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

Socio-economic scenarios of low hanging fruits for developing climate-smart biochar systems in Ethiopia

Biomass resource availability to sustainably improve soil fertility, agricultural productivity and food and nutrition security

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Important acronyms and abbreviations

AFOLU	Agriculture, forestry and other land Use
AGP	Agricultural Growth Program
ATA	Agricultural Transformation Agency's
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (The German Federal Ministry for Economic Cooperation and Development)
BPA	Best Practice Association
BSE	Bovine Spongiform Encephalopathy
CEC	Cation exchange capacity
CIA	Central Intelligence Agency
CPWD	Community-based participatory watershed development
CRGE	Climate Resilient Green Economy
EFPA	Ethiopian Flower Producer Association
EIAR	Ethiopia's Institute of Agricultural Research
EPA	Environmental Protection Authority
ESC	Ethiopian Sugar Corporation
FAO	Food and agriculture organization of the UN
GDP	Gross domestic product
GHG	Greenhouse gas
GOE	Government of Ethiopia
GTP	Growth and Transformation Plan
Ha	Hectare
INDC	Intended nationally determined contribution
IPCC	Intergovernmental panel on climate change
ISD	Institute of Sustainable Development
ISFM	Integrated soil fertility management
ISWC	Integrated soil and water conservation
MDGs	Millennium Development Goals
MOANR	Ethiopian ministry of agriculture and Natural resource
NRRDSE	National Rice Research and Development Strategy of Ethiopia
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
PELUM	Participatory Ecological Land Use Management
SLM	Sustainable land management
SNNPRS	Southern nations and nationalities regional state
SSA	Sub-Saharan Africa
UN	United Nations
UNFCCC	United Nations framework convention on climate change

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Executive summary

Ethiopia, with a total area of 1.10 million km^2, is the largest landlocked country in Africa. Its topographical features encompass high and rugged mountains, flat-topped plateaus, deep gorges, and rolling plains; with altitudes ranging from 125 m below sea level at the Danakil Depressions in the northeast to 4533 m above sea level at Ras Dashen Mountain in the northwest. Despite the roughly 12 different landform patterns within this altitudinal range, the country is generally divided into three basic geographical units: the eastern plateau, the Rift Valley and the western plateau. The country has a tropical monsoon climate but with wide topography-induced variations including climatic conditions typical of tropical savanna and desert in the lowlands. These climatic variability, topographical diversity, and the various geological factors endowed Ethiopia with a variety of biophysical environments that include different vegetation types, water resources and soil, as well as multitudes of ecosystems and production zones with contrasting agricultural potentials. With a population of more than 105 million, Ethiopia is the second most populous country in Sub-Saharan Africa (SSA), and is expected to cross 300 million margin by the year 2050 - projected to become among the world's top ten most populous countries. This is anticipated to induce greater demand for increased agricultural production, food, forest, energy and other natural resources such as land, and it is also expected to significantly influence the manner in which these resources are utilized.

Despite a recent economic upturn where the country's economy was estimated to be growing at 8-11% annually making it the fifth-fastest growing economy among the 188 countries, Ethiopia still faces a number of critical development challenges. Smallholder agriculture is the main livelihood for an overwhelming majority of Ethiopia's population, and it is the basis of the country's national economy. However, most Ethiopian smallholder farmers still practice subsistence level and less diversified rain fed agriculture with very low agricultural productivity. Thus, food and nutritional insecurity still remain high in the country, and most rural smallholder farming households live under a very fragile existence. Energy poverty and burning solid fuels such as wood - which results in millions of tons of biomass going up in smoke every day leading to extensive greenhouse gas (GHG) emissions to the atmosphere, deforestation, land degradation, as well as loss of biodiversity, soil fertility and productive ecosystems are other problems which are impairing the capacity of the country's land to contribute to food security of 85% of Ethiopia's population currently living in rural setup. Hence, there is an urgent need in Ethiopia for multidisciplinary initiatives working towards reversing the negative social, health and environmental implications of forest and woodland-sourced solid fuels, open fires and traditional stoves that affect indoor air quality and threatens the health and well-being of the most vulnerable parts of the resource-poor community – women and children. Moreover, Ethiopia's rapid population growth and lack of alternative employment opportunities in other economic sectors have further increased the pressure on the limited arable land under smallholder farming system, and have led to extensive subdivision of the already small and fragmented family farms, making them too small to grow the required food for the household. The country's rugged topography, coupled with inadequate sustainable land and livestock management and agricultural knowledge and poor extension service, limited adoption of integrated soil conservation and soil fertility management practices in watersheds and integrated agricultural landscapes, as well as the breakdown of traditional land productivity restoration measures

