cropland increases by 40% between 2004 and over the 1961 value it remains comparatively low by international standards.

Respondents/ Responses	Alemtena Sirbo		Nuna Raba		Loke Hada		Total	
	Nr	%	Nr	%	Nr	%	Nr	%
Total respondents	51	30%	50	29%	71	41%	172	100%
Exp. food shortage in normal rainfall years	44	86%	44	88%	62	87%	150	87%
Exp. food shortage in drought years	48	94%	50	100%	68	96%	166	97%
Number of months of food shortage in normal rainfall years								
0 months	7	14%	6	12%	9	13%	22	13%
1-2 months	8	16%	3	6%	8	11%	19	11%
3-4 months	16	31%	33	66%	44	62%	93	54%
5-7 months	20	39%	8	16%	10	14%	38	22%
Months in which food shortage is experienced in normal rainfall years								
January	7	14%	2	4%	5	7%	14	8%
February	10	20%	5	10%	12	17%	27	16%
March	24	47%	16	32%	25	35%	65	38%
April	30	59%	26	52%	30	42%	86	50%
May	36	71%	41	82%	46	65%	123	72%
June	34	67%	34	68%	42	59%	110	64%
July	25	49%	29	58%	38	54%	92	53%
August	6	12%	11	22%	19	27%	36	21%

Table 17: The food security situation for respondent households in normal rainfall years versus drought years, and a normal year's lean season months for the three kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district Ethiopia, as per the 2015 SILVR project baseline survey.

Respondents state that they use one or more of the following coping strategies in periods of insufficient food supplies: In total, 85% of the households reduce the number of meals per day and/or reduce the quantity of food per meal (83%); 83% also receive some sort of food aid; 21% resort to selling livestock, whereas 13% take out a loan to purchase food; 8% migrate in search of opportunities such as wage labour (see Table 18). It is noteworthy that, on average, the villagers of Alemtena Sirbo have a slightly different mix in coping strategies from the 2 other kebeles, especially in terms of migration/waged labour (18%) and sales of livestock (20%). This may be explained by the fact that Alemtena Sirbo has a relatively better access to local markets and transport opportunities than the other kebeles.

Coping strategy	Alemtena Sirbo		Nuna Raba		Loke Hada		Total	
	Nr	%	Nr	%	Nr	%	Nr	%
Receiving food aid	33	75%	39	89%	53	85%	125	83%
Reduce number of meals	32	73%	37	84%	58	94%	127	85%
Reduce quantity of food per meal	34	77%	35	80%	55	89%	124	83%
Sale of livestock	12	27%	7	16%	12	19%	31	21%
Take loans to purchase food	9	20%	5	11%	6	10%	20	13%
Migration & wage labour	8	18%	2	5%	2	3%	12	8%

Table 18: Cited coping strategies of interviewees to overcome recurrent, periodic household food deficits for the three kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district Ethiopia, as per the 2015 SILVR project baseline survey (172 respondents in total).

Respondents state the following main reasons for the experienced recurrent household food deficits: 59% of all respondents identify a shortage of available cultivable land, 23% mention low production yields and 21% list a lack of capital. Their large household size is seen by 19% of the total respondents as a reason for insufficient food supplies, whereas 18% cite a lack of mineral fertilizer use.

3.3.1.2. Crop production practises

Parts of the Ethiopian highlands experience two periods of precipitation (McSweeney et al. 2010). For Siraro, these two rainy periods lead to two separate cropping seasons, called *Belg* (March to May) and *Meher* (July to September). In terms of agricultural area, 34% of the total annual area is brought under cultivation during the Belg season, according to survey data, leaving 66% for the Meher season (see Table 19). Vegetable production was assessed in the survey but cultivation area and production are negligible in comparison major cereal crops identified. It seems that vegetables, first and foremost kale (*Brassica oleracea)*, are mainly produced for home consumption on small homestead plots and do play an important role in household nutrition. Although wheat figures prominently in national crop statistics, is grown in many parts of Ethiopia and has grown in importance during the last decades (see Figure 13), it is not normally planted in Siraro.

Crop	Belg area (in % of total cult. land)	Belg yield (qt/ha)	% of Belg prod. sold	Meher area (in % of total cult. land)	Meher yield (qt/ha)	% of Meher prod. sold
Maize	23,2%	16,2	26.8%	43,4%	18,4	24.2%
Teff	2,0%	6,3	77.1%	7,1%	5,8	84.1%
Finger millet	3,1%	7,8	3.4%	7,3%	10,8	16.8%
Haricot bean	4,2%	8,6	54.5%	6,5%	8,8	59.7%
Potato	1,4%	38	40.5%	1,4%	36	67.8%
Sorghum	0,2%	6	0%	0,3%	7,4	81,1%
Total	34,1%	82,9		65,9%	87,2	

Table 19: Major crops by land under cultivation, their yields and share of harvest sold reflecting the year 2014 for the three kebeles Alemtena Sirbo, Nuna Raba and Loke Hada of Siraro district Ethiopia, as per the 2015 SILVR project baseline survey.

The interviewees state that remarkable changes have taken place in cultivation which 78.6% lead back to a reduction in average rainfall amounts, 62.5% to reduced soil fertility, 24.4% to a reduction in available farmland and 20.2% to the introduction of new varieties. Intercropping is seen as an adapted farming practice and is used by 81% of the respondents, mainly by intercropping maize with beans (17.4% of total respondents). Improved seeds are used by 54% of the farmer households. In the context of Siraro this is almost 100% hybrid maize seed.

The interview question on fallowing was only answered by 30 respondents, out of which none practises fallowing. From the total of 172 household representatives, only 38% responded that they use some sort of organic fertilizer to improve soil fertility in their fields, whereas 58% stated that they do not use any organic matter on their fields. 4% stated they do not cultivate. The organic matter applied to the fields stems almost exclusively from manure and droppings of penned animals. Only one respondent prepared and used compost. Asked for the reasons why farmer households apply relatively little organic fertilizer material to their agricultural land, 42.7% of the respondents cited a lack of available biomass, 29.2% a shortage of available water (it must be assumed here that this refers to the preparation of compost), 16.8% mentioned a lack of awareness, while 6.7% put forward a deficit in manpower and 3.6% stated the absence of livestock.

In contrast to organic materials, chemical fertilizers are used by 59% of the total respondents while 37% state they do not. The remaining 4% again do not cultivate. As can be seen in Table 20, DAP (Diammonium phosphate, $(NH_4)_2HPO_4$) is by far the most widely used chemical fertilizer and applied by 100% of those farmers using chemical fertilizers on all crop types. Urea application is much less frequent.

Crop	Chem. fertilizers applied		DAP applied		Urea applied	
	HHs	%	HHs	%	HHs	%
Finger millet	27	27%	27	100%	4	15%
Haricot bean	17	17%	17	100%	2	12%
Maize	101	100%	101	100%	17	17%
Potato	8	8%	8	100%	2	25%
Teff	21	21%	21	100%	9	43%

Table 20: Application of chemical fertilizers on different crop types in total and disaggregated for DAP and Urea of those 101 respondents using chemical fertilizers, for three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey.

3.3.1.3. Natural resources and land degradation

Land degradation and deterioration of natural resources is recognized by 92% (or 158 respondents) as an issue to be addressed. Replies of the interviewed household heads are clustered into three distinct manifestations for land degradation: deforestation, or the loss of forest and woodlands; soil fertility decrease; and soil erosion through water. Furthermore, 6 causes for these manifestations of degradation are identified by the respondents: an increasing shortage of land and, closely linked to this, the impracticality of fallowing land, the given elevation gradients in cultivated lands, demographic pressure and the absence of adapted farming methods (in this instance, contour ploughing). Moreover, deforestation is mentioned both as a manifestation of natural resource depletion and as a cause for soil fertility loss and soil erosion by water.

