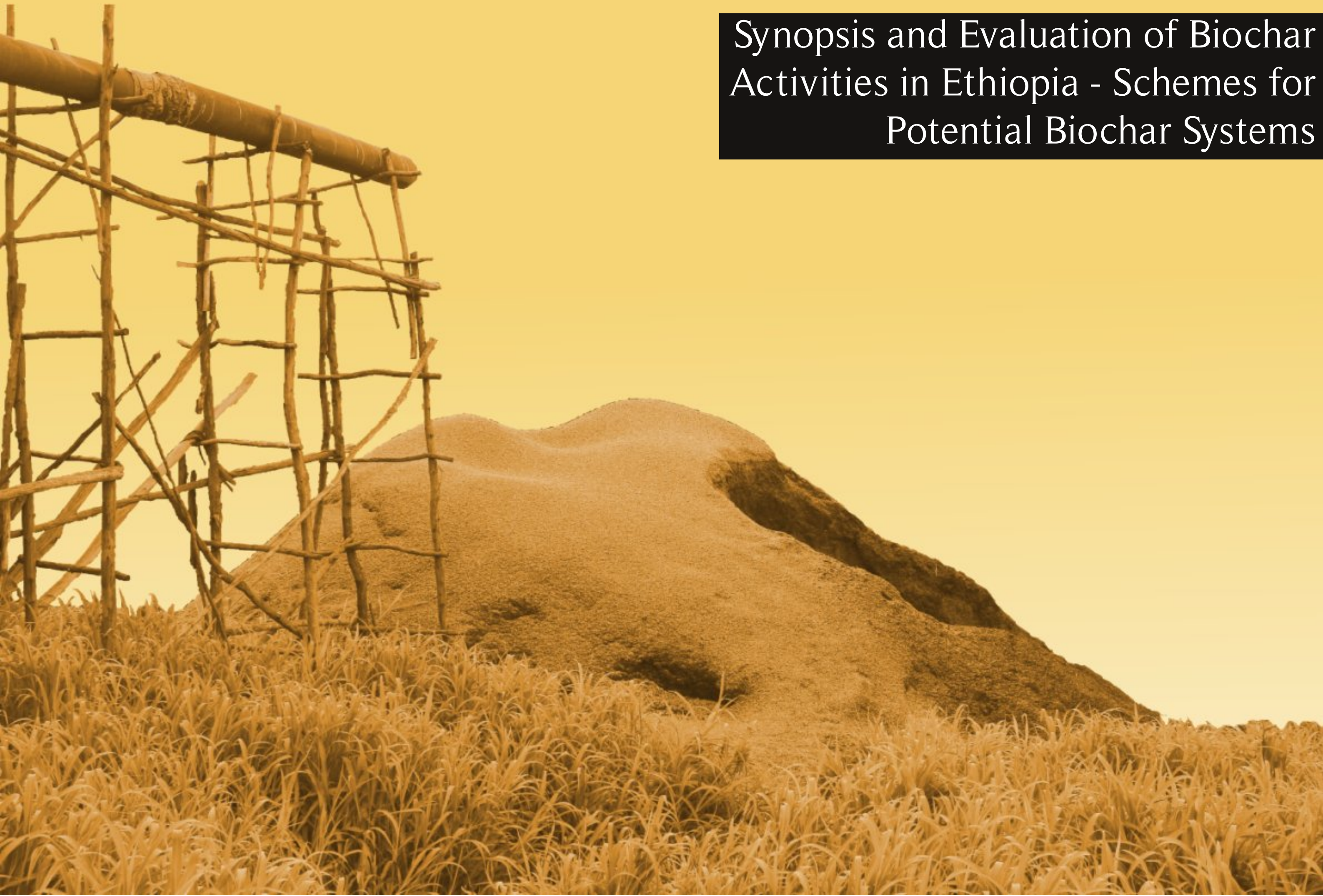
Potential Analysis of Biochar-Systems for Improved Soil and Nutrient Management in Ethiopian Agriculture

REPORT 2

Synopsis and Evaluation of Biochar Activities in Ethiopia - Schemes for Potential Biochar Systems



Potential Analysis of Biochar-Systems for Improved Soil and Nutrient Management in Ethiopian Agriculture

Report 2: Synopsis and Evaluation of Biochar Activities in Ethiopia - Schemes for Potential Biochar Systems

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Biochar Europe

Summary

Several actors have been involved, and are currently or prospectively involved in the introduction of biochar systems to Ethiopian cropping systems. Among these actors are the universities of Jimma (ETH), Haramaya (ETH), Injibara (ETH), Hawassa (ETH), Bahir Dar (ETH), Addis Abeba (ETH), Dilla (ETH), Cornell (USA) and James Cook University (AUS). One of the most comprehensive activities was probably the joint research programme of Jimma and Cornell Universities, that have developed a set of "indigenous biofertilizers" on the basis of biochar and bone char (charred residues of animal bones). Apart from universities, also the Amhara Regional Agriculture Research Institute (ARARI) and the Mekelle Agricultural Research Centre have contributed to biochar research in Ethiopia. Some of these research activities have identified promising feedstock sources to produce biochar, such as, coffee husks, *Prosopis juliflora*, or animal bones. But none of them could present a well-suited technology to convert this biomass to biochar.

Alongside the pioneering of research institutions, there have been attempts to put their results into practice. Some private entrepreneurs have started to produce biochar from either bamboo, coffee husks or other agricultural residues. But the agronomic impact of their substrates could not be evaluated, yet. Several other companies and organizations have become aware of biochar systems as soil improvement and they have indicated their interest in establishing this technology. Generally, practical approaches face several issues, such as limited budgets, lack of knowledge, awareness and demand, inappropriate production technologies and missing support from public institutions.

A key factor for the sustainability of biochar (and bone char) systems is a constant and incompetitive feedstock. Among the most promising biomass options in Ethiopia are small-holder farms residues, coffee residues, *P. juliflora*, flower residues, animal bones, sugar cane residues, sesame residues and human faeces. Some of them are readily and abundantly available all over the country, and their overall amounts can be roughly estimated, e.g. coffee residues 403 kilotonnes, or animal bones 192 – 330 kilotonnes. The amounts of other sources, such as sugar cane or *P. juliflora*, are difficult to estimate and their availability for biochar production can hardly be predicted.

Different schemes for potential biochar systems in Ethiopia can be drawn. The most determining factor that distinguishes one biochar system from another, is, from our point of view, the scale of production. Small-scale biochar systems can be established on small-holder farms. They can draft on different harvest residues and particularly on coffee husks as feedstock, and on pyrolysis/gasifier cookstoves as production unit. Medium-scale biochar systems are based on the production of biochar in small- and medium-scale enterprises (SMEs), such as restaurants, bakeries, coffee roasteries, textile and leather industries. Several

feedstock sources are feasible for these biochar systems and the resulting biochar can be distributed as a part of commercial organic fertilizer substrates. However, medium-scale biochar systems would be challenged by high investment costs, high transportation costs and the logistical management of inputs and outputs. Large-scale biochar systems can be established where large amounts of feedstock are constantly available. These systems require large pyrolysis plants that produce heat for industrial purposes. There are good opportunities to develop such systems on the basis of sugar cane residues, flower residues or biomass briquettes.

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Abbreviations

ADLI - Agricultural Development-led Industrialization
ARARI - Amhara Regional Agriculture Research Institute
ARE - apparent recovery efficiency
CEC – cation exchange capacity
CRR – crop residue ratio
CSA – Central Statistical Agency
DAP – diammonium phosphate
ECX – Ethiopian Commodity Exchange
EnDev – Energising Development Partnership Programme
EthioSIS – Ethiopian Soil Information System
GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
HoA-REC&N – Horn of Africa Regional Environment Centre and Network
ICS – improved cookstoves
IRDP - integrated rural development project
ISFM+ - Integrated Soil Fertility Management Project
LIFT – Land Investment for Transformation
LZ – livelihood zone
MfM – Menschen für Menschen
MoANR – Ministry of Agriculture and Natural Ressources
MSME – micro, small and medium enterprise
NGO – non-government organization
PASDEP - Plan for Accelerated and Sustainable Development to End Poverty
PIF - The Agriculture Sector Policy and Investment Framework
RARI - Regional Agricultural Research Institute
SDPRP - Sustainable Development and Poverty Reduction Program
SLM – Sustainable Land Management Programme
SME – small- and medium-scale enterprise
SNNPR – Southern Nations, Nationalities and Peoples' Region
SOC – soil organic carbon
TERI - The Energy and Ressource Insitute
TLUD – Top Lit Up Draft
UNEP - United Nations Environment Programme
USFS – United States Forest Service
WIYA - Women Innovators of the Year Award

1 Introduction to biochar experiences in Ethiopia

It has been demonstrated that biochar is a promising tool for climate smart agriculture with manifold positive effects on crop productivity, soil fertility, biogenic waste management, energy supply and carbon sequestration (see report 1). It is necessary to consider biochar not as a soil amendment that is applied purely, but rather to grasp it as one component of a sustainable circular bioeconomy production system. The implementation of biochar technology can only be successful when the interrelationships of feedstock availability, production technology, use of process energy, cropping system, cascade usage options, combination with other soil amendments, business models and policies is taken into account. Yet, this systemic approach has not been put into practice in Ethiopia entirely, and a well-functioning biochar system thus cannot be found. However, some actors have brought up promising ideas and technologies and they are ready to establish their biochar or bone char models. Several Ethiopian research institutions have already started to investigate the impacts of this technology on crop production and soil fertility. However, these are scattered over the country and a conclusive picture cannot be drawn, yet.