further exposed the land to erosive forces also contributed to the current extensive land and ecosystem degradation observed in the country and to the heightened the food-insecurity, vulnerability and fragility of the country's resource-poor rural farming households livelihoods. Ethiopia is also feeling the impacts of climate change. Historical trends show that Ethiopia's temperature increased by up to 1.3°C from 1900 to 2006. Future projections show that the country is becoming even warmer, with average projected increases reaching up to 2.2 °C by the 2050's and by 3.-6°C by 2100. This is expected to be associated with heat waves and higher water losses from soil, plants and water sources affecting both crop and livestock system. In some areas, this means a real risk of more droughts that will constrain crop growth and yield or could lead to catastrophic failure and chronic famine. However, it is also likely that climate change will not only bring new risks and shocks but also it will worsen existing problems. In such cases, the normal weather shocks affecting people's livelihoods could become more severe, frequent, and could appear with much shorter warning times. In order to respond to the changing climate, Ethiopia - despite contribute only to 0.27% of the global emissions - has made an ambitious commitment to curb its greenhouse gas emissions between now and 2030 through its recently submitted Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), where the country as part of its Climate Resilient Green Economy (CRGE) intends to limit its net GHG emissions by 2030 to 145 Mt CO_2e or lower. This would constitute a 255 Mt CO_2e reduction from the projected conventional economic growth emissions scenario by 2030. It represents a major shift, since the business-as-usual economic growth could more than doubled Ethiopia's greenhouse emissions by 2030 to 400 Mt CO_2e. Ethiopia's INDC also shows that 86% of the expected abatement potential is anticipated to come from the agriculture, forestry and other land use (AFOLU) sector, and calls for higher efficiency from the country's integrated agricultural landscapes to mitigate climate change. However, initial estimate show that the sink capacity of Ethiopia's forests and grasslands are decreasing rapidly due to deforestation mainly for agricultural and energy use and via overgrazing, respectively. Therefore, there is a great interest - as part of the country's CRGE and Growth and Transformation Plan (GTP) that is now in its second phase - for initiatives which target to integrate implications of climate change into agriculture, environment, energy and public health. It is against these backdrops that we propose to develop the next-generation sustainable biochar systems to explore supplementary avenues that can complement Ethiopia's various climate-smart initiative by helping reduce the pressure on natural forest, woodlands and community forest, the alarming trends in land and ecosystem degradation, improve soil fertility and health, agricultural productivity and food and nutrition security, while also contributing towards reducing energy poverty, clean-up the environment, and sequestering carbon in agriculture soils supporting the country's strategic policy whereby the AFOLU sector is expected to contribute towards adaptation and mitigation to climate variability and change, as well as to the country's INDC.

Biochar is the solid carbon-enriched product of thermal decomposition obtained when non-competitive biomass residues are heated at relatively low temperatures (typically between 300 °C to 700 °C) under oxygen-deprived environment, a process technically known as "pyrolysis". Although biochar production process often mirrors the production of charcoal, it distinguishes itself from charcoal in that it is a system-defined term referring to black carbon that is produced intentionally to manage carbon - with a downstream single sector-based or integrated application to soils - for sustainable agriculture, environmental management, and climate change mitigation purposes. It is often produced with the intent to be applied to soil as a means of improving soil productivity, carbon storage, or both. Agricultural and agro-industrial biomass residues typically contains about 50% carbon, which is relatively quickly decomposed and reemitted to the atmosphere in the form of GHGs such CO_2, CH_4 etc. upon decay in soil. Biochar retains on average about 50% of the carbon present in the original biomass and slows down the rate of carbon decomposition by one or two orders of magnitude, that is, in the scale of centuries or millennia. Although, in principle biochar can be made from any type of biomass, it is important to understand how different production conditions can result in different types of biochars, and how they interact with different soil types. In line with this, the German Federal Institute for Geosciences and Natural Resources (BGR) has launched in February 2016 the GeoSFF part measure "Potential analyses of biochar systems for improved soil and nutrient management in Ethiopia" financed by The German Federal Ministry for Economic Cooperation and Development (BMZ). Within the project BGR commissioned this study which describes the "Socio-economic scenarios of low hanging fruits for developing climate-smart biochar systems in Ethiopia to improve soil fertility, agricultural productivity and food and nutrition security." The project goals assist the Ethiopian climate-smart agriculture initiative. The report explores existing non-competitive agricultural and agro-industrial biomass waste streams in Ethiopia's various regional states, while from the outset recognizing the multiple economic constraints and tradeoffs involved in biomass residue streams in Ethiopia's resource-poor smallholding farming system. It highlights the three critical elements to every biochar system including the proposed one in Ethiopia: source and availability of biomass, means of biochar production at the envisioned scale, and whether and how it is applied to soil. For each element there are a wide range of alternatives. Theoretically the source for biochar feedstock can be almost any type of biomass. However, biomass is one of the most important resources in smallholder farms in Ethiopia. It provides rural households with ecosystem services such as soil organic matter, soil protection against erosion, nutrient recycling to crops, to other common usages such as source of fuel, building materials and animal feed. Conversely, it is also important to realize the fact that although biomass in most cases come at a cost, it can also pose tremendous environmental burden often disposed in water ways polluting drinking water or allowed to decompose in open air releasing substantial amounts of GHGs. Therefore, the judicious choice of feed stocks plays an important role not only for matching biochar properties to soil needs, but also for the sustainability and socio-economic viability of biochar systems. The focus in this report is, therefore, placed heavily on identifying the availability and developing subsequent strategy for efficient utilization of "true" non-competitive agricultural and agro-industrial waste streams present in Ethiopia to design climate smart sustainable biochar systems that: (i) minimize the pressure on the county's natural forest and woodlands, (ii) support rehabilitate of degraded land and agroecosystems, and (iii) enhance sustainable agriculture without disrupting local agroecosystem carbon and nutrient recycling. Based on these considerations, and follow up discussions with the Soil Fertility Improvement Directorate of Ethiopia's MOANR, and other public and private sector partners - in the aftermath of the September, 2016 international conference - a strategic decision was made to identify low hanging "true" agricultural an agro-industrial waste streams from the country's crop and livestock subsectors that can provide biomass feedstocks in sustainable manner to develop economically viable and scalable pilot model commercial biochar systems projects in private-public partnership scheme in Ethiopia. This report explores the socio-economic scenarios and potentials of (i) animal bone, (ii) coffee husk, (iii) flower cutting, (iv) invasive weed (Prosopis) species, (v) bagasse, (vi) rice and sesame residues streams distributed across the country.