Table 21 below depicts the identified list of perceived causes for the degeneration of natural resources and its tangible manifestations. 46% of the respondents (158 households) see deforestation as the main cause of natural resource loss, especially with regard to soil erosion. 36% of the respondents attribute observed deforestation patterns, soil fertility decreases and soil erosion through water to an identified shortage of cultivable land. And closely linked to this, 12% of the respondents maintain that the cause of soil fertility loss, and to a lesser extent soil erosion, is the practise of not fallowing. As mentioned in the data section, degradation by animal grazing was not specifically included in the survey questionnaire and is therefore not represented.

Causes of degradation	**Manifestations of natural resource degradation**						**Total**
	Deforestation		**Soil fertility decr.**		**Soil erosion**		
	HHs	%	HHs	%	HHs	%	
Deforestation	-	-	8	16%	117	55%	46%
Shortage of land	6	86%	21	43%	69	32%	36%
No fallowing	0	0%	19	39%	12	6%	12%
Strongly sloping land	0	0%	0	0%	7	3%	3%
Demographic pressure	0	0%	0	0%	7	3%	3%
No contour ploughing	0	0%	1	2%	1	0%	1%
No answer	1	14%	0	0%	0	0%	0%
Totals	7		49		213		100%

Table 21: Resource depletion and their related causes as identified by 158 out of 172 farmer household heads of three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey.

62% of all interviewees report that they have carried out soil and water conservation (SWC) measures on their farmland[4]. According to the respondents, the majority of the structures established were soil bunds. An astonishing 98% of those that have done SWC work on their own farmland observe beneficial effects of these. These beneficial effects include reduced erosion (34%), increased soil fertility (25%) and yields (22%), increased soil moisture (19%). Moreover, 69% of all respondents have planted trees in the past. More than 80% of the respondents planted those trees in their homestead, only a small minority also planted trees

[4] While water erosion of the tilled, unprotected cropland at the onset of the rainy season is identified as a major manifestation of land degradation (Nyssen et al. 2003), farmers are often reluctant to implement soil and water conservation measures on their own farmland. In the context of Ethiopia, farmers may report the completion of such works in order to avoid the cost of labour for land preparation associated by farmers with SWC structures on cropland.

in their farmland. 93% of the households that planted trees chose *Eucalyptus spp.*, 26% *Grevillea robusta*, with all other tree species such as *Azadirachta indica* (Neem) or *Olea africana* amounting to insignificant numbers. Wood for construction, for sale, for shade, for fuel are all mentioned as reasons for planting trees with a similar relative share in a range between 28 and 22% each, while the purposes of planting trees for fruit and for fodder amount to insignificant shares.

As the Ethiopian government annually mobilizes the rural population throughout Ethiopia to participate in large-scale programs aimed at conserving natural resources, 87% of all respondent households report that at least one member has taken part in these activities in the past. Many of these mass mobilizations involve the construction of stone and soil bunds on sloping terrain and tree planting, in some instances also measures to control and defuse erosion gullies. These measures most often take place on communal land which is intensively used for grazing and prone to high levels of degradation.

3.3.2. Grazing land and livestock

Livestock plays a major role in the mixed crop-livestock farming system practised in Siraro. 127 respondent households or 74% hold some sort of livestock, while 45 farmer households (26%) have no livestock. Almost half of the farmers (49,4%) hold cattle, 37.2% rear chicken, while 21,5% own goats or, much less so, sheep (10,5 %). The average animal number calculated on the basis of all respondent households is 1.69 for cattle, 0.44 for goats and 0.28 for sheep. Also on average 2.30 chicken, and 0.56 beehives are owned per household. With a statistical confidence level of 95% it can therefore be extrapolate that the total cattle head count is around 5,731, while the added number of sheep and goats amounts to 2,450 animals for the three kebeles analysed (see Table 22 for reference). It should be recalled that, on a national scale, HANPPluc per hectare for grazing land steadily increases and land use efficiency (as measured in HANPPharv as % of HANPPluc) declines from 45% of HANPPharv as % of HANPPluc in the 1960s to 29% in the final decade of the study (see Figure 17 and Table 13). In per capita values, HANPPharv from grazing land drops significantly from 3.6 t dm/yr in 1961 to 1.2 t dm/yr in 2013. This reflects the inefficiencies of the grazing land production system currently practised in Ethiopia as well as the results of rapid population growth witnessed over the last 5 decades.

Unit	Cattle		Goats		Sheep		Poultry		Beehives	
	Nr	% all HHs	Nr	% all HHs	Nr	% all HHs	Nr	% all HHs	Nr	% all HHs
Total owner HHs	85	49,4	37	21,5	18	10,5	64	37,2	25	14,5
Total animals/hives	290		76		48		396		97	
Average/all HHs	1,69		0,44		0,28		2,30		0,56	
Average/owner HHs	4,08		2,05		2,67		6,19		3,88	
Animal pop./3 keb.*	5.731		1.502		949		7.826		1.917	

Table 22: Livestock holder data for cattle, goats, sheep, poultry and beehives of three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey. For % values, note that these reflect multiple livestock type ownership.

*** The total animal population for the three kebeles is extrapolated on the sum total of all 3 kebele HHs with a statistical confidence level of 95%.**

For cropland cultivation, especially for ploughing and seedbed preparation, oxen play a vital role with regard to animal traction in Siraro as well as throughout Ethiopia (Astatke 1999). In fact, the livestock component of the Ethiopian mixed farming system is often focused on providing oxen for traction (Astatke 1999; Mengistu 2006). Timely access to oxen becomes a critical issue for the food security of farmers: preparing land too early or, worse, too late for sowing often has detrimental effects on crop yields (Wilson 2003). In total, the respondent households hold 72 oxen or about 25% of total number of cattle owned. By extrapolation, the three kebeles have a total oxen population of 1,422 (+/- 5%) available for farm work. Oxen numbers are included in the cattle section of Table 22, so that it can be inferred from the data that 97% of all male adult cattle are kept in the form of oxen.

Respondent households report that 73% of them have no oxen, 26% have 1 oxen and 2% have 2-5 oxen. Research suggests that, depending on soil type, 90-150 hours per team of oxen are necessary to plough one hectare of cropland and prepare the seedbed (Astatke 1999). But only 5% of the households questioned declare having sufficient available access to animal traction by oxen to prepare their cropland. Thus, 85% of all respondents resort to borrowing oxen, with 51% of those borrowing from relatives, and 49% from neighbours.

Figure 19: Draught power by oxen plays a vital role in the cropland farming system of the Ethiopian highlands (Picture taken by the author Harald Grabher on May 7, 2014 in Adami Tulu/Jido Kombolcha district)

Apart from the utilization of oxen for traction labour on cropland and for threshing, livestock fulfils other important functions in the local mixed farming systems and for the household economy. In total, 93 respondents (or 54%) derive additional products from animal rearing (including beekeeping) for household consumption and/or sale. The most important animal product is dairy. In total, 67 out of 85 cattle-owning households consume or sell dairy products, with the major share of 85% allocated to household consumption (see Table 23). Eggs are the second most important product derived from animals while honey takes the third place. Both appear to be used to generate household income to a relatively larger extent than dairy. Interestingly, only 6 respondents or only 3.5% of all households questioned reported to utilize meat as a product from their animals while 1 respondent seems to sell his total production commercially.

Livestock product	HH consumes 100%	HH consumes 100%	HH consumes & sells	HH consumes & sells	HH sells 100 %	HH sells 100 %	Total HHs
Dairy	57	85%	9	13%	1	1%	67
Eggs	17	29%	31	53%	11	19%	59
Honey	5	25%	15	75%	0	0%	20
Meat	4	67%	1	17%	1	17%	6
Hides		0%	1	100%		0%	1
Total	83	54%	57	37%	13	8%	153

Table 23: Products derived from livestock keeping and their utilization in the household for consumption or sale. Data taken from respondents of three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey.