Therefore, the aim of this report is to gather and evaluate all available information on scientific and practical biochar activities in Ethiopia (figure 1), and to draw conclusions for further implementations of biochar systems in Ethiopia. The compilation of these activities will elucidate the chances and challenges, that biochar systems are facing or might face in the

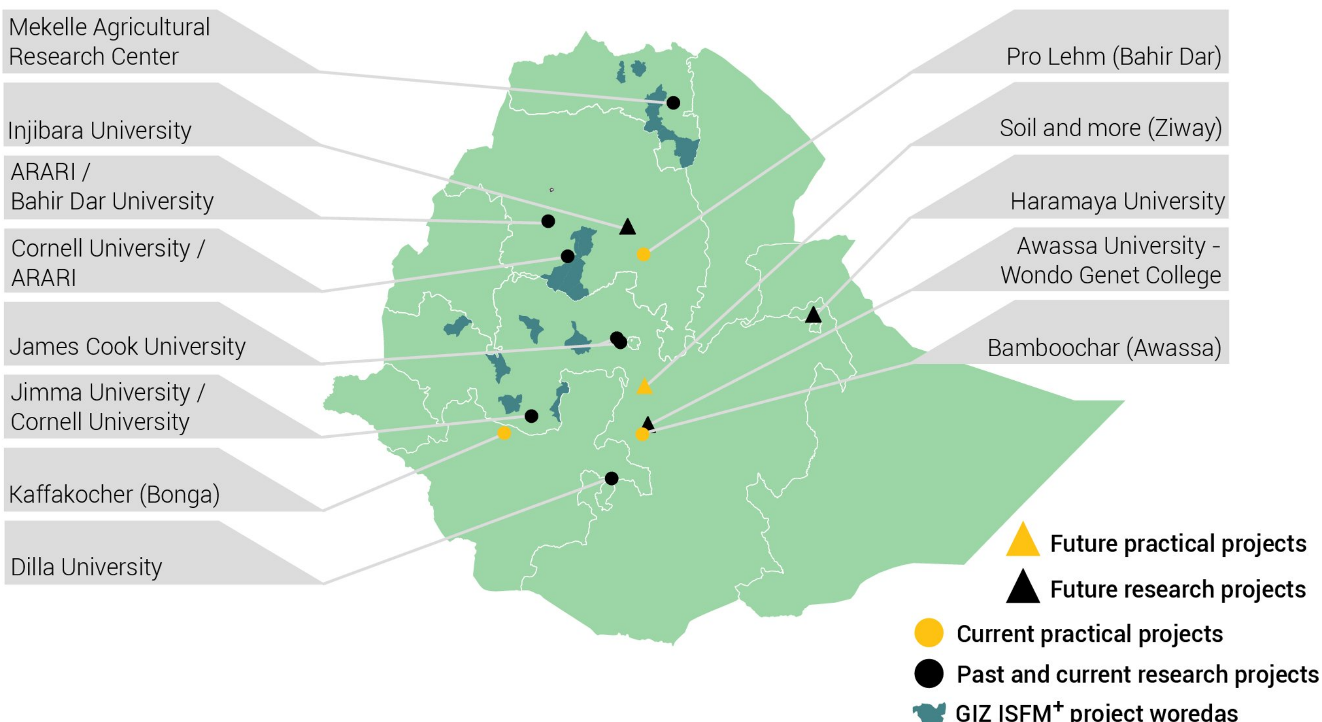

Figure 1. Outline map with compilation of biochar activities in Ethiopia

future. Subsequently, we present a selection of the most promising feedstock sources, with an expert based quantification of their potential resources. Based on these information, we will give an overview of potential biochar systems; from household scale to industrial production. This will lead to a better understanding of the opportunities for biochar systems in Ethiopia.

2. Synopsis of biochar activities and evaluation of obtained results

2.1. Scientific perspective

An overview of recent biochar research in Ethiopia is given in Table 2 of Report 1. In this section, we evaluate obtained results of available scientific biochar projects in Ethiopia.

2.1.1 Jimma-Cornell-Group

In recent years, Jimma University has collaborated intensively with Cornell University (USA), and has gained a leading role in Ethiopian biochar research. Their joint program called ''Indigenous Bio-Fertilizer Development for Agro-Ecological Intensification of Sustainable Enset Legume Cereal Production in South and Southwestern Ethiopian Smallholder Farming System'' has included many activities on different subjects around biochar, addressing the following objectives:

1. Identify opportunities to restock soils with nutrients and carbon from non-competitive residues and wastes from agricultural and agro-industrial sources.
2. Develop indigenous and low-cost alternative fertilizers and soil conditioners targeting specific production constraints.
3. Provide a proof-of-concept for a recapitalization of soil fertility using local nutrient sources.
4. Develop an appropriate technology for the production, packaging and delivery of indigenous fertilizers for small-scale farmers.

A central activity of the group, in the early stage, was to detect the most promising feedstock sources in the region for biochar production. This was done by a review of secondary data and a socio-economic household and agro-industry waste streams survey. The survey included detailed questionnaires to assess the locally available biomass resources and their competitive uses, the farmer's perception towards these resources and their willingness to pay for so-called indigenous fertilizers, that are based on biochar and bone char. Initially, the group's activities were directed to establish a biochar system. But their biomass-assessment found a huge potential for animal bones as feedstock. However, the char obtained from bones must not be called biochar, but "bone char", since it consists mainly of tricalcium phosphate and not carbon. Apart from animal bones, their assessment mainly stressed the potential of coffee husks, but also sawdust, *Prosopis juliflora* and sugar cane residues as feedstock. Further details on biomass availability from this study are given in section 3.1. Their survey also revealed that for Jimma area only 13% of farmers were not willing to pay for any fertilizer.

Table 1. Macronutrient contents of biochar and biochar-based indigenous fertilizers from Jimma-Cornell Group (derived from internal report)

Indigenous Bio-fertilizer	N	P	K	Ca	Mg	S
	mg kg⁻¹					
Coffee husk biochar	14.6	497.5	10549.5	1485.9	603.7	835.1
P. juliflora biochar	13.7	228.6	6218.7	1482.7	124.6	254.2
Bone char	14.7	5088.8	389.9	23683.1	2363.0	102.7
Coffee husk biochar-compost mix[1]	21.7	3408.6	5296.2	7197.8	1636.1	138.0
Sawdust biochar-bone char mix[2]	13.2	4268.7	5109.5	18624.9	2078.5	24.9
P. juliflora biochar-compost mix[3]	16.1	9349.3	3884.7	11428.8	2545.8	350.9
Jimma-biochar-based indigenous fertilizer mix[4]	19.2	2519.0	5085.9	7768.9	1841.7	225.0
Awassa-biochar-based indigenous fertilizer mix[5]	14.6	3167.9	3916.3	10568.9	2455.6	485.8

[1]Coffe husk biochar mixed and cocomposted with coffee husk, farm yard and chicken manure. [2]Sawdust biochar co-pyrolyzed and composted with bone char. [3] *P. juliflora* biochar mixed and co-composted with sugarcane, farm yard and chicken manure. [4] Coffee husk biochar, coffee husk, farm yard and chicken manure compost, ash and bone meal co-composted. [5] *P. juliflora* biochar, sugarcane, farm yard and chicken manure compost, ash and bone meal co-composted

Among those who are willing to pay for fertilizers 62% would prefer a combination of inorganic and organic fertilizers. For Awassa area the willingness to pay for a combined fertilization is even higher (70%). They also observed that most farmers used only one third of the recommended amount of mineral fertilizers, if they used fertilizers at all. From this assessment the group developed several so called “indigenous bio-fertilizers” and characterized them by their nutrient content (table 1). Substrates that contained bone char or bone meal had an outstanding P content, compared to the others. Now, having the idea of a bone char based P-fertilizer, the group calculated that the average livestock herd kept in Ethiopia between 2008 and 2011, could provide between 17,291 and 36,272 tonnes of phosphorus for plant uptake per year (table 4), by converting their bones into char. This could substitute up to 58% of the Ethiopian P fertilizer consumption every year, if every single bone from slaughtered animals in Ethiopia is used for bone char production.

In on-farm field trials, their biochar-based indigenous fertilizers, which was made out of biochar from *P. juliflora*, compost, bone meal, ash and additional NPK fertilizer, was the only treatment that significantly increased crop yields compared to conventional fertilizer use (figure 2). This underlines one more time the need to combine biochar with other soil amendments to achieve clear yield improvements. The biochar used in their experiments had been produced by a research-

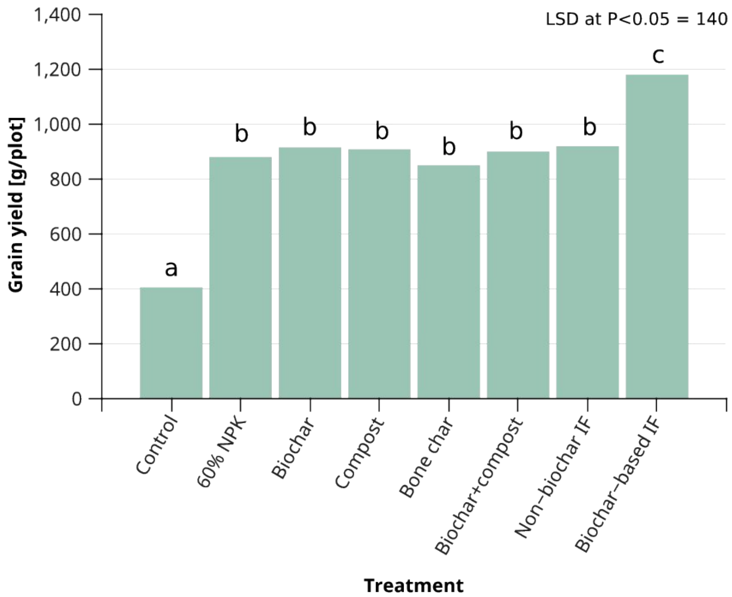

Figure 2. Maize yield of on- farm field plot trials of Jimma-Cornell Group (taken from internal report)

grade pyrolysis unit manufactured at Cornell University. The merits of their activities was a series of commercial indigenous bio-fertilizers called Abyssinia Phosphorous (figure 3), which they plan to put on the commercial fertilizer market.

Within the groups efforts for local capacity building was also the plan to design, fabricate, test and distribute improved fuel-efficient cookstoves for clean cooking and for the production of biochar, which could be used for home-made indigenous fertilizer. Several types of cookstoves have been developed at Jimma University (see Report 1, section 3.3), however, on a field demonstration during a biochar workshop at Jimma University in June 2016, local cookers failed to use the cookstoves as intended by the researchers. For local cookers it seems to be a bigger challenge to shift their cooking habits according to the new stove's requirements, than most researchers and designers have expected. Therefore, the adoption of improved cookstoves is a common problem of such projects around the globe (Global Alliance for Clean Cookstoves 2011, Jeuland et al. 2013, GIZ 2014a, Palit and Bhattacharyya 2014, Thacker, Barger and Mattson, 2014, Dickinson et al. 2015) and conclusively Prof. Johannes Lehmann from the Jimma-Cornell-Group stated on the workshop at Jimma that the stove design remains a key-challenge for their project.

Cornell did not only collaborate with Jimma, but also with the University of Bahir Dar and Amhara Regional Agriculture Research Institute (ARARI). In a joint study, they observed the effect of different biochars on water retention and hydraulic conductivity of very clayey soils in the Anjeni watershed, that are affected by waterlogging (Bayabil et al. 2015). The biochars were obtained from Acacia (*Acacia abyssinica*), Croton (*Croton macrostachyus*), Eucalyptus (*Eucalyptus camaladulensis*), Oak (*Quercus*) and Maize (*Zea mays*) by charring them in the local way or in a research pyrolyser at 450°C. The only relevant observations were that wood biochars significantly decreased soil moisture content at low pF-values (pF 2 and 2.4) (low water potentials) and that the same increased hydraulic conductivity, due to coarser particle sizes. The use of these woods as feedstock is not recommendable in Ethiopia for ecological reasons, nor is it to produce biochar in the same way as charcoal is being produced.