The livestock subsector has a huge contribution to Ethiopia's national economy and livelihoods of many Ethiopians promising to rally round the economic development of the country. Taking this subsector into account, this report envisages a future scalable medium (regional) scale model project with socio-economic scenarios that involve a close collaboration of successful private and public sector institutions that can catalyze a path to a commercially viable indigenous phosphorus fertilizer industry using locally procured bone residue waste streams in Addis Ababa federal capital district. The partnership consists of Menagesha Biotech organic fertilizer Industry P.L.C (Private partner), The Addis Ababa Central Abattoir Enterprise (Public enterprise), Jimma University (Ethiopian Federal Government Entity) and Cornell University (Land-grant International Institution of higher learning from the US that can provide technical support and backstopping) to launch the first bone biochar-based private-public indigenous phosphorus fertilizer production facility in Ethiopia. The results of the analysis show that there are three scenarios whereby the Addis Ababa Abattoir Enterprise could potentially generate about 519, 1247, and 14,543 tonnes of bone residue per year, which could potentially transfer to about 177, 426, and 4965 tonnes of phosphorus as P_2O_5 per year, respectively. The analysis also show that this alternative and renewable source of phosphorus could generate a product with a financial value of $112,627, $270,304 and $3,153,541 USD, respectively, demonstrating the potential economic value under the envisioned private-public partnership to turn this livestock waste stream into renewable agricultural input that can supply phosphorus for the country's smallholder rural and peri-urban farmers.