The household heads partaking in the survey state that their animals are not usually sold: 66% of 164 respondents to this question do not see the sale of live animals as the main aim of rearing them. If animals are sold, then resulting income is used to buy manufactured goods (56%), to buy food (31%) and for social expenses (29%). Out of the 34% (or 56 households) that do sell animals regularly, 52% will fatten the animals before taking them to the market. For those households that do not sell animals on a regular basis, the major reasons for selling an animal is that they have a sudden problem or cash need. 58% of the households that sell animals unprepared (and unfattened) for this reason.

In spite of the benefits derived from livestock in terms of income, capital savings, consumable products and transportation, animal husbandry is also a major contributing factor to the workload of farmer households (Wilson 2003). Chores such as herding or milking and preparing dairy products such as butter from it demand a constant allocation of labour.

To keep labour demand in check, free grazing of animals is by far the most common way of feeding in Siraro. Cut and carry systems of animal feeding are mainly used in high-intensity milk production in Ethiopia (Mengistu 2006), which is still rare. It is not surprising, then, that in the extensive livestock rearing system of Siraro is most common: only 4% of the respondent households engage in animal husbandry systems based on “cut and carry”, i.e. keeping livestock in one place and supplying them with feed. While only 10% of 113 respondent households have private grazing land available to cover the majority of their livestock feed demand, 71% rely on communal grazing land and 99% use crop residue, mostly as a supplement when livestock is around the homestead or during the dry season when other feed sources become rare (Mengistu 2006). 12% state that they have planted fodder crops, which is almost exclusively elephant grass (*Pennisetum purpureum*).

Even during normal rainfall years, biomass supply for livestock is not sufficient, according to the survey data. 77% of the responding households assert that livestock feed resources are insufficient to feed animals throughout the year (see Table 24). The feed deficit lasts between 3 to 5 months, with the main deficit period beginning between December and March. For 93% of the farmer households, crop residues are the most important resource to bridge the months of biomass deficit. In addition to this, 15% of the responding HHs resort to reducing the offered feed rations, while 6% migrate to other grazing areas. Only 1 household or 1% produces fodder.

Along with the biomass deficit, farmer households also identify insufficient water resources for their animals as a major challenge. In total, 84% of the responding households state that resources are insufficient for animal watering during normal rainfall years (see Table 24). The water deficit commences in October or November and lasts for 5 to 7 months. In response to these challenge, farmer households react by increasing the watering interval (77%), by buying water (22%) and/or by migrating with the livestock to available water sources like rivers (11%).

Response	HHs	% *	HHs responding
Animal feed			
Animal feed sufficient	30	23%	129
Animal feed not sufficient	99	77%	129
Duration (Months)			
Duration of feed deficit			
3 Months	37	46%	81
4 Months	20	25%	81
5 Months	14	17%	81
Main starting months of animal feed deficit			
December	11	18%	86
January	14	23%	86
February	30	49%	86
March	20	33%	86
Coping strategies for animal feed deficit			
Storing crop residue	80	93%	86
Reducing ration	13	15%	86
Migration	5	6%	86
Producing Fodder	1	1%	86
Water resources			
Water resources sufficient	19	16%	118
Water resources not sufficient	99	84%	118
Duration of water shortage			
5 Months	36	37%	98
6 Months	17	17%	98
7 Months	24	24%	98
Main starting months of water shortage for animals			
September	14	14%	98
October	29	30%	98
November	39	40%	98
Coping strategies for water shortage			
Increase interval of watering	77	64%	121
Buying water	27	22%	121
Taking livestock to the river	13	11%	121
Digging a well	4	3%	121

Table 24: Resource deficits in feed and water for livestock as identified by household respondents of three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey. * Note that percentages are calculated in relation to the basis of responding HHs for each section in the third column.

Figure 20: Lack of animal feed and water become major constraints to cattle herding in Siraro district in the dry months (Picture taken by the author Harald Grabher on March 6, 2013 in Siraro district.)

Besides the recurrent, seasonal deficits in animal feed and water, other major challenges to livestock rearing are related to animal diseases (Jemberu et al. 2016). Survey respondents identify the following pathologies: for cattle, anthrax, internal and external parasites and blackleg (*gangraena emphysematosa*) are cited as most common, while for small ruminants the list of diseases is led by parasites, followed by ovine pasteurellosis, sheep and goat pox and ovine rinderpest. The only disease identified as afflicting poultry is Newcastle disease. Yet only 43% of the surveyed farmer households have their cattle vaccinated. Likewise, only 23% of the respondents vaccinate their small ruminants and only 4% vaccinate poultry. Less than 2% of all farmers have their livestock de-wormed. As an animal health post is located in Alemtena Sirbo kebele, 55% of all household heads concede that they would have access to animal health services.

3.3.3. *Forest and woodland use for household energy provision*

In Ethiopia, almost 90% of the total energy consumed is biomass-based (Berhanu et al. 2016). The household survey results of this study underline this fact. Except for homestead lighting, all household energy consumed is derived from biomass: A share of 77% of all respondents use fuel wood as their main source of energy for cooking; the rest uses mainly crop residues (13%) or leaves and twigs (9%) (see Table 25).

In spite of the fact that dung is collected and worked into dung cakes with considerable labour allocation, dung cakes are not mentioned as a *main* energy source for cooking. This may imply that dung cakes cannot be produced in sufficient amounts to be considered a main source of energy, or that dung cakes are mainly used to supplement the combustion process.

In terms of fuel energy, homesteads in the district of Siraro frequently have small integrated woodlots mainly consisting of Eucalyptus trees and shrubs. As a consequence, 66% of the respondents report that they use fuel wood from their own woodlot. Nevertheless, 23% state that they need to buy fuel wood, while 12% collect fuel wood from their own cultivated land and 11% from natural vegetation[5]. 6% of the respondents collect wood from natural forest, almost all of them from Loke Hada kebele. While 41% of all households, most of whom may have a homestead woodlot, report fuel wood collecting times of less than 30 min, 39% of the farmer households spend up to an hour on fuelwood collection, and 20% more than 1 hour. Interestingly, none of the questioned households used any of the energy-efficient cook stove solutions, a technology that has been promoted in Ethiopia for more than ten years and is available in many parts of the country (Accenture 2012).

[5] Note that respondents may be reluctant to disclose sourcing fuel wood from natural forests and trees as it is illegal in Ethiopia to fell trees. Other response options, like the purchase of fuel wood, may therefore have been overstated.

Respondents/ Response	Alemtena Sirbo		Nuna Raba		Loke Hada		Total	
	HHs	%	HHs	%	HHs	%	HHs	%
Respondents	51		50		71		172	
Energy for homestead lighting								
Kerosene/oil	51	100%	50	100%	71	100%	172	100%
Main source of energy for cooking								
Fuel wood	42	82%	35	70%	56	79%	133	77%
Leaves/twigs	0	0%	8	16%	8	11%	16	9%
Crop residue	9	18%	7	14%	7	10%	23	13%
Sources of fuel wood								
Own planted woodlot	34	67%	25	50%	54	76%	113	66%
Purchasing	11	22%	11	22%	18	25%	40	23%
Collecting from natural vegetation	0	0%	8	16%	11	15%	19	11%
Own cultivated land	9	18%	6	12%	6	8%	21	12%
Main source(s) of collected fuel wood								
Natural forest	0	0%	1	13%	9	82%	10	6%
Trees in/around fields	0	0%	7	88%	4	36%	11	6%
Walking distance to collect fuel wood								
1-29 mn	8	16%	7	14%	12	17%	27	8%
30-60 mn	8	16%	11	22%	7	10%	26	15%
61-600 mn	1	2%	1	2%	11	15%	13	16%
Access to energy-efficient technologies								
Fuel-saving stoves used	0	0%	0	0%	0	0%	0	0%

Table 25: Main household energy sources, their corresponding resources, time allocation for provision and adoption rates for energy-efficient stoves, disaggregated for three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey. Values in % are calculated on the respondents per village in columns 2, 4, 6 and for all respondents in column 8.