Also Jimma published some studies on their own. Dume et al. (2015) compared biochars

Figure 3. Commercial indigenous bio-fertilizer products called "Abyssinia Phosphorous" from Jimma-Cornell Group (Copyright: Berhanu Belay)

made from coffee husks and corn cobs at two different pyrolysis temperatures (350 °C and 500 °C) with a research pyrolysis unit. Both feedstocks can be a sustainable source for biochar production in the area. Their results regarding soil amendment effects are:

- Every biochar treatment increased soil pH, SOC and total N at every application rate (5 t, 10 t and 15 t ha^{-1}) compared to the control. The highest increases for pH (from 5.2 to 6.1) and SOC (from 3.70% to 6.69%) were achieved with an application rate of 15 t ha^{-1}
- Available P was mainly increased by biochars derived from higher pyrolysis temperatures.
- Coffee husks biochar tended to have a bigger effect on soil properties than corn cob biochar.

Most of these findings concur with an earlier study from Jimma, which observed that pH, SOC, total N and available P was significantly increased by applying 10 t ha^{-1} of maize stalk biochar pyrolysed at 500°C with the same research unit (Nigussie et al. 2012). In most cases, also 5 t ha^{-1} led to significant improvements of the same soil properties. Further on, they found that biochar can significantly improve the plant uptake of N, P and K and reduce the uptake of harmful Cr in a pot experiment with soil from a Nitisol.

2.1.2 James cook university (australia)

Other universities and institutes have also been working on biochar, however, not within such a large scale project as Jimma and Cornell. A research group from James Cook University (Queensland, Australia) has been working on organic fertilizers, including biochar and their effect on soil properties of an Eutric Nitisol and the performance of barley in Ethiopia (Agegnehu et al. 2016a, Agegnehu et al. 2016b). The group used biochar that has been produced as ordinary charcoal from acacia, in traditional earth kilns, which does neither represent a sustainable feedstock, nor a sustainable way of production. Fortunately, Agegnehu et al. (2016a, b) did not only compare pure biochar and compost with inorganic fertilizers but also tested a mix of biochar and compost and co-composted biochar, with a gravimetric biochar content of 17%. In this study, all inorganic and organic amendments increased yields significantly and organic amendments were sometimes even higher. But the highest yields

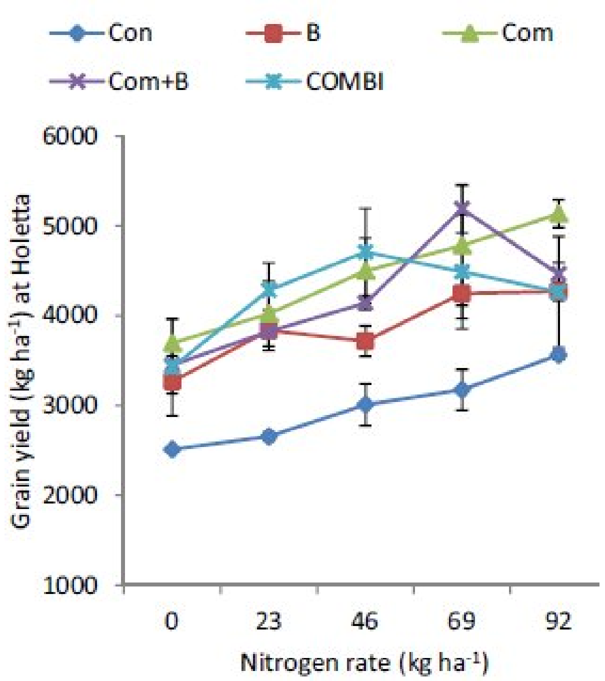

Figure 4. Barley grain yield as influenced by the interaction of organic amendment and N fertilizer rate at Holetta (taken from Agegnehu et al. 2016a). Con: control, B: biochar, Com: compost, Com+B: compost mixed with biochar, COMBI: co-composted biochar.

were achieved when organic and inorganic fertilizers were combined with each other (figure 4). Regarding the impact on soil conditions, organic amendments had a clear advantage over inorganic ones. Almost all organic amendments increased soil pH significantly, whereas inorganic ones did not. The biggest changes were achieved by 10 t ha^{-1} of pure biochar (from pH 4.85 to 5.37). The same was found for SOC content, which was even decreased by some inorganic fertilizers (Agegnehu et al. 2016a). Another remarkably positive effect of organic amendments were their effect on soil water content after harvest, which remained unaltered by inorganic soil amendments. The highest value was achieved by 10 t ha^{-1} of pure biochar with 49%, compared to the control with 38% (Agegnehu et al. 2016a). This property is of special interest in a country like Ethiopia, where water is rare after the rain season, since it will promote the germination of new seeds. Regarding nitrogen use efficiency, the group's results demonstrate a clear advantage of biochar. Pure biochar treatments achieved an apparent recovery efficiency (increase in N uptake per unit of N applied, ARE) of 50% at a fertilizer rate of 69 kg N ha^{-1}, whereas all other treatments have an ARE below 40%. Also the agronomic efficiency (yield increase per unit of N applied) significantly increased by biochar treatments, especially at low fertilizer rates (Agegnehu et al. 2016b). These findings underpin the potential of biochar to improve the efficiency of inorganic fertilizers and to contribute to the success of large-scale fertilizer projects such as EthioSIS[1].

2.1.3 Mekelle Agricultural Research Centre

A pilot pot experiment, which observed the effect of biochar, compost, and their mixture combined with mineral fertilizers on soil properties and the yield of wheat was conducted at the Mekelle Agricultural Research Centre, Tigray (Gebremedhin et al. 2015). The feedstock for the biochar was *P. juliflora*, which is very suitable, since it is an invasive tree in the Eastern part of the country. However, the biochar has been produced in the local way as charcoal, which is not recommendable. Since the test soil was already alkaline (pH 8.1), it is no surprise that biochar did not have a liming effect. But very puzzling is the observation that neither biochar (4 t ha^{-1}), nor compost (7 t ha^{-1}), nor their combination (2t biochar + 3.5 t compost ha^{-1}) could increase the SOC and the CEC compared to the mineral fertilizer treatment (100 kg urea + 100 kg DAP). However, grain yield was significantly increased (+16%) by the combination of biochar and mineral fertilizers. Even though the researchers infringed basic scientific principles, this outcome concurs with other findings mentioned above.

2.1.4 Dilla university

According to a paper by Berihun et al. (2017), farmers around Dilla recently started to use biochar as a cheap and readily available lime supplement. A small survey among 50 farmers revealed, that they were using various kinds of feedstock to produce biochar: maize cobs, barley straw, wheat straw, pea straw, bean straw, Lantana camara, Eucalyptus globulus and

[1] The Ethiopian Soil Information System (EthioSIS) project gathers and analyzes soil samples from each of the country's 18,000 agricultural kebeles to develop soil fertility maps and fertilizer recommendations for each region.

Bamboo. Mostly, however, they used *E. globulus*, *L. camara* and maize cobs, in descending order. Unfortunately, no information is available on the agronomic impacts of these biochars and how the farmers got aware of this technology. The study itself investigated the effect of biochar from *E. globulus, L. camara* and maize cobs on physical and chemical soil properties of an acidic Nitisol. All biochars significantly decreased bulk density and increased porosity at every application rate (6, 12, 16 t ha^{-1}). Moreover, every biochar treatment significantly increased pH, SOC and available P. Total N and K were only increased by application rates of 12 and 16 t ha^{-1}, and exchangeable acidity only by 16 t ha^{-1} independent of the type of feedstock. The researchers, and presumably also the farmers, produced their biochar in traditional earth mounds, which restricts the efficiency and sustainability of this biochar production.

2.1.5 Amhara regional agriculture research institute

The Amhara Regional Agriculture Research Institute (ARARI) has published a paper on the effects of biochar on soil conditions and the yield of teff (*Eragrostis teff*), Ethiopias most important crop (Abewa et al. 2013). In their study, ordinary charcoal from eucalyptus (*E. globulus*) produced in traditional earth kilns served as biochar, which does neither represent a sustainable feedstock, nor a sustainable way of production. The group observed the highest yields for each biochar rate (4, 8 and 12 t ha^{-1}) when it was combined with 60 kg N ha^{-1}.

2.1.6 Addis abeba university

Recently also Addis Ababa University has launched research on biochar and soil fertility. They investigated the carbon sequestration potential and the effect on soil conditions of two different feedstock types (rice husks and maize straw) and different pyrolysis temperatures (Tesfamichael and Gesesse, unpubl.). However, the results are not available, yet.

Box 1 - Summary of scientific activties

In Ethiopia, various universities and research groups are involved in biochar research. Their studies show clearly that biochar, in combination with other organic and inorganic fertilizers, has the potential to substitute mineral fertilizers and to overcome serious soil constraints. Even application rates of <10 t ha^{-1} significantly reduced acidification and SOC depletion in Ethiopian soils. The results demonstrate that biochar substrates are an excellent nutrient carrier that increase the availability of nutrients and reduces nutrient losses. Furthermore, the studies have identified several non-competitive feedstock sources that can improve waste management and biomass use efficiency, such as animal bones, *Prosopis juliflora*, or coffee husks. However, all of these studies lack an appropriate production technology, that is affordable and fits the needs of either rural households or small- and medium-scale enterprises (SMEs). Studies that investigate potential barriers related to this new technology and farmers perceptions are still missing.

2.2 Practical perspective

2.2.1 Kaffakocher

At Kafa area around Bonga (SNNPR) a project called "Kaffakocher" has been established by a Swiss consortium of two companies, called Kaskad-e GmbH and bonnepomme (kaffakocher.ch). Their aim is to improve livelihoods and health of local people and to reduce deforestation and CO_2 emissions by using clean and fuel-efficient gasifier cookstoves. These stoves are fed with coffee husks from dry processing units in the area. The project cooperates with the Kafa Forest Coffee Farmers Cooperatives Union, which represents 30 coffee cooperatives in the area and runs a dry processing unit on its own. Within the project, a pyrolysis cookstove has been developed for the use of loose sun-dried coffee husks as fuel and for baking injera (figure 5). They have been developed based on the gasifier "PyroCook" developed by Kaskad-e GmbH and are based on a Top Lit Up Draft (TLUD) principle. However, it is still under development. These clean burning and fuel-efficient stoves decrease the amount of fuel and also indoor air pollution, compared to traditional three stone stoves (Roth 2011, Martin et al. 2013). In workshops the project wants to train local craftsmen to manufacture these stoves and to distribute them independently. The biochar is intended to be co-composted and subsequently applied to the farmers fields.