The crop-based agriculture subsector, although dominated by mostly small-holder and largely subsistence farming with low productivity on fragmented and highly degraded lands, is crucial for Ethiopia's economy and food and nutrition security. This subsector is the largest contributor to overall economic growth and poverty reduction. Therefore, it is understood that leading the sector to higher productivity and efficiency is not just fundamental to poverty reduction and food security, but can also contribute to meeting a number of other key development challenges that Ethiopia faces. The GOE recognizes the importance of agricultural development, and has shown a long-standing and strong commitment to this sector. However, there is also a general concusses in the country that the sector needs transformation, and Ethiopia together with its international development partners have started the process by designing its Agricultural Growth Program (AGP) - which is widely implemented in the country to drive the revival and long-term sustainability of this sector. Ethiopia is currently executing the second phase of this strategic program. The GOE's Growth and Transformation Plan (GTP) also includes bolstering the productivity of both major staple and cash crops and the livestock sector: enhancing marketing systems, upgrading participation of private sector, increasing volume of irrigated land and curtailing amount of households with inadequate food among other things. Ethiopia's major crops (both staple and cash crops) include a variety of grains (principal grains include teff, wheat, barely, maize, sorghum, millet etc.), pulses (peas, beans, lentils, chickpeas etc.) and oilseeds (sesame, niger seed, flax etc.), as well as vegetables, root crops (potatoes, onion, enset etc.), and fruit (bananas, avocado, papayas, mangoes, oranges etc.) crops; while the cash crops include sweetener and stimulant crops (sugarcane, coffee, chat, hops etc.), pulse (peas, beans, lentils, peanuts etc.) and oilseeds (sesame, niger seed, etc.), flowers (roses, chrysanthemum, carnations, etc.), fiber (primarily cotton) crops. Taking this into consideration, the current report envisions coffee-, flower-, sugarcane- and rice and sesame-based agricultural and agro-industrial waste stream-based future socio-economically viable and scalable medium (regional) scale model private-public sector projects, as well as it also includes strategies to convert invasive weed species affecting this subsector into useful agricultural inputs using similar scheme. According this study, there is a fertile ground to establish the frame work for a future medium sized private-public sector partnership model project at the Jimma zone of the Ormoia region, whereby coffee agro-industry waste stream (coffee husk) from three processing plants could be converted into coffee husk biochar-based soil conditioner and fertilizer. The results show that about 4888 tonnes of coffee husk is generated each year by the private sector partner, and if 100% of this 100% of this biomass feedstock is used for biochar production - at 30% recovery rate, the partnership is potentially capable of producing about 1466 tonnes of coffee husk biochar per year which can be used directly as a soil conditioner on 367 ha of land at 4 t/ha rate. Currently a new approach is being tested at using a 4 years on-going agronomic trials at Jimma Zone by Cornell and Jimma University where coffee husk biochar at 2 t/ha is being used in a co-composting process and applied as pelletized organic soil conditioner into the soil. If this approach is implemented, the total area of smallholder agricultural land coverage that could benefit from this renewable agricultural input could be doubled to 733 ha to enhance soil fertility, agricultural productivity, food and nutrition security, while also sequestering carbon and potentially reducing the release of nitrous oxide from composing process - contributing to climate change mitigation efforts of the country. The report also highlights the potential for utilizing sugarcane waste residue streams for bagasse biochar-based soil conditioner production, and also to develop a private public partnership scheme around it to explore possible entrepreneurship and market-based opportunities by taping the rapidly expanding sugar industry sector at the Wonji-Shoa sugar factory at the Adama Zuria woreda in East Shewa Zone of the Oromia region - where up to 10000 tonnes of the bone dry bagasse is considered as surplus to the requirements or not effectively used for the production of steam and electricity, and present in the premises as a component of sugar industry waste stream. Considering the vast amount of flower cut solid waste stream currently available in the country, Ethiopian Government's effort to foster future expansion of this agro-industry sector, as well as the existing well established demand-driven supply system and branding efforts already in place, this report explores opportunity to propose to develop a future scalable medium size model project with socio-economic scenarios that involve collaboration between private and public sector institutions. For example a single private sector enterprise (in this case Soil and More Ethiopia) aggregates massive amount of flower waste (up to 44532 tonnes per year out of which 30% (about 13360 tonnes per year) is composed of hard woody and root material and deemed difficult to compost. This waste could produce up to 4008 tonnes of biochar per year (at 30% biomass feedstock conversion rate efficiency) to guarantee a viable medium scale private-public partnership that can provide soil conditioner for 1002 ha land occupied by smallholder farmers in Zewaye woreda in East Shewa Zone of the Oromia regional state at 4 t/ha rate or to 2004 ha of land at 2 t/ha rage in a co-composted scheme described above in this this report. Rice is a relatively new crop for Ethiopia. However, recognizing its importance as a food security crop and a source of income and employment opportunities, Ethiopia is now emerging as one of the potentially largest ice-producing countries in sub-Saharan Africa. In fact the government of Ethiopia has named rice as the "millennium crop", and has ranked it among the priority commodities of the country. The information collected in 2016 from Tselemeti woreda in western Tigray zone indicated that there is currently about 1862 ha of land where rice crop production is practiced. Rice production in this woreda ranges from about 3 to 6 t/ha, which show that on the average (by considering 4.5 t/ha to be the average rice crop yield for this woreda) this woreda produces about 8379 tonnes of rice crop per year. Considering 20% of the rice yield is husk, this woreda could potentially produces about 1676 tonnes of rice husk per year. If 100% of this rice husk is used for biochar production, at 30% recovery rate, this woreda is capable of potentially producing about 503 tonnes of biochar per year, with the capacity to be used directly as a soil conditioner on 126 ha of land at 4 t/ha rate or on 251 ha land if it is used as an additive in co-composting process at a rate of 2 t/ha at the Tselemeti woreda in Western Tigray Zone, Tigray regional state. Similarly, the preliminary survey and data collection from Kafta Humera, Wolkayit, Asgede Tsimbila, Tahtay Adiyabo and Tsegede woredas of the western Tigray zone show that sesame crop is grown in about 300000 ha of land. By taking a more conservative approach (i.e., national average sesame crop yield of about 0.69 t/ha), these five woredas in the western Tigray zone could potentially produce about 288000 tonnes of sesame crop seeds. Using the FAO conversion factor for grain yield into fibrous residue, the five woredas could potentially produce about 345600 tonnes of sesame biomass feedstock for biochar production. If 100% of this sesame crop waste stream can be used for biochar production, at 30% biomass to biochar conversion rate, these wordas are capable of producing about 103680 tonnes of sesame waste stream-based biochar per year, that can be used directly as a soil conditioner on 25920 ha of land at 4 t/ha rate. If this residue is used as an additive in co-composting process and used as organic fertilizer at 2 t/ha rate, the soil conditioner that can be produced from the sesame residue stream could help to alleviate soil fertility related constraints from 51840 ha land occupied by smallholder farmers in western Tigray zone of the Tigray regional state. The current study also examined the socio-economic scenarios to develop scalable medium scale invasive species (in this case Prosopis) biochar-based soil conditioner model project development that involve a private and public sector partnership with a capacity to put together a pyrolysis plant that can aggregate the supply of Prosopis from individual smallholder farmers, and consequently process it into pelletized soil conditioner. Although finding pertinent information about the dry matter yield of Prosopis juliflora is difficult past investigations indicate that it has a potential to produce 12.6 t/ha. Considering the fact that this invasive tree species covers more than 490000 ha land in 2006 in the Afar regional state alone, the there is a potential to produce each year 6.17 million tonnes of dry matter for biochar production in the region. By considering 30% conversion rate from Prosopis dry matter to Prosopis biochar, this will provide about 1.85 million tonnes of Prosopis biochar each year for use as soil conditioner. If a socio-economic scenario is considered where by only 25% of this resource can be utilized, it could yield about 462,500 tonnes of biochar. At the current 4 tonnes per ha rate, this can potentially help to ameliorate soil fertility and productivity related problems in about 115750 hectares of land in the Afar region. If the biochar is used for composting at 2 t/ha rate, there is a potential to double the total smallholder farm area coverage into 231500 236 ha of land to tackle massive basic soil fertility and productivity constraints of the resource poor farming communities in the region, while also sequestering carbon in agricultural soils and contributing to climate change mitigation.