4. Discussion: Extraction, degradation and food insecurity

Ethiopia has reached a very high level of Human Appropriation of Net Primary Productivity (HANPP) and shows increasing trends. On a national level, this demand is unsustainable and leads to deteriorating natural resources, land degradation and aggravates food insecurity. As demonstrated in this study, the overall HANPP for Ethiopia shows considerable increases in extracted biomass over the past five decades. In the final decade of this study, its level is much higher than both the average for Africa and the global average, and on a par with densely-populated countries in other parts of the world (Fetzel et al. 2012). Ethiopia reaches the 60% mark of HANPP as % of NPPpot in 2002 and has stayed above 60% ever since, while its population density increased from 70 cap/km2 in 2002 to 95 cap/km2 by 2013. Given the fact that the global average HANPP rate in % of NPPpot is reported at 23.8 % for the year 2000 (Haberl et al. 2007), and is clustered around the 20% mark for other sub-Saharan countries (Fetzel et al. 2012), the high level of HANPP in the case of Ethiopia appears counterintuitive, but only at first sight. In fact, Ethiopia shows similar patterns of HANPP to countries with high population densities despite enormous differences in socio-economic development or climate. In a study comparing six country-level HANPP analyses (Krausmann et al. 2012) the total HANPP in % of NPPpot ranges between 60% and 70% around the turn of the 21th century for the United Kingdom, Spain, Hungary and the Philippines, which is similar in range to Ethiopia. Their population densities range from 80 to 249 cap/km2 in the year 2005, and Ethiopia's population has grown to meet this range.

While HANPP for Ethiopia almost doubled from 442 Mt dm/yr in 1961 to 760 Mt dm/yr, total HANPP per capita decreased from 18.3 t dm/yr to 8.0 t dm/yr in tandem with population increases. The general trend of these findings is in line with results of a global HANPP study (Krausmann et al. 2013) in which per capita HANPP for the Africa declines from 5.8 to 2.6 tC/cap/yr between 1910 and 2005, which roughly translates into a fall from 11.6 t dm/yr to 5.2 t dm/yr. For Ethiopia a similar trend for extracted biomass is visible, with HANPP per capita decreasing form 18.3 t dm/yr 1961 to 8.0 t dm/yr in 2013, although on a much higher level of appropriation relative to NPP. This underlines the relatively high intensity of HANPP in Ethiopia as compared to the regional African average (Fetzel et al. 2012). In this respect, Ethiopia may be more comparable to the Latin America findings of the Krausmann et al. study which reports 5.8 tC/cap/year or 11.6 t dm/cap/year HANPP in 2005. For Ethiopia in 2005 this HANPP value stood at at 9.2 t dm/cap/yr. The large livestock populations with extensive foraging, relatively low crop yields, high HANPPluc and high degradation rates for both regions may contribute considerably in this similarity.

Given the uncertainties addressed in Chapter 2, findings of this study also appear within a plausible range of deviation, when comparing Used Extraction (UE) rates of another global HANPP survey (Krausmann et al. 2008). In this analysis, values for Used Extraction are broken down into country data. Ethiopia in the year 2000 falls into the bracket of 2.5 to 4 t dm/cap/yr Used Extraction while the value calculated for the study at hand in the year 2000 stands at 2.4 t dm/cap/yr, thus marginally below the stated bandwidth. Likewise, while Ethiopia falls into the 1 to 1.5 t dm/ha/yr span for the year 2000 when relating Used Extraction to unit area (ha), the HANPP calculation, the current study results show a value of 1.6 t dm/ha/year for the same year, again only marginally off the given bandwidth. This is well above the average UE for Sub-Saharan Africa of 0.6 t dm/ha/yr calculated by Krausmann et al. 2008 and, for example, on a par with their Eastern Asia value (1.4 t dm/ha/yr).

4.1. The costs of cropland expansion and land use dynamics

In this study, increases in crop production, and in turn, in HANPPharv have been related to cropland expansion in 3.1. Cropland expansion has had detrimental effects on the natural resource stocks. In fact, total cropland HANPPharv for Ethiopia quintupled from 18 Mt dm/yr to 97 Mt dm/year between 1961 and 2013 as agricultural land area increased from 11.5 to 16.3 million hectares. In a decomposition analysis by Taffesse et al. (2011) cropland expansion is identified as *the* major driver for the increased crop production of Ethiopia, although crop yields show remarkable increases in many analysed settings and therefore contribute significantly to production increases. Findings of the study at hand show a similar, but more complex, picture. On the one hand, the rise in total cropland HANPPharv can be attributed to cropland expansion. Cropland increased by 54% between 1993 and 2013, from 10.5 Mha to 16.3 Mha (see Figure 8). Nevertheless, efficiency gains remain a strong driver in cropland production and amounted to an increase by 290% (measured as HANPPharv as % of HANPPluc) between the first and the last decade of the study (see Table 11). In line with these findings, cropland HANPPharv per hectare increases markedly by 287% between 1961 and 2013, from

1.5 t dm/ha/yr to 6 t dm/ha/yr. Total cropland HANPP for Ethiopia shows its lowest level in the decade between 1971 and 1980. These findings are corroborated by results by Taffesse et al. (2011) which report a 31% decreases in cereal production from the cropping seasons 1972/73 to 1975/76[6] which is in turn reflected in the FAO data underlying this study.

As can be inferred from Figure 8, cropland expansion in Ethiopia has largely taken place at the expense of forests and woodlands. While land used for agricultural crop production increased from 10.5 Mha in 1961 to 16.3 Mha in 2013, the area under forests and woodlands decreased from 27.2 Mha to 12.4 Mha. Throughout the same period, grazing land showed little variation and amounted to 69.7 Mha in 1961 and 69.3 in 2013. This trend is corroborated by two recent studies. A recent assessment of land use and land cover changes between 1972 and 2013 based on satellite imagery underlines the rapid agricultural colonization and the decline in forest cover (Kibret et al. 2016). Although this assessment is limited in scope to the central highlands (but touches geographically Siraro district boundaries) it spans the four most important agro-ecological zones of Ethiopia (Hurni 1998). Another analysis based on remote sensing for three districts in North-Western Ethiopia shows a similar negative relationship between forest cover loss and cropland expansion (Alemu et al. 2015). The broad developments in terms of land use therefore are clear. Still, neither this HANPP study nor the research cited shed a light on the surmised succession of land use change from woodlands to cropland to grazing land. Further exploration of this succession in the context of Ethiopia may be important to understand the connection between deforestation, crop production, intensification, soil degradation, abandonment of cropland, the use of abandoned cropland as grazing land and the consequences with regard to further degradation and erosion as postulated by Nyssen et al. (2003.)

In addition to the apparent net expansion of farmland into other land cover classes, above all woodland, Ethiopia's current land use system and prevalent farming practises contribute critically to soil degradation and soil erosion. From the national HANPP perspective, this may be a consequence of comparatively high levels biomass utilization in an ecologically sensitive mountainous area. Overall HANPP in % of NPPpot for all land use categories rose from 30% to

[6] Taffesse et al. attribute the slump in cereal production and thus, in cropland HANPP, during this period to the fall of the Ethiopian empire under Haile Selassie in 1973, ensuing agricultural land reforms and price regulations for cereals introduced in 1975.