Figure 5. Burning Prototype 1 from Kaffakocher (Copyright: Nadine Guthapfel)

The first phase of the project has been completed and the project has faced several barriers for the implementation of their biochar system. The biggest issue is the stove technology. For more than 3 years, the group around Stephan Gutzwiller has been working with support from international gasifier experts, such as Christa Roth, to develop a proper stove model. However, technology adaptation remained challenging and results remained unsatisfactory until the end. Loose coffee husks turned out to be very variable depending on the climate and the time of the year, therefore a fan for forced draft was necessary. Furthermore, the cookstove could not completely fulfill all the expected requirements of a proper stove so far. In addition, user acceptance is lacking, e.g. due to complicated handling or shorter burning duration. Currently, a stove model for injera baking exists, using a traditional Mirt stove as outer cylinder of the stove and a fan for forced draft. Further adaptations might be possible. For additional simplifications, using a stove model with natural draft, pelleting of the coffee husk is required.

Apart from technical challenges, the coffee farmers in the project area do not have SOC depleted soils. The traditional forest coffee and semi-forest coffee cropping systems are quite sustainable agroforestry systems that return a lot of organic matter to the soils and conserve their fertility (Gole 2015). Consequently, the soils have little potential to be improved by biochar, and farmers are not interested in it. For these reasons, the project has not conducted any agronomic pilot trials to demonstrate their biochar-compost-concept to farmers, yet. But a follow-up project is being prepared that intends to intensify their agronomic activities.

2.2.2 Pro lehm - marius bierig

Another private entrepreneur is Marius Bierig who runs the company *Pro Lehm* (Germany) and has been developing different gasifier stoves from clay and recycled materials in Ethiopia for more than four years. He has been working in Addis Abeba and, since 2014, also in Barhar Dar. His recent activities are embedded in a project of Welthungerhilfe. They have established a workshop to train locals in manufacturing different types of clay gasifiers, and they have supervised ten test households in using them and producing biochar. A *Wot*-gasifier has been developed for cooking and a *Mirt*-gasifier for baking Injera. The latter, however, still needs modifications. Unfortunately, a detailed evaluation of these activities and biochar quality test results are not available, yet. According to Marius Bierig, clay stoves are cheap, easy and fast to produce, very fuel-efficient and clean-burning. Moreover, they have calculated all expenses and revenues of their stoves and have developed a profitable business model. So far, the project has been working with eucalyptus wood as feedstock, which should be reconsidered, since one great advantage of gasifier technologies is their ability to burn different types of organic materials. The clay gasifier stoves of *Pro Lehm* seem to be one of the most promising technologies for a houshold-scale production of biochar. And the inventors are eager to continue their work in the longer term and to move the development of well-working stoves forward. Agronomic pilot trials with biochar were not included in their activities, but eventually in a follow-up project in the future.

2.2.3 Bamboochar - tarikayehu gebresilassie

At Awassa, one biochar project already runs a medium-scale pyrolysis unit and produces biochar. It is a private entrepreneur called Tarikayehu Gebresilassie, who has launched her own enterprise with biofertilizers, and who won the Women Innovators of the Year Award (WIYA) 2015. She produces approx. 100 kg of biochar per day from bamboo in a furnace that she has built on her own (figure 6), and also bamboo vinegar for soap production. Her products are sold at several bio-fertilizer hubs in the country, which have been financed and installed by LIFT[2] (Land Investment for Transformation) Ethiopia. Apart from that, she sells her products privately and plans to cooperate with the Agricultural Regional Bureau of Awassa. However, the biggest challenges she faces are limited funds, lack of people's awareness of the topic and trained

[2] Land Investment for Transformation (LIFT) is a project being implemented under the Ministry of Agriculture of the Government of Ethiopia by DAI Europe and Nathan Associates. LIFT aims to improve the incomes of the rural poor and to enhance economic growth through second level land certification (SLLC), improved rural land administration and the development of the rural land market system following the M4P approach. LIFT will distribute 14 million second level land certificates to small rural landholders in 5.5 years.

manpower. So far, she did not have the capacities to assess the agricultural potential of her biochar in pilot field trials.

2.2.4 African briquet factory PLC

Since 2011 the African Briquet Factory PLC produces briquettes from different agricultural residues, such as coffee husks, maize stalks, bagasse, peanut pods, etc.. These briquettes are a sustainable and environmentally friendly energy source that is being used in different industries, such as textile, leather, soap production, cement, paper and others. Earlier activities of the company were directed to gasifier stoves for households and small- and medium-scale enterprises (SMEs). They have developed their own stove models for that purpose, which are still running in approximately ten SMEs. This business, however, was not profitable and the company stopped their activities. There is no information available on the use of the resulting biochar.

2.2.5 Slopefarming

In 2015, the Hamburg University of Technology (Germany) in cooperation with the Arba Minch University (Ethiopia) has set up the *Slopefarming* project. They will develop a holistic approach regarding the restoration of degraded soils and ecosystems. Different measures will be set into practice in order to tackle the deterioration of arable land by soil erosion and degradation, which is caused by non-adapted conventional agricultural practice and the destruction of natural vegetation. Among these measures are rain water harvesting, agroforestry

Figure 6. Furnace for biochar production from bamboo (Copyright: Tarikayehu Gebresilassie)

and silvopastoral systems, but also gasifier cookstoves and a Terra Preta Sanitation system, that combines composting of faeces, biochar and other organic wastes. The feedstock for biochar production in the stoves is sawdust from nearby sawmills. Still, their stove model is under development and results from agronomic trials are not available, yet.

2.3 Other suitable institutions and opportunities

In Ethiopia, many present activities are dealing with soil protection, climate-smart and sustainable agriculture, efficient use of natural ressources, and rural development in general. Since biochar can be a promising complement for such projects, some of them are already planning to establish biochar systems. Others, that provide good preconditions for this technology, have indicated their interest.

Box 2 - Summary of practical activities

Little experience has been gained in the practical application of biochar in Ethiopia, yet. Those pioneers who try to establish biochar systems face numerous barriers in their activities. The most important ones are:

- Lack of awareness and knowledge of farmers about biochar
- Inappropriate production technologies
- Limited capital and high investment costs
- Low demand for biochar on the market
- Missing support from public institutions
- Lack of guidelines and standards

Practical activities using biochar as soil conditioner are rare in Ethiopia. Generally, these activities are carried out by non-governmental organizations or private entrepreneurs. Public projects with biochar have not been established, so far. There are no projects that have been running continuously for a long time.

2.3.1. German Gesellschaft für internationale Zusammenarbeit (GIZ)

The German Gesellschaft für internationale Zusammenarbeit (GIZ) is an important player in agricultural development projects in Ethiopia. The Integrated Soil Fertility Management (ISFM+) project is a component of the GIZ contribution to the joint Sustainable Land Management (SLM) program of the Ethiopian Ministry of Agriculture and Natural Ressources (MoANR). It promotes integrated soil fertility management approaches and practices in rural areas in Tigray, Amhara and Oromia on 57,000 ha. Yet, biochar is not a tool within its basket of soil fertility enhancing techniques, but it may become in the future, provided following prerequisites are met:

1) Proof-of-concept that biochar increases yields and income.
2) Possibility of on-farm production of biochar, based on locally available and non-competitive feedstock.
3) No or only little extra labour and costs connected to biochar for farmers and rural households, e.g. through the use of cookstoves that produce biochar as a by-product.

Not only that biochar systems fit the objectives of ISFM+ perfectly, but also other reasons make the project a potential collaborator for the establishment of biochar systems. Its large action radius gives the possibility to identify those farmers who have the most depleted soils, which have the highest potential to be upgraded by biochar. Its suite of soil-enhancing techniques allows to combine biochar with different practices, such as compost, urine collection or minimum tillage. The project is closely connected to the MoANR, Regional Agricultural Research Institutes (RARIs) and, most importantly, to the country's extension system, which can promote the use of biochar among farming communities all over the country. The operational plan of the project is based on a participatory learning cycle, and underlines the importance of knowledge and capacity building with methods, including model farmers, field demonstrations, training manuals and awareness creation materials.

Apart from the SLM program, there is another program from GIZ that might be beneficial for the implementation of biochar systems. The Energising Development (EnDev) program includes the dissemination of improved cookstoves (ICSs) to reduce fuel consumption by raising awareness and establishing a network of stove producers. In several regions, the program trains around 500 artisans in producing different types of ICSs. If an appropriate biochar producing gasifier stove is available, their network could contribute to a broad dissemination of these stoves.

2.3.2 Soil and more ethiopia

Soil and More Ethiopia is a for profit private company engaged in environmentally and socially sound business. Their focus is on the establishment of large scale composting sites and technology transfer. It is a social entrepreneur company that strives to promote sustainable and climate-smart agriculture from grass root level through addressing the issue of input and knowledge gap. The company runs a commercial compost production site at Ziway. The feedstock for compost production are flower residues from nearby flower farms. Around 20% of the flower residues they receive are hard-to-compost rootstocks and they accumulate on their compound. A rough estimation, based on internal intake-data from March to September 2016, accounts for a weekly average of 150 tonnes of non-compostable biomass (fresh matter). The company plans to use this biomass for biochar production and to combine it with their compost, to create a commercial organic fertilizer substrate. Yet, they lack appropriate partners, qualified staff and fundings for the production of biochar. The constant stream of non-competitive residues from flower farms would allow for a large-scale pyrolysis unit. A feasible option to use the process energy of a pyrolysis plant has not been identified, yet.

Apparent from their activities at Ziway, they have signed a contract with LIFT to establish 30 compost hubs within 15 months that will produce and distribute compost products in the four project regions (Oromia, Amhara, Tigray and SNNPR). Their activities include trainings of hub owners and demonstrations for farmers. Soil and More International has a compost management license that allows to use the following feedstocks for composting: woodchips, shredded cardboard / paper, straw, leaves, grasses, harvest residuals, waste fruit, peels, pulps, cow, chicken and other manure, but no municipal waste or slurry, nor pig and hog manure (Soil and More 2016). As potential suppliers for biomass the organization has identified farms, agricultural and animal husbandry industries, processing industries and municipalities, private and public organizations. Due to this network and their focus on tailor-made business plans, Soil and More Ethiopia can be an excellent partner for the establishment of a medium or large-scale biochar system.

2.3.3 Awassa university

In march 2017, the *Forschungszentrum Jülich* (Germany), in collaboration with the Awassa University (Ethiopia), has approved a 4-years project that aims at building capacities in climate-smart agriculture and ecological sanitation of human faecals by the use of compost and biochar. The project will establish an experimental farm at Wondo Genet College of Forestry and Natural Resources, that serves as both, research site and training center for local farmers. The project will evaluate suitable feedstock sources and options to combine biochar with compost. The biochar will be produced in clay cookstoves, in cooperation with *Pro Lehm* (see section 2.2.2).