These results also combined with the recent Jimma and Cornell University effort to develop appropriate technology to pelletize co-composted biochar to improve handling and enhance ease of application, among other things described in this report show: (i) the enormous potential for converting non-competitive waste streams into useful agricultural input that could contribute to enhance soil fertility and agricultural crop productivity in Ethiopia, as well as (ii) the potential to develop business models for scalable private-public partnership-based pilot projects to test the socio-economic viability of such approaches in the country and build entrepreneurship opportunities that could empower women and unemployed young people in the region.

1 Ethiopia - background and statement of the problem

1.1 Spatial and topographical context

Ethiopia, with a total area of 1.10 million km^2, is the largest landlocked country in Africa. Its topographical features encompass high and rugged mountains, flat-topped plateaus, deep gorges, and rolling plains; with altitudes ranging from 125 m below sea level at the Danakil Depressions in the northeast to 4533 m above sea level at Ras Dashen Mountain in the northwest. Despite the roughly 12 different landform patterns within this altitudinal range, the country is generally divided into three basic geographical units: the eastern plateau, the Rift Valley and the western plateau (Debele, 1985; Abebe et al., 2012).

1.2 Climate context

Ethiopia has a tropical monsoon climate but with wide topography-induced variations including climatic conditions typical of tropical savanna and desert in the lowlands. However, the country's climate can be generally classified into three very broad climatic zones: (i) a cool zone consisting of the western and eastern sections of the high plateau with altitude over 2400 m above sea level, (ii) a temperate highland zone between 1500 and 2400 m above sea level and (iii) a hot lowland zone below 1500 m above sea level (Abebe et al., 2012).

Ethiopia's temperature is significantly influenced by altitude among other factors, and varies from 35°C in the Danakil lowlands to less than 7.5°C at the Ras Dashen Mountain. The amounts rain fall vary from over 2200 mm per annum in the southwestern highlands to less than 100 mm per annum in the extreme North, and in lowlands of the northeastern and southeastern parts of Ethiopia. The precipitation pattern is highly erratic, and falls often as convective storms with very high intensity and extreme spatial and temporal variability. The result is that there is a high risk of erosion, intra-seasonal dry spells and drought that impact agricultural productivity, and deepening of food insecurity (Debele, 1985; Abebe et al., 2012).

1.3 Soil and agroecological context

The great climatic variability, topographical diversity, and the various geological factors endowed Ethiopia with a variety of biophysical environments that include different vegetation types, water resources and soil, as well as multitudes of ecosystems and production zones with contrasting agricultural potentials.

The Food and Agriculture Organization (FAO) of the United Nations revised soil map provides the description and regional distribution of soil types of the country (FAO, 1988; Hurni et al., 2007). Of the 28 soil orders described in FAO's revised legend (FAO, 1988), 17 soil orders are known to occur in Ethiopia (Debele, 1985; Haileslassie et al., 2005; Hurni et al., 2007; Shiferaw et al., 2013). In spite of the variability, however, six units in increasing order of importance (i.e., Leptosol - [16%], Cambisols - [15%], Nitisols - [12%], Vertisols - [10%], Xerosols - [9%], and Solonchaks - [7%],) cover up to 62% of Ethiopia's land mass. Nitisols and Cambisols are the dominating soil types over much of the highlands, while Vertisols and Regosols are prevalent mainly on the East and West along the edge of the arid lowlands. Regosols, Yermosols and Xerosols occupy much of the Somali plateau and the arid lowlands of Ethiopia (Hurni et al., 2007; Abebe et al., 2012).