63% (see Figure 10). With a value of 61% of HANPP in % of NPPpot in 2005, Ethiopia displays more than three times the African average of 20% for the same year reported by Fetzel et al. (2012). With a per hectare perspective on cropland, it has also been shown in Chapter 3 that cropland HANPPharv increased fourfold from 1.5 t dm/ha/yr in 1961 to 6.0 t dm/ha/yr (see Figure 12.) In this period HANPPluc per ha cropland decreased from 9.9 t dm/ha/yr to 6.0 dm/ha/yr, resulting in a HANPPluc to HANPPharv ratio of just under 100% for 2013 (see Figure 11). This is well above average results for the year 2005 for East Africa which stood at 82% HANPPharv to HANPPluc ratio (Fetzel et al. 2012). Again, this may serve to highlight the comparative intensity with which biomass is extracted in the Ethiopian land use system.

On local scales, the intensive extraction of biomass is also evident. For cropland, the harvest of the agricultural product itself and the use of its plant residues and stubbles as food for human consumption, as animal feed and as fuel, all contribute to the high levels of extraction. In Alemtena Sirbo village of Siraro, interviewed farmers even report to save adequate crop roots of maize, sorghum etc. that is encountered during ploughing for household fuel (Grabher 9/1/2016). Similarly, in the context of biomass scarcity in Ethiopia, animal dung is frequently used as an alternative source of fuel (Guta 2014). Past research concludes that the combination of these exploitative practises leaves too little organic matter to be cycled back into the cropland soil through animal droppings or natural deposition and thus lead to immense nutrient losses, productivity losses and continuous soil degradation (Duncan et al. 2016). In the major crop producing regions of Ethiopia, productivity losses due to nutrient exports from dung and residue burning or residue feeding are estimated between 0.7% and 4.4% of the total crop production for the year 2000 (WBISPP 2004). In the longer term, one serious consequence of these extractive land use practises is massive soil erosion mainly caused by rainfall and water runoff (Nyssen et al. 2003; Hurni et al. 2015) and wind.

Figure 21: Recent soil erosion on cropland lead to a vicious cycle: abandoned cropland is used as grazing land, often exacerbating erosive effects (picture taken by the author Harald Grabher on Aug 30, 2016 in Siraro district).

It is obvious that soil degradation and concurrent soil erosion as a consequence of excessive levels of extraction of organic matter have become a serious concern for food security in Ethiopia. Estimated average top soil losses of for the country amount to between 20 t/ha/yr (Hurni et al. 2015, measuring only water erosion in the central Ethiopian highlands) to 40 t/ha/yr assumed for all cropland (Hurni 2010). Both estimates lie well beyond the reproduction rate for topsoil estimated at an average of 1 t/ha/year and lead to losses in crop productivity of up to 8% per year without considering replenishment (Pimentel et al. 1995). Other estimates show a yield reduction due to past erosion of between 6% and 8% for Africa (Lal 1995). To ascertain conservative estimates, the study at hand considers soil degradation on cropland in terms of yield changes. It is assumed that eroded cropland will be used as grazing land, and therefore productivity losses are taken into account on grazing land.

Nevertheless, a per unit area perspective does not reflect the yield reductions which could be attributed to land degradation and erosion. As already mentioned, HANPPharv per ha shows an increase from 1.5 t dm/ha/yr to 6.0 t dm/ha/yr between 1961 and 2013, and agricultural efficiency gains as represented by the HANPPluc to HANPPharv ratio are clearly evident (see Figure 11). Agricultural intensification due to high-yielding cultivars, chemical inputs and intensive farming practises may explain this increase, and may at least partially hide degradation losses. In this respect, a factor that remains under-researched and which the HANPP methodology, as pursued here, cannot account for adequately, is the impact of successive cycles of degradation in which productivity losses of woodland turned to cropland abandoned to grazing land (and potentially reforested to a less productive secondary forests) are accounted for.

On a per capita basis, HANPPharv stays within a very low bandwidth of 0.7 to 0.4 t dm/cap/year until 2004, but displays a significant increase in the last years of the study and peaks at 1.0 t dm/cap/yr in 2013 (see Figure 11). In terms of food security, this study therefore finds evidence that efficiency gains in the Ethiopian agricultural system have had a positive effect on per capita biomass extraction, despite detrimental land degradation effects. Nevertheless, the increase in HANPPharv as % of HANPPluc of 290% (see Table 11) between decade 1 and decade 5 is only partially represented by per capita gains due to the enormous population growth Ethiopia has witnessed in the study period, but per capita HANPPharv does increase by 40% over the 1961 value by 2013. This finding stands in stark contrast to the survey results of Siraro, where food security is identified as a major concern.

4.2. Well-trodden paths: from livestock feed to soil erosion

The crop-livestock system currently practised in Ethiopia also shows clear signs of unsustainably high levels of biomass extraction from grazing land. The inefficiencies entailed in the current livestock system appear to aggravate land degradation, erosion and, as a consequence, food insecurity. HANPP on grazing land for Ethiopia on average represents 69% of its NPPpot. More significantly, grazing intensity as measured by grazing land HANPPharv (representing the aggregate grazing demand of all livestock) in relation to aboveground NPPact of grazing land reaches the mark of 56% in 2013. In accordance with findings by Fetzel et al. (2016), this is among the highest grazing intensities observable on the planet and exceeds levels reported for Southern Asia for the year 2000. This result is in line with a recent village-level study which reports 80% of the biomass is removed from communal grazing lands in Northern Ethiopia (Alemayehu et al. 2013). The country's livestock production system has traditionally been dominated by cattle. The main aim of cattle raising, in turn, has been to provide animal traction for land preparation (Gryseels, Goe 1984; Astatke 1999; Mengistu 2006) in the mixed crop-livestock land use systems predominant in Ethiopia. In Chapter 3.2, this study depicts the significant increase in livestock levels over the five decades under scrutiny. This steep rise is mainly driven by the cattle population, which increases from 25 Mill. heads in 1961 to 54 Mill. heads by 2013. It is important to keep in mind that the main cattle holdings with the highest animal densities are located in the intensively farmed agricultural areas of the highlands (Leta, Mesele 2014).

The use of oxen for draught power may be pivotal for the overall performance of the current crop/livestock system prevailing in Ethiopia. For 2007, the Ethiopian Agricultural Sample Survey (Central Statistical Agency 2008) reports 47.5 Mill heads of cattle[7] and disaggregates this total number by sex, purpose and geographical areas. According to the survey data 39% of all cattle aged 3-10 years (or 11.5 Mill heads) are used for draught purposes, 24% for dairy production, and a further 29% are kept for breeding purposes. Of the latter category, it is reasonable to assume that a major breeding objective is again draught power, so that providing animal traction may form the basis of more than 50% of the cattle population of the country. In terms of Used Extraction from grazing land, this means that as much as 55 Mt/dm/year or 21% of the total Used Extraction of biomass of Ethiopia in 2013 may be linked to animal draught provision. At the same time, animal power (90% from by oxen, the rest from donkeys) is used only for about 1,050 hrs per farm or less than 6 months of the year (Gryseels, Goe 1984). Since this study was published, draught power efficiency per household may have further decreased as the average farm size has significantly shrunk in the past 30 years, which may, at least in some instances, have led to a further underutilization of the available oxen.

Similarly, the head count of sheep and goats as the other major livestock category hints at yet another characteristic animal production system with severe negative impacts. The 2007 Ethiopian Agricultural Sample Survey results may help to interpret the massive increases in the sheep and goat populations (see Chapter 3.2.3 or also Leta, Mesele 2014) in the past decades. According to survey findings, a staggering 90% of all sheep and goats aged 2 years and more are kept for the purpose of breeding, and only an aggregate 9% for meat, milk or wool production (Central Statistical Agency 2008). In practical terms, it therefore seems reasonable to assume that in the Ethiopian livestock system, sheep and goats are most often kept as sources of income, household and status assets, for traditional ceremonies and as barter units rather than for primary production of meat and milk (Mengistu 2006). The Siraro

[7] FAO data, on which this study relies, is based on these large-scale sample surveys by the Ethiopian Ministry of Agriculture and therefore report the same number for 2007.

household survey data confirms that animals are most often kept as an emergency cash asset and for home consumption of animal products (see 3.3).