2.3.4 Injibara university

The newly founded Injibara University in the Amhara regional state plans to establish a biochar research program connected to the local production of charcoal and the cultivation of acacia trees. The president of the university, Prof. Berhanu Belay, has been a main promoter of the biochar programme at Jimma University, before. In the area of Injibara, the production of charcoal and the supply to the central market at Addis Abeba is a common practice. The fines and leftovers of the charring are applied to the soil and farmers are aware of the positive impact that the char has on soil fertility and crop productivity. Acacia, which is the preferred species for charcoal making, is cultivated in nurseries, transplanted to fields and cut at the age of 4-5 years for charcoal production (figure 7). The focus for biochar application to soils will be on high value crops such as vegetables and fruits. The university wants to conduct a systematic value chain analysis of charcoal from seed collection to charcoal selling at the central market in Addis Ababa, and investigate the role of charcoal fines as soil amendment and crop productivity enhancement. Further on, they want to assess the complementary and competitive aspects of charcoal being used as fuel or as soil amendment. Since these charcoal fines are a non-competitive byproduct, and there is no deforestation caused by the charcoal production, this biochar source seems to be sustainable. However, efforts should be made to combine the biochar application with other soil amendments and to develop an appropriate pyrolysis technology, in order not to promote the environmental pollution of traditional charcoal production with earth kilns (figure 7).

2.3.5 Haramaya university

Haramaya University has been working on vermicompost and plans to establish a new biochar technology center on their main campus. The biochar research group wants to

Figure 7. Left: Mound of acacia stems for charcoal production. Right: Smoke emissions during traditional charcoal production. (Copyright: Berhanu Belay)

address following objectives:

1) Produce various types of biochar from different organic waste streams and materials. Several biomass sources, including bones, maize cobs, animal manures, khat residues, *Lanthana camara*, paper wastes and *Parthenium* are found close to the campus and can be used for biochar production.
2) Provide biochar in quantities and qualities required for research purposes and the amendment of degraded soils, in order to serve as one of the most important component inputs for climate smart agriculture.
3) Contribute to environmental health and reduce emission of green house gases by converting organic wastes and materials into economically and environmentally useful materials.

Research activities are supposed to start in mid-2017. However, their work plan does not reveal which production technology they are going to install and which options there are to use the process energy.

2.3.6 Menschen für menschen

The German NGO *Menschen für Menschen* (MfM) has been working in Ethiopia since 1981 and strives to trigger a permanent and sustainable improvement of people's living conditions by using the principle of integrated rural development projects (IRDPs). These projects are initiated as long-term projects on Kebele or Woreda level, that run up to 17 years and that have five key areas: agriculture, water, health, education and income. The key areas are interlinked with each other and most measures within the project are connected to more than one area. Yet, biochar is not within their agricultural measures, but the organisation indicated that they are open to implement a biochar pilot project in one of their IRDPs. In general, MfM is a promising partner for the implementation of biochar pilot projects, since the principles if IRDPs guarantee a long-term and professional support of farmers. Other measures that are already applied in their projects, such as composting or improved cookstoves are important for potential biochar systems.

2.3.7 The climate foundation

The Climate Foundation is a non-profit organization based in the United States which has developed and tested a pyrolysis reactor for the production of biochar from human faeces in the USA and India. The reactor works independently from the electricity grid and can process faeces of about 2,000 persons per day. While the reactor was originally developed to overcome sanitation problems in urban areas in developing countries, the co-produced biochar could be used for energy and/or soil improvement applications. Although the Climate Foundation has not been working in Ethiopia yet, the organization is interested in testing its reactors in urban areas of Ethiopia.

It should be kept in mind that a large part of macronutrients (e.g. nitrogen and phosphorus) contained in human faeces is lost during pyrolysis (Fischer and Glaser 2012; Glaser 2015; Ippolito et al. 2015). For this reason, the use of composting or the

Table 2. Selected feedstock potentials for Ethiopia

Feedstock source	Feedstock potential [kilotonnes]
Houshold waste	high variation
Coffee husks	403
Flower waste	140
Sugar cane	3,148 – 4,206
P. juliflora	9,198 – 9,975
Sesame	236
Animal bones	192 – 330
Human feaces	75 (only Addis Abeba)

Table 3. Crop residues production [Qt] using crop residue ratios in 2012/13 from Jimma-Cornell Group (taken from internal report)

Type of crop residue	Jimma (n=150)		Awassa (n=200)	
	Mean	SD	Mean	SD
Coffee	0.7	0.4		
Maize	32.4	17.8	30.8	13.6
Chat	1.3	0.4	1.4	0.6
Fruits	7.5	3.8	7.4	3.7
Sugar cane	4.7	1.2	5.4	2.7
Tubers	14.6	4.6	15.1	4.3
Enset	4.9	1.3	5.0	1.5
Total	**67.1**	**19.3**	**65.2**	**15.3**

hydrothermal carbonization [HTC] technology should be preferred, if nutrient losses during faeces management shall be minimized. However, composting faeces is challenging in an urban agglomeration like Addis Abeba and the HTC technology has still to be adapted to the local infrastructure conditions. Besides that, the current status of human faeces management in Addis Abbeba offers a huge potential for improvements in terms of mitigation pollution risks and improving resource use efficiency.

3 General feedstock potentials

In the following sections, we estimate the total amounts of biomass residues from different sources and processes that are potentially available for the production of biochar in Ethiopia. The calculations are based on data from primary and secondary sources. Consequently, it is not a detailed survey, but rather an estimation of the order of magnitude of the potential of available biomass for biochar production. We are aware that there are numerous other feedstock sources that could be used for biochar production, but the selection below represents those, which are most promising from our point of view, and to the best of our current knowledge. The term "feedstock potential" is used as the total amount of biomass residues from one or more feedstock sources that can potentially be used for biochar production, no matter which other competitive uses this biomass might have at present. An overview of all feedstocks and their feedstock potentials is given in table 2.

3.1 Smallholder farms residues

Only few data are available to estimate reliably the feedstock potential of waste from rural households and smallholder farmers. In 2013, the Jimma-Cornell research group has conducted a survey, in order to quantify the average amount of crop residues and to identify their uses on farms. They have collected data from a total of 350 households around Jimma and Awassa. Since the amount of crop residues was not assessed directly but was calculated by crop residue ratios (CRRs) from literature, table 3 shows only a rough estimation of average crop residue production. The total amount of crop residues accounts for 6.7 t ha^{-1} and 6.5 t ha^{-1}

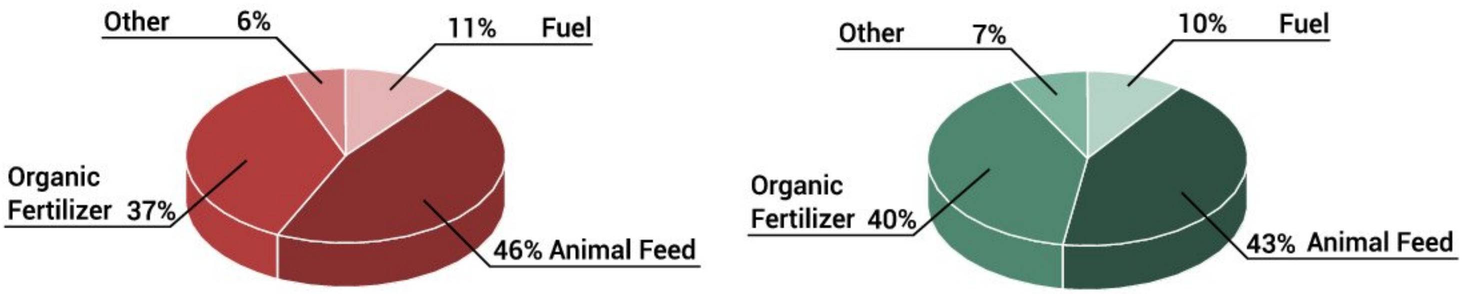

Figure 8. General uses of crop residues in Jimma area (left) and Awassa area (right) from Jimma-Cornell Group (derived from internal report)

annually for Jimma and Awassa area, respectively, with maize residues representing almost half of it. However, no crop residues are left as non-competitive waste. Mainly, they are used for feeding own animals (either collecting crop residues, or grazing animals on the fields after harvest), kitchen or household fuel, and soil fertility management (leaving crop residues in the fields as fertilizer, mulching or collecting biomass to apply as organic soil amendments). Figure 8 shows that in both areas more than 80% of crop residues are already being used for animal feed and organic fertilizer. Only few crop residues serve as fuel for cooking.

However, there are indications that the availability of this resource might differ considerably, dependent on the region. Peter Renner, a member of the executive committee of the German NGO *Menschen für Menschen* approved that within their IRDP communities, sufficient farm residues are available to launch a pilot project with pyrolysis cookstoves (Peter Renner, personal communication). Moreover, the survey of Berihun et al. (2017) showed that the straw of wheat, barley, peas and beans have other uses for rural households, but maize cobs were non-competitive in their project area.

3.2 Coffee residues

Generally, coffee residues, including pulp, mucilage and hull, are regarded as one of the most promising biomass sources. Box 3 shows common advantages that are related to the use of coffee residues as feedstock.

To estimate the total amount of coffee residues being produced in Ethiopia and, thus, its overall biochar feedstock potential, we used the official coffee yield from the Central Statistical Agency (CSA) of Ethiopia, that is assessed by farmers surveys. The total amount of dry coffee beans produced in Ethiopia on private peasant holdings accounted for 419,980 tonnes, and on commercial farms 79,971 tonnes, in the cropping season 2014/2015, which corresponds to an average yield of 7.4 Qt ha^{-1} on both farm types (CSA 2015a, CSA 2015b). The total amount of coffee production we obtained from the Ethiopia Commodity Exchange (ECX) was much lower. Therefore, we decided to use

Box 3 - Advantages of coffee residues as feedstock for biochar production

- Available in large parts of the country
- Centralized accumulation at coffee processing units
- Few competitive uses
- Constantly available
- Nutrient poor material

the data from CSA, in order to get the full picture and not just the legally traded share of it (ECX). To estimate the amount of coffee residues we assumed that beans constitute 55.6% of the coffee berry's weight (on DM basis), and the rest are residues (Brahan and Bressani 1987). Consequently, the overall feedstock potential of coffee residues in Ethiopia accounts for 402,488 tonnes or 5.9 Qt ha^{-1}. Detailed feedstock potentials for each region are given in appendix AI and AII. A big advantage of coffee husks is, that they are available in large parts of the country and that they are being produced throughout the year (at least for most dry processing units). Generally, there are few other uses for this biomass source, and many times, mounds of coffee husks decompose spontaneously and start to burn (figure 9). Recently, however, more actors became aware of it and some entrepreneurs started to tap this resource. The African Briquette Factory PLC, for example, produces briquettes from coffee husks, that can be used for industrial furnaces (see section 2.2.4). Since 2012, the Dilla Briquette Factory, that has been established by the Horn of Africa Regional Environment Center and Network (HoA-REC&N), produces between 1,800 and 5,400 tonnes of coffee husks briquettes per year (HoA-REC&N 2013).