Ethiopia's agroecological zones are traditionally classified mainly based on temperature, rainfall and altitude into: dry hot, dry warm, sub-moist warm, sub-moist cool, moist cool, cold, moist cold and very cold or alpine (Debele, 1985; MOA, 2000; Abebe et al., 2012). The natural vegetation in these agroecological zones ranges from Afro-alpine through dense high canopy montane forest and wetland to woodland savannah, grassland, scrubland, semi desert and desert vegetation.

1.4 Population context

With a population in 2017 of more than 105 million, Ethiopia is the second most populous country in Sub-Saharan Africa (SSA) (WB, 2012; CIA, 2017). Most of the world's population growth in the next 40 to 50 years is expected to come from Africa. Ethiopia will be a large part of this growth, if its current growth rate stays at about 2.88 %. Ethiopia's population is expected to almost double in the next 20 years, and cross 300 million by 2050, projected to become among the world's top ten most populous countries (UN, 2012; CIA, 2015). This will induces increased demand for increased agricultural production, food, forest, energy and other natural resources such as land, and also greatly influence the manner in which these resources are utilized.

1.5 Sectoral (agriculture) context

Despite a recent economic upturn where the country's economy was estimated to be growing at 8-11% annually making it the fifth-fastest growing economy among the 188 IMF member countries, Ethiopia is still one of the poorest countries in the world and faces a number of critical development challenges. It has a gross per capita income of US$ 505 and a low human development index of 173 out of 185 countries worldwide (WB, 2013; UNDP, 2014).

Smallholder agriculture is the main livelihood for an overwhelming majority of Ethiopia's population, and it is the basis of the country's national economy. It accounts for up to 80% of the employment, contributes up to 43% of the gross domestic product (GDP), and makes up to 70% of the country's export revenue (Wondifraw et al., 2014). However, most Ethiopian smallholder farmers still practice subsistence level and less diversified rain fed agriculture with very low agricultural productivity. Thus, food and nutritional insecurity and malnutrition still remain high in the country, and most rural smallholder farming households live under a very fragile existence.

1.6 Energy, health and gender context

Energy poverty and burning solid fuels such as wood results in millions of tons of biomass going up in smoke every day leading to extensive greenhouse gas emissions to the atmosphere, deforestation, land degradation, loss of biodiversity, soil fertility and productive ecosystems; impairing the capacity of the land to contribute to food security of 85% of Ethiopian people living in rural communities. Hence, there is an urgent need in Ethiopia for multidisciplinary initiatives working towards reversing the negative social, health and environmental implications of forest and woodland-sourced solid fuels, open fires and traditional stoves that affect indoor air quality and threatens the well-being of the most vulnerable parts of the resource-poor community – women and children.