Figure 22: Goats and sheep are mainly reared for cash income and as an emergency asset by the rural poor (picture taken by the author Harald Grabher on Aug 29, 2016 in Siraro district).

Across all ruminant categories, pasture-derived biomass is still *the* major source of animal feed within the Ethiopian livestock system (see Figure 14). According to study data, grazing covered 69% of the total ruminant feed demand in 2013, crop residue accounted for 30% with the remainder coming from commercial feed. Other sources attribute between 62% and 90% of animal feed (Central Statistical Agency 2008; Mengistu 2006) to grazing. Depending on the season, livestock is fed from a mix of different sources: During the agricultural campaign, when large tracts of land are fenced off, and until harvest, animals frequently feed on communal lands, sloping, stony or eroded areas or other land not deemed fit for agriculture, roadsides or farm plot margins (Mengistu 2006). As the seasonal rains normally fall during this period, net primary productivity is at its peak and feed quality may be relatively better than in the dry months. After harvest and throughout the dry season until the time of seedbed preparation, free grazing of all ruminants on crop stubble is usually practices in the cropland areas of Ethiopia. The available feed resources quickly decay in quality and deplete with the absence of rain and thus, the longer the dry season last, the more crop residues must be supplemented to feed the animals, with preference going to draught animals (Mengistu 2006).

Grazing land, which is often under communal tenure in the Ethiopian context, bears the brunt of the grazing pressure and therefore is prone to the most severe forms of soil erosion. This is in line with global findings on rangeland degradation (Steinfeld et al. 2006; Haberl et al. 2014). As outlined in 2.2.4 and 2.2.7, in the HANPP results of this study this fact is taken into consideration in a twofold manner: Firstly, by a reduction of the NPPact of grassland by 20% to account for NPP losses due to normal grazing, trampling and nutrient exports (Haberl et al. 2014). Secondly, soil degradation and soil erosion on grazing land are taken into account by assuming an exponential erosion coefficient between 1961 and 1992 and a constant reduction of NPPact by 35% thereafter as it is assumed here that by this time reforestation as well as soil and water conservation activities have been upscaled and bear some fruit (Hurni et al. 2015).

The significant reduction in grazing land NPPact assumed in the model underlying the study is based on a variety of contributing factors: Highland pastures are normally grazed throughout the year without recovery phase, and therefore most prone to degradation (Gebremedhin et al. 2004). Extreme levels of overstocking can be encountered, especially on communally managed grazing lands (Alemayehu et al. 2013). Regionally limited studies suggest that stocking levels may be well beyond the optimum carrying capacity of the land under research (Alemayehu et al. 2013; Amsalu, Addisu 2014). As pointed out above, findings from the study at hand suggest that grazing intensity has reached levels on a par with the planets' most intensely grazed regions. Furthermore, ongoing erosion processes on grassland due to grazing and trampling may be further amplified by droughts (Fetzel et al. 2016). Often, cropland degraded or eroded by unsustainable farming practises may be taken out of cultivation by farmers and turned into grazing land, exacerbating the extent of erosion (Nyssen et al. 2003; Alemayehu et al. 2013; Kassa et al. 2016). In addition, there is strong evidence from the research results (see 3.1) that much of the current Ethiopian grazing land was once covered by woodland or forests which were initially converted into cropland (Nyssen et al. 2003; Hailu et al. 2015) so that large tracts of grazing land have gone through various phases of degradation and erosion (Nyssen et al. 2003).

Figure 23: Land cover change and erosion effects: Eroded cropland is given up and used as communal grazing land, exacerbating erosion. (Picture taken by the author Harald Grabher, Aug 24, 2016 in the Rift Valley approximately 20 km from Meki town.)

Figure 24: Historical development of erosion: Picture of the same micro watershed taken from a different angle showing the downstream extent of erosion. Local interviewees state that 50 years ago area was used as farmland. (Picture taken by the author Harald Grabher, Aug 24, 2016 in the Rift Valley approximately 20 km from Meki town.)

For Ethiopia, cattle feeding constitutes roughly 50% of the livestock feed demand. As mentioned in the data section, to calculate the grazing feed demand of cattle two specific linear feed demand models were applied to FAO data on beef and milk production based on Krausmann et al. (2008). In the context of Ethiopia that cattle feed demand ist based on meat production. This means that even if carcass weight is low, milk yields remain even lower compared to international standards.

Still, Siraro household survey results show that dairy production, although practised on a very low-intensity level, is still important: the survey finds that the most important animal product is dairy. In total, 67 out of 85 cattle-owning households consume or sell dairy products. Yet, it must be noted that the major share of 85% is allocated to household consumption (see Table 23) and is never brought to market. Additionally, milk yields in Siraro remain at very low levels of 1.7 l per cow per day on average, although these reported figures are well above the very low national average of 0.68 l/animal/day (Table 12). The apparent inefficiencies of the current livestock system represented by the three villages in Siraro may be exemplified by Table 26. As stated, average milk yields per cow are reported at a very low level of 1.7 l/cow/day, far from the locally attainable maximum of 8 l/cow/day, which is in turn a low output compared to international daily milk yields. The apparent inefficiencies in the Siraro livestock system may therefore lead to the similar negative effects encountered on larger Ethiopian scales, including severe degradation and erosion (Alemayehu et al. 2013; Gebremedhin et al. 2004). Yet it must be noted that the Siraro baseline survey was not intended as a field inquiry into the complex topic of degradation impacts, and therefore results do not account for degradation from grazing land.

Item	Average	Min. reported	Max. reported
Cow milk (l/cow/day)	1,7	0,3	8,0
Eggs (eggs/hen/week)	3,4	1,0	7,0
Traditional beehive (kg/hive/year)	4,7	2,0	10,0
Modern beehive (kg/hive/year)	20,8	8,0	40,0

Table 26: Production yields derived from livestock keeping. Data taken from respondents of three kebeles of Siraro district, Ethiopia, as per the 2015 SILVR project baseline survey.

Nevertheless, apart from severe drought incidents, it seems reasonable to assume that the majority of the Ethiopian cattle population will finally be utilized as a proteine resource for human consumption. About 50% of the cattle population is never kept or bred for dairy purposes but to secure draught power supply for the present and the future. It must be conceded that the reliance on a marketable production data for cattle in the HANPP calculations in this sense does not fully cover ground realities for cattle rearing for large parts of Ethiopia. Still, feed demand calculated on carcass weight seems to offer a reasonable approach and may be the best option given the available data.

4.3. Biomass energy: rising demand, shrinking supply

Ethiopia remains largely dependent on biomass to cover its energy needs. Biomass energy in the year 2000 accounted for about 97 percent of the total energy supply, with 78 % derived from woody biomass. About 16% of the biomass energy stems from crop residue and animal dung (WBISPP 2004; Berhanu et al. 2016). Research further reports that about 1/3 of the total Ethiopian biomass extraction is used for energy consumption (Berhanu et al. 2016). Despite recent large investments into hydro energy and an ongoing transition towards fossil energy carriers, this picture has not changed much throughout the study timeframe. WBISPP 2004, citing the Ethiopian Forestry Action Plan, reports an enormous deficit of fuelwood demand (58.4 Mill. m3) over sustainable supply (12.5 Mill. m3) which underlines the unsustainability of the current fuelwood consumption patterns. Although WBISPP 2004 itself sees a less dramatic situation on a national level, it does report considerable decreases in woody biomass stocks for the major, most populated parts of the country and an over-exploitation of woody biomass over sustainable production in 335 out of 500 districts (*woredas*) of the country. Furthermore, this excessive biomass extraction from forests and woodlands to cover rising energy needs and for cropland expansion has resulted in productivity losses and increased the risk of erosion (WBISPP 2004; Bane et al. 2007).