Figure 9. Spontaneous composting and ignition of discarded coffee husks (Copyright: Nadine Guthapfel)

3.3 Animal bones

Ethiopian slaughterhouses produce huge amounts of animal bones that have no other use, than being dumped as waste. Also, small, local butchers would only discard these bones, making them a reliable biomass source being scattered all over the country and easily available. According to an article in *ensia* magazine, this biomass source could become a reliable income for young unemployed, who collect the bones and sell them to local producers of bone char fertilizers (Gewin 2016). The total potential of animal bones as feedstock for bone char production has been assessed by

Table 4. Total phosphorus in annual bone residues from slaughtered animals in Ethiopia (taken from Simons et al. 2014)

	Total no. of animals	Bone mass [kg per animal]	% of animals slaughtered [per year]	Bone residues [tonnes per year]	Total Phoshphorous [tonnes per year]
Cattle	50,283,000	20 - 30	16 - 17	160,908 – 256,447	
Sheep	23,642,000	4 - 5	19 - 34	17,968 – 40,192	
Goats	22,070,000	4 - 5	15 - 30	13,242 – 33,106	
Total	95,995,000			192,118 – 329,744	17,279 – 36,272

Simons et al. (2014) (table 4) and is estimated between 192,118 and 329,744 tonnes per year. Around 80% of these bones derive from cattle, and the rest from sheep and goats with almost equal shares. As outlined in section 2.1.1, char produced from bones is very well suited as a phosphorous fertilizer supplement.

3.4 Flower residues

Almost all Ethiopian flower farms are located in Oromia, where they are classified into different clusters, according to the altitude of their location. The amount of stems produced, as well as the amount of stems rejected vary significantly with respect to these clusters (appendix BI). It seems likely that the total amount of residues also varies for each cluster, however there is no data or information available to verify. The residues consist of rejected stems and flowers, but also uprooted rootstocks (figure 10). We received some production and reject data from the Ethiopian Horticulture Development Agency (EHDA) from 2013/14 and calculated the overall feedstock potential (appendix BII). According to their data the total amount of residues from flower production accounted for 6,415 tonnes, representing only rejected stems, but not rootstocks. Hence, discussing our results with experts from Soil and More Ethiopia revealed that the actual flower residues production must be much higher than our estimation. Therefore, we used the waste intake data from March to September 2016 from Soil and More Ethiopia and calculated the total amount of biomass they received on a weekly basis. Assuming that one truck load is around 10 tonnes, they received 856 tonnes of fresh flower residues every week. Consequently, the annual amount the company received accounted for 44,532 tonnes. Given that the flower farms that supplied Soil and More Ethiopia had 428 ha under cultivation, the average feedstock potential for flower residues per hectare and year is 104 tonnes. Ethiopian flower farms cultivated a total of 1,348 ha in the cropping season 2013/14 (EHDA data). Finally, the overall feedstock potential for flower residues accounts for 140,000 tonnes per year. It is important to emphasize that this is a rough estimation on basis of several generalizations.

Figure 10. Branches and rootstocks from rose flowers

3.5 Sugar cane residues

The amount of sugar cane grown on medium and large scale commercial farms is much bigger than sugar cane grown on smallholder farms. The commercial farms are directly connected to one of the six sugar factories in Ethiopia. On average, three of these factories produced 279,000 tonnes of sugar per year between 2003/04 to 2012/13 (Bayrau et al. 2014), the other three launched production after 2012/13. The total amount of sugar cane accounted for 6,748,000 tonnes in the cropping season 2011/12, with a share of 85% by commercial farms (Bayrau et al. 2014). Meanwhile, the production should be much higher, since three new sugar factories have started to work, but detailed data is not available.

The amount of bagasse produced per tonne of cane stalks processed can vary significantly, and depends on many factors, such as variety, growing area or pressing techniques (Hassuani et al. 2005, Valk 2014). Reliable crop residue ratios (CRR) for sugar cane in Ethiopia are missing. Therefore, we draw on an average proportion of bagasse of 29%, that is frequently found in literature (Hassuani et al. 2005, Valk 2014, Gebre et al. 2015) and is in line with a case study at Metehara Sugar Factory (Berhane, 2007). Consequently, the annual feedstock potential of bagasse accounted for 1,956,920 tonnes in 2011/12, but is much higher today, due to the expansion of sugar cane production. However, the proportion of bagasse that is available can not be estimated easily, since it is used in sugar factories for co-generation of heat and electricity.

Another by-product of sugar cane that may serve as feedstock, are cane tops that get chopped in the field during the harvest. In most cases they do not have a competitive use and get burned. Detailed information on the amount of cane tops is not available, for Ethiopia. On average, cane tops represent 15-25% of the cane's above ground biomass (Heuzé et al. 2016). Consequently, the feedstock potential of cane tops accounted for 1,190,823-2,249,333 tonnes in 2011/12.

Combining the feedstock potentials of bagasse and cane tops, the overall feedstock potential of sugar cane accounted for 3,147,743 – 4,206,253 tonnes in 2011/12. At present, the feedstock potential is probably much higher, but it is not clear, which amount might be available for biochar production, due to the co-generation of heat, as mentioned before.

3.6 Prosopis juliflora

The invasive species *P. juliflora* has spread to many areas of the Afar region. Yet, reliable reports are missing about the exact area covered by the tree, since it is a dynamic state, driven by fast expansion of the species and controlling measures against it. However, an estimation that has been adopted by several reports recently (e.g. GIZ 2014b), accounted for 700,000 ha in the Afar region (USFS 2006). The total amount of biochar that can be produced potentially from this area can not be predicted certainly. However, two different studies from USFS and Farm Africa calculated that from one hectare of *P. juliflora*, it is possible to yield 438 - 475 bags of charcoal, with each bag weighing around 30 kg (Admasu 2008, Wakie et al. 2012). According to these figures, the current stand of *P. juliflora* has the potential to produce between 9,198,000 and 9,975,000 tonnes of charcoal or biochar. However, it needs to be stressed that a total eradication of *P. juliflora* is neither possible, nor sustainable. A recent impact assessment by an Ethiopian-German research team emphasizes the need for a participatory management strategy that integrates local and

Figure 11. General uses of sesame straw at Metema area (left) and Humera area (right) (derived from Aregawi et al. 2013)

national institutions and that takes traditional knowledge and pastoral practices into account (Ilukor et al. 2016). Since charcoal production from *P. juliflora* threatens indigenous trees, which are (illegally) similarly cut, causes air pollution and brings benefit to only 18% of local households (Ilukor et al. 2016) (Appendix C), the authors advocate charcoal production only in selected areas. The same restrictions are probably valid for biochar production. The main uses of *P. juliflora* among Afar pastoral households are given in Appendix C.

3.7 Sesame

Sesame (*Sesamum indicum*) is mainly grown in Oromia, Amhara and Tigray regions, in descending order, regarding the cultivation area. For Ethiopia, a total of 420,491 ha are cropped with sesame. A recent study has conducted a household survey to investigate the amount of sesame straw and its competitive uses in two disctricts in Tigray and Amhara (Aregawi et al. 2013). According to their results, the straw yield was 5.6 Qt ha^{-1} in both districts and thus, much lower than an estimation by Gebresas et al. (2015), who assumed a straw yield of 20 Qt ha^{-1} in the same district, without elucidating the origin of that figure. Therefore, it is recommendable to draft on the conservative estimation of 5.6 Qt ha^{-1} by Aregawi et al. (2013). Using this amount, the overall feedstock potential of sesame in Ethiopia accounts for 235,475 tonnes per year. Apart from the amount of sesame straw, Aregawi et al. (2013) also found that 67.7% and 75.3% of these residues are not of any use to the farmers in both areas and get burned. Other uses of sesame straw are given in figure 11.

3.8 Human faeces

The availability of biomass feedstock for biochar production in the urban agglomeration of Addis Abeba is limited. However, the inhabitants of the capital (about 3.3 million people in 2016) produce about 75,000 tonnes (dry mass) of faeces every year (calculation based on data from Geselllschaft für ökologische Technolgie und Systemanalyse e.V. 2010). A large part of the faeces is currently being dumped in an open landfill. Since this existing waste management problem has to be solved for health and environmental reasons anyway, biochar production based on pyrolysis processes or hydrothermal carbonization might be a solution for this challenge, independent from the subsequent use of the produced pyrochar or hydrochar.

4 Schemes for biochar systems in Ethiopia

According to our investigations, a variety of biochar systems could potentially be established in Ethiopia. Several opportunities and challenges are connected to each biochar system. The most determining factor that distinguishes one biochar system from another, is from our point of view the scale of production. Therefore, we classified all biochar systems according to their scale of production and identified their most important characteristics (table 5).

4.1 Small-scale biochar systems

4.1.1 Technology, feedstock and biochar management

On a household level or for individual peasants, the only production unit that is feasible, is a pyrolysis or gasifier cookstove, with an annual production of up to 1 tonne per unit. Yet, a suitable cookstove technology is missing, but promising models are being developed by Jimma University, Marius Bierig (Pro Lehm) or Stephan Gutzwiller (Kaffakocher), and it is likely that in the near future a well-working model is available. Several household and farm residues are suitable as feedstock for the stoves: coffee husks, maize stalks and cobs, rice husks, sesame straw, peanut pods, etc.. Low investment costs, fuel savings and the combined use for cooking and biochar production, will lead to a fast amortization of the stove, depending on the prize of the stove. The biochar obtained can be mixed up or co-composted with other organic household waste or it can be used as litter in stables and applied with the manure to the field. Both will charge the biochar with nutrients and promote soil improvement and nutrient recycling.