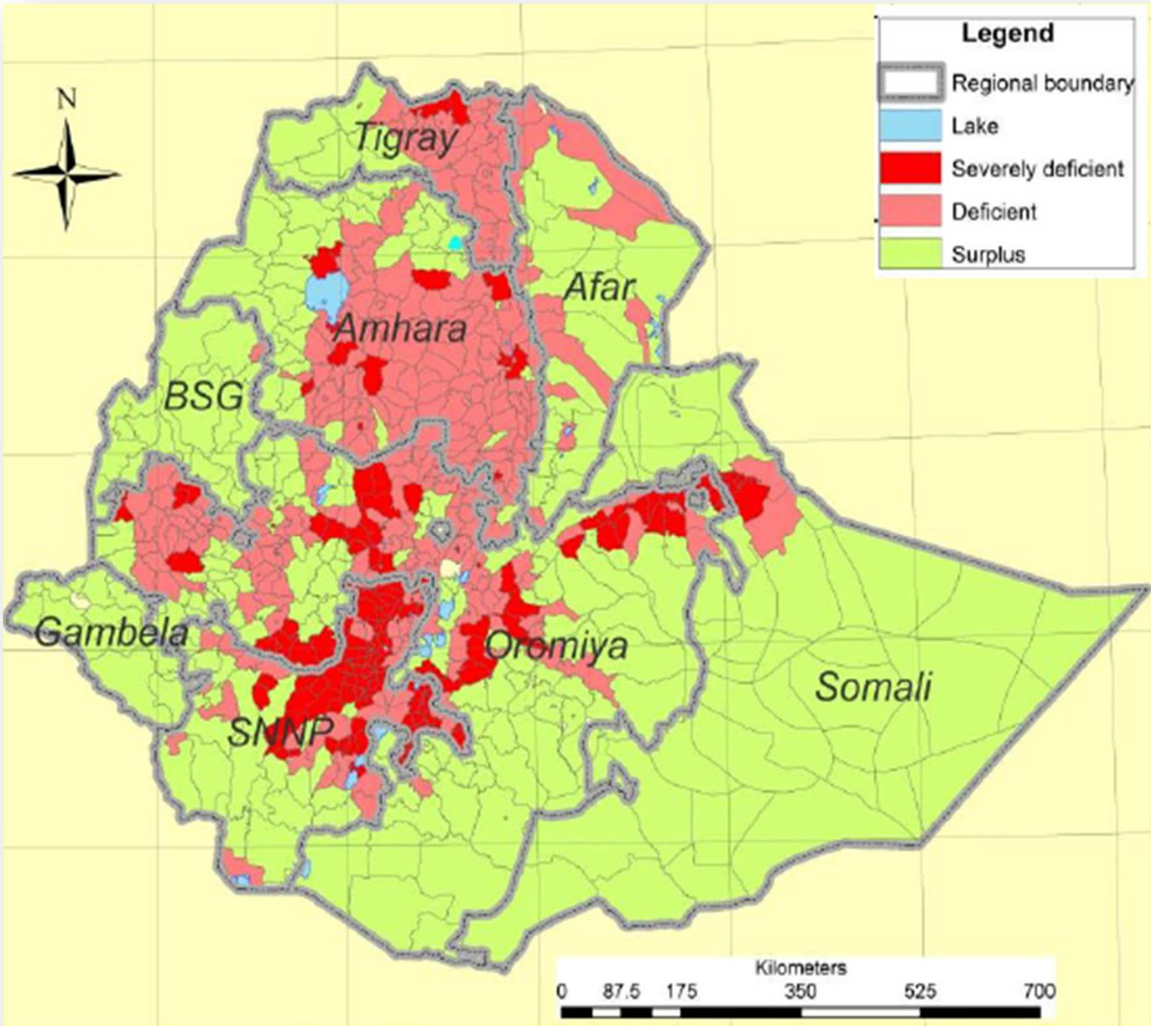

Figure 1. Woody biomass energy source assessment map of Ethiopia showing severely deficient and deficient or “hot spots” woredas , as well as areas with relatively surplus amounts of woody biomass resource for energy (Geissler et al., 2013).

Energy and fuel sources underlies all economic activities and enables basic human needs to be met. The use of energy services is, therefore, an integral part of enhanced economic development and human wellbeing. During the current era of increased global demands, however, the availability of good-quality energy sources to poor people living in countries with limited resources such as Ethiopia have declined; and a large fraction of the population is unable to access modern forms of energy and energy services at all. Worldwide, over three billion people depend on biomass-based solid fuels (wood, dung and agricultural residues) to meet their most basic energy needs. The largest concentrations of these ‘energy poor,’ people i.e., those who are economically poor and lack access to modern forms of energy, are currently in sub-Saharan

African countries such as Ethiopia. In fact, since electrification of rural Ethiopia is very limited, about 95% of the rural Ethiopia's household energy supply comes from traditional biomass-based solid fuels. However, the availability and supply of even these traditional sources of energy is dwindling creating a number of energy deficient 'hot spots' (see Figure 1) in the country for the countries further exacerbating the problems of Ethiopia's energy poor population.

Burning solid fuels on an open fire or in inefficient cookstoves creates a dangerous cocktail of hundreds of pollutants (e.g. carbon monoxide, nitrogen and sulfur dioxide, and a variety of organic vapors), black soot and small particulate matter resulting in extremely high levels of indoor air pollution in the dwelling of rural Ethiopian households. This disproportionally expose the poor and the most vulnerable part of the community (infants, young children and women) to increased risk of acute respiratory infections, chronic obstructive pulmonary disease, pulmonary tuberculosis, lung cancer and cataract etc. creating a major public health issue for the country.

Energy poverty and reliance on solid biomass-based fuel resources on a daily basis is also linked with forcing young girls and women to spend many hours in forests and woodlands foraging for biomass fuels such as wood at a great personal risk and loss of time which otherwise would have been invested to enhance the capacity and productive capacity of these social groups affecting the gender balance and equitable participation in the overall economic and social activities of the country as a whole . However, until recently, the gender imbalance in the over representation of the country's economic and social system, and the concentrated health effects have been somewhat neglected by the research community, donors and to some extent among policy-makers; and very little documented experimental and pathogenesis information exists in Ethiopia.