In the past decades, the extraction of biomass from Ethiopian forests and woodlands has shown an immense increase and appears to have reached unsustainable levels. For Ethiopia as a whole, land under forest and wood cover more than halved from 27 Mha in 1961 to 12 Mha in 2013. Total woodland HANPPharv almost tripled from 31 Mt dm/yr to 88 Mt/dm/yr in the research period. HANPP in % of NPPpot showed a discomforting trajectory, rising from 8% in 1961 to 53% in 2013. Given that the highest common thresholds for HANPP as % of NPPpot do not normally exceed 30% for forest biomes (Schulze et al. 2012) as the remaining NPP may neither be available over time or suitable for human uses, the high rate of forest and woodland

HANPP in Ethiopia must be attributed to large-scale deforestation. Not surprisingly, NPPeco as the amount of annual regrowth of biomass remaining in the environment after harvest fell from 341 Mt/dm/yr to 77 Mt/dm/yr. It seems clear that Ethiopia has been using considerable parts of its standing stocks of forests and woodlands to cover its energy demand. A recent study covering the geographical area of Siraro underlines this and reports that between 1972 and 2000 82% of the forest cover in the research area was lost (Dessie, Kleman 2007).

4.4. Synthesis: National and local trends

Comparing the results of the global HANPP analysis with the household survey results of the three villages in Siraro, there are a number of parallels which reciprocally reinforce findings of both research sections. Both study areas may serve to highlight competing uses of biomass, be it on a local or national level, and delineate common impacts thereof. As already shown in detail in 3.3, it is important to remember that a vast majority of survey respondents perceive their household as food insecure even in normal-rainfall years and that 6 out of 10 household heads attribute their food insecurity to a perceived shortage of agricultural land. Additionally, around a quarter of the respondents see the reason for their food insecurity in low production yields. These in turn can be linked to farmers' perception that soil fertility has declined. In contrast to these results, the HANPP findings of the study do show a more complex scenario: on the one hand, cropland HANPPharv per hectare cropland rises markedly from 1.5 t/dm/yr in 1961 to 6.0 t/dm/yr in 2013, representing an increase of 287% over the 1961 basis. Yet these yield per area gains are more than compensated by population growth, which shows a population increase of 292% over the same time span. Nevertheless, total cropland efficiency ratio expressed as HANPPluc to HANPPharv rises from 16% in 1961 to 99% for 2013 (see Figure 11) and thus increases by 435%. Yet, on a per capita basis, cropland HANPPharv sees a much more moderate increase, and only in the last years of the study, from 0.7 t dm/yr to reach 1.0 t dm/cap/yr 2013, which represents an increase of 40% over its 1961 value. While by itself representing a comparatively low value, it is reasonable to assume that this moderate per capita agricultural increase is unevenly distributed across Ethiopia. Thus, farmer households toiling in Siraro, an area of identified and food insecurity, may not have benefited to the same extent from these yield increases and efficiency gains. The prevalent crop/livestock system of

Siraro with its dependence on draught animals brings with it serious consequences to agricultural productivity and, thus, food security. This holds also true for energy consumption based on biomass, which is acknowledged as a major driver of deforestation by Siraro farmers. These findings are reflected to some extent by the national HANPP results and have been discussed there.

4.4.1. Cropland expansion

While cropland expansion is a major trend on the national scale, a shortage of cropland for agricultural production has been identified as one of the main challenges for food security Siraro survey respondents. Although no trend data is available for the three villages under research, it is reasonable to assume that population dynamics are also a driving force behind agricultural colonization (Biazin, Sterk 2013) in Siraro district. As most of the land is already under some mode of use, even more so in the intensely farmed productive highlands, the scarcity of land in Ethiopia is critically linked to rural population density (Josephson et al. 2014). With only 0.5 to 1 ha of cropland available to more than 85% of the Siraro village households in 2014, it is comprehensible that access to productive agricultural land is perceived by farmers as a major challenge to food security. Loss of farmland due to degradation may play a considerable part in these dynamis. Study results focusing on the rift valley region of Ethiopia from a historical point of view suggest that the major transition from pastoralist livelihoods to sedentary agriculturalism took place only during the past century. This development was driven by a reduced vulnerability to drought events by cropland farming systems (Biazin, Sterk 2013). In line with the national-level findings of the study at hand, therefore, cropland is reported to have expanded rapidly in the rift valley area of the country, and was matched by rapid declines in dense and scattered acacia woodlands (Biazin, Sterk 2013). It seems worth mentioning again that these gains in cultivable land at the expense of land under wood cover have been linked to soil degradation and soil erosion (Nyssen et al. 2003; Kassa et al. 2016).

4.4.2. Productivity decreases and soil degradation

The other major driver of food insecurity is the perceived decline in cropland production yields, as reported by household survey respondents. As discussed earlier, this result is not reflected in the national HANPP study which shows significant per hectare increases in cropland yields over the last 50 years and a reasonable increase of 40% in per capita cropland HANPPharv. These divergent findings may at least partly be explained by an uneven distribution of such efficiency gains across Ethiopia. Siraro may be encountered in the list of the most food insecure districts of Ethiopia, exactly because it has not fully participated in the developments that have resulted in yield increases and efficiency gains. Many interlinked factors may be accountable for the situation the three villages find themselves in: Firstly, for lack of sufficient cropland, none of the farmer households reports to be able to practise the traditional way of replenishing soil nutrients through fallowing. Biomass and water scarcity are reported as major constraints to composting, so it is also not practised widely. On the one hand, household survey data hint at significant nutrient exports from the cropland as harvest, as animal feed and energy source in the case of crop residues, and as fuel in the form of animal dung. These organic matter and nutrient exports from the agricultural land are likely to have direct impacts on plant nutrient availability (Duncan et al. 2016) and crop yields (WBISPP 2004). Moreover, a reduction in soil cover and soil organic matter may aggravate soil degradation and erosion (Nyssen et al. 2003; Lal 1995; Pimentel et al. 1995). On the other hand, almost 60% of the smallholder households interviewed use chemical fertilizers to overcome nutrient deficits and yield declines but apparently application does not translate into more food security for the population. Disquietingly and contrary to theories put forward by Esther Boserup in the 1960s (Boserup 1965), research on Ethiopian smallholder farming suggests that increased population densities may not lead to higher levels of productivity and have been associated with a decrease in income from farming per unit area (Josephson et al. 2014). Other researcher findings put forth a more positive view, maintaining that yield increases may still be viable for smallholder farmers in sub-Saharan Africa by a closer integration of crop and livestock systems (Henderson et al. 2016).

The focus on oxen for animal traction prevailing in Ethiopia is also evident from the Siraro farmers' interviews: only 5% state having sufficient animal traction to prepare their cropland, with 28 % of farmers reporting to own one or more oxen. Oxen in the three villages represent 25% of all cattle owned, which seems to be somewhat lower than the national average which shows that 39% of all cattle are used for draught purposes, 97% of these are oxen (Central Statistical Agency 2008). With regard to food security and animal power, it seems that smallholder farmers are caught in a serious dilemma: research suggests that the cost for renting animals for traction results in less agricultural crop production and, as a consequence, reduced food security. Nevertheless, more draught animals available in the community may decrease the natural resource base available to all on the communal lands and during free grazing periods to a much larger extent (Wilson 2003) and may therefore induce soil degradation and soil erosion (Alemayehu et al. 2013).