4.1.2 Evaluation of regional suitability of biochar systems according to livelihood zones[3]

The suitability of small-scale biochar systems is highly dependent on several factors that are represented in the concept of livelihood zones (LZs). We have taken the livelihood zones defined by FAO (Medhin 2011) and have evaluated their suitability for biochar systems. Among the best-suited areas for small-scale biochar systems are the mixed LZs 7, 11, 13 and 14 (figure 12) of the central and eastern highlands. These LZs are characterized by relatively productive agro-ecological conditions, due to abundant precipitation and moderate temperatures. Especially in LZ 13 and LZ 14, however, long years of extractive forms of production, high population and livestock densities have led to advanced levels of soil degradation. The agricultural production in both LZs is based on a mixture of different crops and livestock. LZ 13 is dominated by cereal crops (mostly teff), pulses and oil crops, whereas LZ 14 is rather characterized by horticultural crops, such as enset, coffee, chat, root crops and fruits. In both cases a surplus of crop residues can be

[3] The objective of a livelihood mapping or zoning is to delineate coherent areas where people share broadly similar livelihood patterns – methods of food and other agricultural production, methods of securing other incomes, market systems, food consumption or preference habits, poverty levels, etc. In doing so, the delineated areas typically fall into biophysical (agro-climatic) and socio-economic (poverty/wealth) zones. Livelihood zoning thus creates an economic-geographical map that shows the varied contexts in which livelihoods are pursued. (Dittoh 2010).

expected and a combination of biochar with manure is possible. The cultivation of annual crops in these LZs provides a periodical source of feedstock, and the frequent tillage allows for a recurrent application of biochar substrate. In northern Ethiopia there are also good opportunities for biochar systems in the lowlands and midlands of LZ 1 and LZ 2. Especially LZ 2 is affected by low soil fertility and drought stress, which can be improved by biochar systems. However, there are few feedstock sources for biochar production in LZ 2. In LZ 1 the sesame cropping systems can provide a reliable feedstock source, since there is abundant other grazing and browsing for livestock. The cropping systems of the western coffee and maize livelihood system (LZ 5) have good preconditions for biochar systems, since their high productivity may lead to a surplus in biomass production. However, their relatively fertile soils may restrict the demand for further soil improving technologies, which is the case in

Table 5. Synopsis of potential biochar systems according to their production scale

Project Scale	Household Level	Small and Medium Enterprises Level	Large Scale Industrial Level
Production volume Per year and unit	< 1 tonne	< 100 tonnes	> 100 tonnes
Potential operators	Private households	Community kitchens, hotels, Bakeries, coffee roasteries	Sugar industry, municipal waste management companies, textile industry, breweries
Suitable biomass feedstock	Crop residues, household waste, coffee residues, Sesame straw	Crop residues (commercial farms), coffee residues, sesame straw, *P. juliflora*	Crop residues (commercial farms), processing residues, feaces, *P. juliflora*
Suitable process technology	Pyrolysis or gasification cookstoves	Medium scale pyrolysis units (e.g. Kontiki, Biomacon), medium scale gasifiers (e.g. Spanner Re²)	Large scale pyrolysis units (e.g. PYREG, Biomacon, PRO-Natura)
Heat usage options	Cooking	Cooking, drying, boiling, roasting	Boiling, fermentation, Pre-drying of faeces, bleaching
Biochar usage options	Soil improvement in gardens and smallholder farms	Soil improvement on smallholder farms, commercial bio-fertilizer, inoculant carrier	Soil improvement on large commercial farms, commercial bio-fertilizers, fertilizer blending
Advantages	Low investment, fuel and heat efficiency, health improvement	Efficient heat use	Efficient heat use, large Environmental impact
Disadvantages	Low impact in initial phase	Inefficient heat use (Kontiki), long transportation distances	long transportation distances
Challenges	Appropriate technology, farmers and cookers awareness and acceptance	Resource use efficiency (Kontiki), combination with other Organic amendments	High investement costs, infrastructure demands, technology adoption, maintenance, combination with other organic amendments, feedstock supply
Risks	Organic pollutants in Gasifier biochars	Organic pollutants in gasifier biochars	Unsustainable feedstock use
Potential Project Partners	Kaffakocher, Menschen für Menschen, GIZ, Pro Lehm	Soil and More, TERI, Moyee C offee, Tarikayehu Gebresilassie	Sugar corporate, Soil & More, Climate Foundation

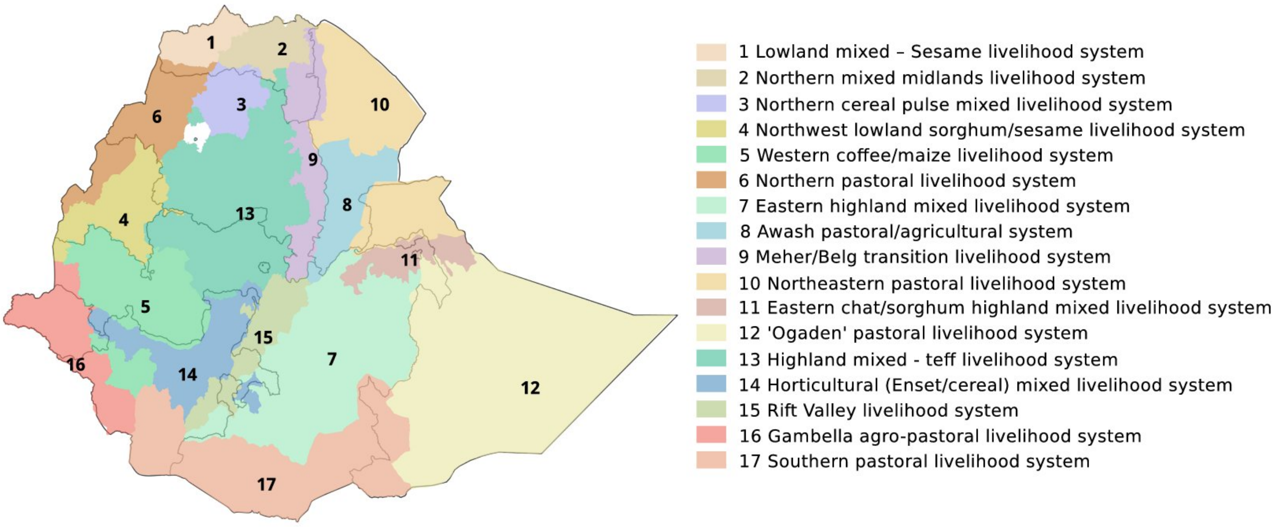

Figure 12. Ethiopia - Livelihoods zones for Agricultural Water Management (FAO 2011)

the Kaffakocher project.

4.1.3 Challenges

The biggest challenge in these biochar systems is the adoption of pyrolysis or gasifier cookstoves, which are not easy to introduce to rural communities (section 2.1.1 and 2.2.1). Moreover, the quality of the biochar is likely to vary and the risk of organic pollutants in the biochar can not be eliminated. Due to the capacity of the stove, the production of home-made biochar substrate is limited and the impact on a farmer's fields is weak, in early years, but the biochar will accumulate on the fields, year by year.

5.1.4 Potential partners

Many activities mentioned in section 2 aim at small-scale biochar systems. Consequently, there are a number of potential partners for these biochar systems: GIZ (ISFM+), Jimma University, Marius Bierig, *Kaffakocher* and *Menschen für Menschen*. All of them can contribute essentially to the success of a biochar project on small-scale production.

4.2 Medium-scale biochar systems

4.2.1 Production technology and identification of operators

Several technologies are available to produce biochar on a medium scale (up to 100 tonnes per year and unit). These technologies are mainly used in micro, small and medium enterprises (MSMEs) and the type of pyrolysis or gasification unit to be used is mainly dependent on the purpose of the process energy in the MSMEs. A very common purpose is the use of bigger gasification cookstoves for restaurants or community kitchens at universities, hospitals, prisons or other institutions. These bigger units are so-called institutional gasifier cookstoves. Jimma University has introduced several units of improved institutional cookstoves to their community kitchen, in order to reduce the air-pollution (figure 13). However, these were not gasifiers. The African Briquette Factory PLC has developed an institutional gasifier cookstove, that is currently used in 10 MSMEs. But evaluations of this model are not available.

Besides cooking, there are several other options to use the heat of medium-scale pyrolysis or gasification units in Ethiopia. The biggest potential is probably given in bakeries, coffee roasteries, textile or leather industries (dying processes) and hotels (hot water, swimming pool). These MSMEs could use e.g. a small pyrolysis unit from Biomacon.

The Energy and Ressource Insitute (TERI) (India) in cooperation with the Swiss Agency for Development and Cooperation has set up a program that aims to establish knowledge transfer with the private/public sector in target regions and to enable local manufacturing of biomass gasifiers for thermal applications in MSMEs (TERI 2014). On a stakeholder consultation workshop at Addis Abeba, an expert of TERI has stressed the experiences of the organization in using gasifiers for textile dying, rubber industries and foundries across India. And they have classified the MSME sector in Ethiopia into six clusters (TERI 2014), out of which only the Kirkos textile and leather cluster in Kirkos sub-city in Addis Ababa has a high potential for the introduction of gasifier technology, from our point of view. The other clusters mainly contain industries with little heat demand. However, TERI has not been engaged in biochar production and use, yet.

Kontiki kilns are also suitable for medium-scale production, but not within MSMEs. The lack of options to use the process energy, prevents its application for (semi)industrial purposes. However, its mobility and easy handling make it a convenient alternative in remote areas where large amounts of biomass accumulate without any options for thermal use nearby. This could be one component of fighting the *P. juliflora* invasion in the Afar region, for example. Also flower farms or coffee processing units could use Kontiki kilns to get rid of their residues. But still, the low resource use efficiency of Kontiki kilns should be improved to make this technology suitable in a country that suffers from deforestation and drought.

4.2.2 Potential feedstocks

Several feedstocks come into consideration for medium-scale production units. Institutional gasifier stoves can be fed with coffe husks, e.g. as briquettes, or other woody crop residues. Even if wood, as the traditional fuel, is kept on being used, this will be an improvement in

Figure 13. Indoor air-pollution by traditional stoves in the community kitchen of Jimma University and replacement by clean institutional cookstoves (Copyright: Ancha Venkata Ramayya)

terms of efficiency and CO_2 balance. Other pyrolysis or gasification units may draw on invasive species, like *P. juliflora*, woody crop residues, e.g. flower root stocks, or briquettes made from other crop residues, e.g. coffee husks.

4.2.3 Challenges

A big challenge of medium-scale biochar systems is the supply of feedstock. Most enterprises are located in urban areas, where most of the feedstock mentioned above is not available. Hence, feedstocks need to be transported from the site of creation to the individual MSME. On our request, some single enterprises estimated that transport costs for one truck are in the range of 2,000 to 4,000 ETB (83 – 166 €) per 100 km. Transportation costs even increase, since the biochar obtained, needs to be transported to rural areas where biochar is being used. Another challenge are high investment costs for pyrolysis technologies, which can not be born by most Ethiopian MSMEs.

4.2.4 End-user analysis

The biochar obtained from these enterprises is a well suited resource for commercial products, such as bio-fertilizers, that can be purchased by farmers or private gardeners. A business-model like that is being established within the frame of the LIFT programme, that cooperates with Tarikayehu Gebresilassie and Soil and More Ethiopia. The biochar can also be used as one component of an indigenous bio-fertilizer, as developed by the Jimma-Cornell group. Another option might be the use as inoculant carrier, as proposed by Vanek et al. (2016). Dr. Assefaw Hailemariam, a representative of the Menagesha Biotech Industry PLC, which produces inoculants, has already indicated his interest in that technology. Also Soil and More Ethiopia uses inoculants for their compost systems and is interested in biochar as a carrier.