Energy consumption patterns of the three Siraro villages closely mirror research findings for Ethiopia (WBISPP 2004; Berhanu et al. 2016): as shown in 3.3 for the 3 villages, cooking energy is derived 100% from biomass, comprising of fuelwood (77%), leaves and twigs (9%) and crop residues (13%). Cow dung was not mentioned by Siraro interviewees as a major source of cooking energy but survey data suggests that dung cakes are in fact prepared and used. As the survey data on energy consumption was not a major component of the Siraro survey, results in this section do not lend themselves to a more detailed interpretation. It may nevertheless be reasonable to assume that the high rates of biomass extraction from natural vegetation encountered for Ethiopia as a whole also remain valid for Siraro and that these result in productivity losses and increased the risk of erosion (Bane et al. 2007; Nyssen et al. 2003; WBISPP 2004).

5. Concluding remarks and further research needs

An increased demand for food for human consumption due to increases in human population, rapidly rising livestock numbers as well as a mounting biomass extraction for household energy have had major impacts on the biomass flows of Ethiopia and have been linked to serious degradation trends for natural resources and food insecurity.

This study tried to reveal dynamics and drivers of land use change which can be observed in Ethiopia, it analysed the long-term trajectories of the Human Appropriation of Net Primary Production (HANPP), and examined current patterns of land use and biomass extraction with regard to their sustainability before an appraisal was made in how far national HANPP trends reflect local ground realities.

On a national level, the study found that land use dynamics have shown considerable variations. Total land available per capita decreased significantly in tandem with population increases. Available cropland more than halved to 0.2 ha/cap while the total cropland area rose from 10.5 to more than 16 Mha of land. The area under forest (including closed woodlands) decreased significantly by 50%. Per capita availability of forest land decreased to 0.1 ha/cap by 2013.

Overall HANPP for all land use categories increases from 30% of NPPpot in 1961 to 63% in 2013, while cropland HANPPharv per hectare almost triples from the 1960s to 2013. The decadal average HANPPharv:HANPPluc ratio of cropland increases almost fourfold to 61% on average in the final decade of the study. On grazing land, the HANPP per ha increases by 58% in a comparison of decadal averages. A significant rise in grazing land HANPPluc per ha of 78% can be observed. The consideration of the modelled land degradation is the most significant contributing factor to the development of HANPP on grazing land. Overall land use efficiency declines from an average of 45% of HANPPharv:HANPPluc ratio in the 1960s to 29% in the final decade of the study. In per capita values, HANPPharv from grazing land drops significantly. Forest and woodland HANPP in % of NPPpot increased from 8% in 1961 to 53% in 2013 and thus shows the biggest relative increase of all land use categories.

On the village level of Siraro, 75% of the respondents state that their household owns between 0.5 and 1 hectare of cultivable land, 10.5% of the households own less than half a hectare.

87% of the respondents report that food shortage occurs in years with normal rainfall, with 54% of the respondents reporting an average lean period of 3-4 months. 85% of the households reduce the number of meals per day and/or reduce the quantity of food per meal. 59% of all respondents identify a shortage of available cultivable land, 23% mention low production yields and 21% list a lack of capital as the main reason for food supply deficit. Low agricultural production is attributed to decreasing rainfall amounts by 78.6%, reduced soil fertility by 62.5%, a reduction in available farmland by 24.4% of the respondents. Chemical fertilizers are used by 59% of the total respondents. Land degradation and deterioration of natural resources are recognized by 92% of the farmers as challenge in their area. 46% of the respondents see deforestation as the main cause of natural resource loss, especially with regard to soil erosion. 36% of the respondents link observed deforestation patterns, soil fertility decreases and soil erosion to an identified shortage of cultivable land. Livestock plays a major role in the mixed crop-livestock farming system practised in Siraro. 74% of the households keep some sort of livestock, with almost half of the farmers holding cattle. Oxen represent about 25% of total number of cattle owned, yet only 5% of the households have sufficient access to oxen to prepare their cropland. 78% of all cattle-owning households prepare dairy products. The average milk yield in Siraro amounts to only 1.7l/animal/day. 66% of the respondents do not see the sale of live animals as the main aim of rearing them. 71% of the households rely on communal grazing land and 99% use crop residue to feed their animals. For 77% of the respondents biomass supply for livestock is not sufficient. 77% of all respondents use fuel wood as their main source of energy for cooking while 13% also use crop residues.

In the discussion part the study clarifies that the rise in total cropland HANPPharv can only partly be attributed to cropland expansion. Cropland expansion in Ethiopia seems to have largely taken place at the expense of forests and woodlands. Nevertheless, efficiency gains remain a strong driver in cropland production which amounted to an increase of 290% over 53 years.

Comparatively high levels of biomass utilization occur in the ecologically sensitive mountainous highland areas of the country. With 61% of HANPP in % of NPPpot in 2005, Ethiopia displays more than three times the African average of 20%. The HANPPluc to

HANPPharv ratio stands at 99% in 2013. This is well above average results for the year 2005 for East Africa at 82%.

This intensive extraction of biomass is also evident on a local scale in Siraro and may have consequences with regard to production amounts and food security. Productivity losses due to organic matter and nutrient exports are estimated between 0.7% and 4.4% of the total crop production for the year 2000 (WBISPP 2004). Estimated average top soil losses due to erosion amount to between 20 t/ha/yr to 40 t/ha/yr.

Nevertheless, this study finds a discrepancy between these research results and a per unit area HANPP view for cropland which does not reflect yield declines. On a national level, agricultural intensification may explain the reported increase, and may even hide degradation losses. In terms of food security, this study finds evidence that efficiency gains in the Ethiopian agricultural system have a positive effect on per capita biomass extraction. On the other hand, the per hectare increase in HANPPharv as % of HANPPluc of 290% in the study is only partially transformed into gains on a per capita basis. A 40% per capita increase of the same ratio over can be reported.

In the predominantly practised mixed crop-livestock system, inefficiencies may aggravate land degradation, erosion and may have direct consequences for food security. Grazing intensity as measured by grazing land HANPPharv in relation to NPPact reaches 56%. This is among the highest grazing intensities observed globally (Fetzel et al. 2016). Biomass from grazing amounted to 69% of the total ruminant feed demand in 2013 and crop residue accounted for 30%. Grazing land is prone to the most severe forms of soil erosion.

Keeping stocking rates below the carrying capacity of the land, improving feed and water management and quality and thus finally increasing the intake of quality feed and water may be vital aspects of alleviating the challenges inherent in the Ethiopian livestock sector (Steinfeld et al. 2006). Improved veterinary services and research into locally adapted animal breeds with better production performance indicators may also be factors contributing to an improved livestock subsystem (Jemberu et al. 2016).

Calculating HANPP of grazing land on animal production data may not fully cover ground realities of Ethiopia, as production is not the main aim of animal husbandry. Further investigations how to meaningfully adapt HANPP calculations for grazing demand and soil degradation are necessary. Unfortunately, data on actual impacts of degradation and erosion is fragmented and inconclusive and degradation remains an under-researched area (Zika, Erb 2009). While national HANPP findings point to massive impacts of degradation on grazing land, also the Siraro livelihood survey did not specifically address this research gap. Local studies like this should in the future be utilized to gain more knowledge on degradation and erosion impacts from all land use categories, but especially from grazing land, and thus help to garner clearer insights into the complexities of the topic.

Neither this HANPP study nor the research reviewed can fully account for the succession of land use changes that is tacitly surmised in this study. Yet, the sequence of land use changes from forests and woodlands to cropland to grazing land merits further exploration in the context of Ethiopia. The environmental causes and socio-economic conditions for each land use change may be important to understand the connection between deforestation, crop production trends, intensification, soil degradation, the abandonment of cropland and the use of abandoned cropland as grazing land with its consequence of further degradation, erosion and food insecurity.

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