4.3 Large-scale biochar systems

The highest output can be achieved by industrial pyrolysis plants that produce more than 100 tonnes per year. Several of these plants have been described in report 1 (report 1, section 3.2). All of them provide a steady stream of heat for industrial purposes. However, they also require a steady stream of feedstock, in order to keep the plant running constantly and to pay off the huge investment costs as fast as possible. Several feedstocks can be considered for large-scale biochar systems.

4.3.1 Briquettes

Processing different biomasses to briquettes will increase the bulk and energy density of the material (Seboka et al. 2009), and thus increase their efficiency. Briquetting factories should be located closely to their biomass supply, such as coffee processing units, in order to keep the transport costs low. Also other biomasses can be used for briquetting, such as cotton stalks, saw dust, bamboo or *P. juliflora* (Seboka et al. 2009). A recent study by the United Nations Environment Programme (UNEP) emphasizes the potential of biomass briquettes as fuel for Ethiopian cement factories (Seboka et al. 2009). But they also could be used for other heat demanding industries, such as dyeing factories or foundries. Theoretically, all of the large-scale pyrolysis units can be integrated to the heat supply of these industries. The biochar they obtain can be sold to enterprises that use it for the production of organic fertilizers, such as indigenous biofertilizers, developed by the Jimma-Cornell group. Or it could become a component of fertilizer blending, as promoted by the Ethiopian Soil Information System (EthioSIS) project by the Agricultural Transformation Agency (ATA), in order to improve carbon-depleted soils.

4.3.2 Sugar cane system

Another feedstock for large-scale production could be bagasse from sugar cane factories. Most factories in Ethiopia already use this resource as fuel for their own heat demand and occasionally even shortages of bagasse occurred (Assefa and Omprakash 2013). But the Ethiopian Government has launched large sugar development programmes to boost the sugar industry, to become one of the world's top 10 sugar producers by 2023 (USDA 2015). Hence, it is expected that the production of bagasse will increase drastically and a huge surplus of biomass will be available (GIZ 2009). Several sugar factories are under construction and new pyrolysis plants could be integrated to these factories or replace old furnaces in old factories. The biochar obtained from these factories can be used for commercial purposes, as described above, or sugar factories could give it to their suppliers, in order to increase soil fertility on sugar cane fields. However, for the latter option possibilities need to be found how to combine the biochar with other amendments, such as manure, urine or compost.

4.3.3 Flower system

Huge amounts of biomass is being produced by flower farms (section 3.4). A big share of it consists of woody rootstocks that are hard to compost and that do not have a competitive use. Therefore, flower residues are an ideal feedstock for biochar. Besides, pyrolysis can degrade pesticide contamination of flowers, as long as they do not contain too much chloride, since this may lead to dioxine formation. Soil and More is about to develop a business model for large-scale production of biochar, that allows to combine biochar with their compost activities. The resulting substrate can be distributed within their network of smallholder farmer communities and the projects of LIFT Ethiopia or sold to flower farms. One opportunity to use the heat from pyrolysis units, might be cooling of cold stores at flower farms. A feasible option for this purpose are so-called adsorption chiller systems, which are run by thermal energy and are very environmentally friendly.

4.3.4 Other

Also breweries have a big potential for large-scale biochar production. The factories produce huge amounts of sludge, that have no other use than being dumped. It is likely that this sludge can serve as feedstock, and that breweries can use pyrolysis plants for their own heat demands. But we lack further information to estimate chances and challenges of such a biochar system.

As mentioned in section 3.8, also human faeces can be a feasible option for large-scale biochar production. Though this system might have a huge potential for the waste management in Addis Abeba, technical and regulatory challenges could not be evaluated conclusively.

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Appendix AI

Coffee and coffee residues production on regions and zones level for private peasants holdings (CSA 2015a)

Region	Zones	Total production [Qt]	Area [ha]	No. of Farmers	Production [Qt/ha]	Total residues [Qt]	Residues [Qt/ha]
Amhara		**33,837**	**8,009**	**412,639**	**4.2**	**27,240**	**3.4**
	North Wolo	3,310	582	48,293	5.7	2,665	4.6
	South Wolo	10,580	1,786	79,387	5.9	8,517	4.8
	North Shewa	2,129	551	52,280	3.9	1,714	3.1
	East Gojjam	905	374	29,478	2.4	728	1.9
	West Gojjam	9,569		91,665		7,703	
	Awi	2,849	987	65,932	2.9	2,294	2.3
	Argoba Special	8	2	398	4.5	6	3.6
Oromia		**2,865,350**	**381,515**	**1,790,042**	**7.5**	**2,306,762**	**6.0**
	West Welega	572,011	75,631	237,924	7.6	460,500	6.1
	East Welega	96,766	11,031	82,318	8.8	77,902	7.1
	Illubabor	426,631	66,597	200,970	6.4	343,461	5.2
	Jimma	803,224	97,155	444,216	8.3	646,639	6.7
	Arsi	65,775	7,564	53,806	8.7	52,952	7.0
	West harerge	124,306	15,154	134,458	8.2	100,073	6.6
	East Harerge	41,038	6,553	132,899	6.3	33,038	5.0
	Bale	113,956	15,467	46,976	7.4	91,740	5.9
	Bolena	79,348	9,342	65,126	8.5	63,879	6.8
	South West Shewa	1,491	258	39,984	5.8	1,200	4.6
	Guji	176,453	17,456	98,073	10.1	142,054	8.1
	Kelem Wellega	279,270	47,018	145,694	5.9	224,827	4.8
Benishangul – Gumuz		**4,011**	**1,126**	**27,889**	**3.6**	**3,229**	**2.9**
	Asoa	1,398	233	16,827	6.0	1,126	4.8
	Moa Komo	1,673	426	3,653	3.9	1,347	3.2
SNNPR		**1,296,098**	**163,874**	**2,470,309**	**7.9**	**1,043,429**	**6.4**
	Hadiya	37,189	6,416	148,103	5.8	29,939	4.7
	Gurage	7,207	2,222	77,955	3.2	5,802	2.6
	Kembata Tembaro	13,019	3,242	79,641	4.0	10,481	3.2
	Sidama	471,732	60,359	863,460	7.8	379,770	6.3
	Gedio	238,685	29,669	196,544	8.0	192,155	6.5
	Wolayita	62,687	9,198	359,953	6.8	50,466	5.5
	South omo	12,522	2,021	37,497	6.2	10,080	5.0
	Sheka	154,899	15,218	47,044	10.2	124,702	8.2
	Keffa	102,377	12,198	150,969	8.4	82,419	6.8
	Gamo Gofa	20,974	3,704	174,679	5.7	16,885	4.6
	Bench Majo	121,850	13,276	104,405	9.2	98,096	7.4
	Yem Special Wereda	1,819	327	13,960	5.6	1,464	4.5
	Dawro	8,978	1,520	73,717	5.9	7,228	4.8
	Basketo Special Wereda	4,620	615	14,303	7.5	3,719	6.1
	Konta Special Wereda	2,585	508	20,713	5.1	2,081	4.1
	Silitie	1,644	293	39,931	5.6	1,324	4.5
	Alaba Special Wereda	1,812	210	14,362	8.6	1,459	7.0
	Segan Peoles Zone	31,499	2,878	53,074	10.9	25,358	8.8
Dire Dawa		**393**	**149**	**5,138**	**2.6**	**316**	**2.1**
Ethiopia		**4,199,802**	**568,740**	**4,723,483**	**7.4**	**3,381,068**	**5.9**

Appendix AII

Coffee and coffee residues production on regions level for large and medium scale commercial farms (CSA 2015b)

Region	Production [Qt]	Area [ha]	Waste [Qt]	Waste [Qt/ha]
Amhara	4524.5	455.2	3642.5	8.0
Oromia	393697.5	46562.8	316947.8	6.8
Benishang	140.1	25.7	112.8	4.4
SNNPR	401335.1	60961.3	323096.4	5.3
Ethiopia	799714.0	108007.0	643813.1	6.0

Appendix BI

Flower growing clusters in Ethiopia

Major Clusters	Number of stems in 1 Kg	Average Reject %	Altitude (*m* a.s.l.)
Unknown Cluster (estimated)	20	15	
Holeta	22	15	>2391
Sebeta	24	12	>2100
Debre Zeyit	38	5	> 1800
Ziway	45	8	> 1643

Appendix BII

Flower production data according to clusters

Cluster	Quantity [mio stems]	Stems per kg	Biomass [t]	Rejected stems average [%]	Reject stems [mio. Stems]	Reject stems biomass[t]	Production area [ha]	Average waste [t ha^{-1}]
Unknown Cluster (estimated)	53.8	20	2689	15	9.5	474	80	5.9
Holeta Cluster	154.7	22	7034	15	27.3	1241	213	5.8
Sebeta Cluster	158.1	24	6588	12	21.6	898	183	4.9
Debre Zeyit Cluster	173.3	38	4560	5	9.1	240	219	1.1
Ziway Cluster	1,842.6	45	40948	8	160.2	3561	573	6.2
Grand Total	**2,382.5**		**61818**		**227.7**	**6415**	**1268**	**5.1**

Appendix C

Main uses of *Prosopis juliflora* among Afar pastoral households (taken from Ilukor et al. 2016)

Environmental good	Harvest/year	Value/year (ETB)	Proportion due to *P. juliflora*	% of HH benefitting	*P. juliflora* income per HH
Fuelwood, home consumption	119	2,983	65	96	1,939
Fuelwood, sale	153	5,648	76	3	4,292
Charcoal, home consumption (bags)	35	1,712	86	18	1,472
Charcoal, sale (bags)	1043	57,631	90	18	51,868
Poles for house construction	69	1,664	54	52	899
Poles for house repair	26	210	68	47	143
Fencing (home farm, kraal)	34	699	71	74	496
Farm implements	14	261	43	21	112
Household furniture	77	1,636	17	4	278
Honey (litres)	48	5,760	5	0.2	288
Wild fruits	65	530	4	3	21
Bush meat	12	2,550	23	1	587
Medicinal use	49	1,294	6	10	78
Leaves for livestock feed	175	3,995	30	12	1,199
Pods for livestock feed	136	3,374	87	39	2,935
Total		95,890	46		69,248

Source: Field Survey Data (January 2014 and December 2013): The harvest per year, value per year, proportion and the proportion of households earning a given income are generated from household survey data. Income due to *P. juliflora* is computed from value per year based on proportion income associated to *P. juliflora*