It is now widely accepted that clean and efficient household cooking solutions are effective ways of saving lives protecting the environment, empowering women improving livelihoods of resource-poor vulnerable communities across the globe. Thus, in Ethiopia alone several improved combustion (non-pyrolysis) cookstoves (Gonzie, Laketch, Mirt etc.) were developed by the private sector and through the support of governments, bilateral organizations and NGOs, and are currently made available in the market to both urban and rural communities, with a goal to disseminate up to 9.40 million cookstoves in 5 years. Many of these combustion cookstoves (e.g., Mirt stove) are also rightfully credited to use only half as much wood compared with the conventional stoves lessen the pressure on limited natural resources. However, although these improved combustion cookstoves are providing a great deal of benefit to the society compared to cooking on open fire or conventional cookstoves, it is worth indicating that in almost all the cases very little emphasis have been given in the design and development of these combustion cookstoves to integrate climate-smart sustainable agricultural and environmental components into the design and development strategies of the clean-burning cookstoves in Ethiopia – in a manner that synergize energy, health, sustainable agriculture and food security, reducing deforestation, pressure on natural forest and rehabilitation of degraded integrated agricultural and forest landscapes, while creating resilience and adapting and mitigating climate variables and change and adaptation to climate change. It is imperative to indicate that future household, medium or largescale energy interventions and practical solutions would greatly benefit from a more holistic approach that incorporate other climate-smart ancillary co-benefits related to environmental sustainability and climate change mitigating measures as upstream elements green energy systems design, testing and technology developments and adaptive response mechanisms. Ethiopia has made an ambitious commitment to curb its greenhouse gas emissions between now and 2030. As one of Africa's most vulnerable nations, and the first least developed country to submit its Intended Nationally Determined Contribution (INDC) to the UNFCCC, Ethiopia communicated its plans to cut emissions below 2010 levels from 150 megatonnes of carbon dioxide equivalent (Mt CO_2e) in 2010 to 145 MtCO_2e in 2030. This represents a major shift, since conventional economic growth would more than double Ethiopia's greenhouse emissions by 2030. Such approaches are expected to diversify the source of biomass feedstock from the system based on traditional wood-based sources by bring new biomass feedstock from non-traditional agricultural and agro-industrial waste streams with limited- to non-competitive use to support the country's climate resilient green economic development policy, its intended National and could also contribute to sustainable agricultural development, food and nutrition security and reduction of vulnerability to climate change. It could also improve the current lack of support and limited attention given to these issues by bring other stakeholders and could facilitate the current limited financing option by providing a quantifiable and verifiable mechanism for carbon capture and climate financing opportunities and incentives including results-based international financing (RBF) to support the sector and also improve the acceptance and market growth of improved cookstoves in Ethiopia.

1.7 Land degradation and loss of productive ecosystem context

Land degradation is the reduction in the capacity of the land to provide ecosystem goods, and services and assure its functions over a period of time for its beneficiaries (FAO, 2011). It is also alternatively defied as the decline of biological and economic productivity of land resources represented by soil carbon stock and nutrient depletions, loss of soil fertility, vegetation cover, and ecosystems and the services that they provide to the society. It is a source of major ecological and socio-economic problem in Ethiopia's chronically food insecure and vulnerable regions (UNCCD, 1994; Haileslassie et al., 2005; Mekuria et al., 2007, 2010, 2011, 2013).

Ethiopia's rapid population growth and lack of alternative employment opportunities in other economic sectors have increased pressure on the limited arable land under smallholder farming system, and have led to extensive subdivision of the already small and fragmented family farms, making them too small to grow the required food for the household. This rapid population growth is, thus, linked to expansion of cultivated land for meeting short-term survival needs at the expense of natural forests, woodlands and grasslands, leading to declining aboveground vegetation cover via deforestation and clearing of undisturbed grassland ecosystems, increased farming on steep slopes usually not suited to agriculture, and hence to extensive land and other natural resources degradation. In fact, Ethiopia is now one of the countries in SSA most seriously affected by environmental and land degradation (Tilahun et al., 2001; Lambin et al., 2003; Shiferaw et al., 2013; Gashaw et al., 2014).

Figure 2. Highly degraded woodland with clear signs of sheet and rill erosion and gully formation as a result of lack of sustainable integrated watershed management interventions at the Asore Woreda, in Ethiopia's Southern Nations and Nationalities Regional (SNNPR) State next to a highly productive corresponding wood and grassland site where proper land capability classification, livestock exclusion and natural regeneration of the wood and grassland was implemented along with integrated physical soil and conservation measures, showing the importance of land management on ecosystem productivity.

The causes of Ethiopia's extensive land degradation and loss of productive ecosystem are, however, complex and diverse, and are not limited to the country's rapidly growing population. They include a number of factors such as the low level livelihood of the rapidly growing rural population, the heavy reliance on subsistence agriculture, the unsustainable farming practices, the very high dependence on wood and other biomass for household energy, and the poor livestock management including overgrazing and expansion of livestock population beyond carrying capacity of the land. The country's rugged topography, coupled with inadequate sustainable land and livestock management and agricultural knowledge and poor extension service, limited adoption of integrated soil conservation and soil fertility management practices in watersheds and integrated agricultural landscapes, as well as the breakdown of traditional land productivity restoration measures (such as fallowing) exposed the land to erosive forces also contributed to the current extensive land and ecosystem degradation observed in the country and to the heightened the food-insecurity, vulnerability and fragility of the country's resource-poor rural farming households livelihoods (Hurni, 1988, 1993; Shiferaw and Holden, 1998; Dubale, 2001; WB, 2008; Abebe et al., 2012; Shiferaw et al., 2013; Gashaw et al., 2014). For example, Osman and Sauerborn (2001) in a comprehensive review of the experiences and lessons learned from Ethiopia's soil and water conservation activities elaborated that the progressive deforestation and lack of effective catchment management on the highlands of Ethiopia have resulted in high water yield due to increased runoff caused by reduced water retention capacity of the soil (see Figure 2). These authors indicated that consequently, in addition to onsite impacts, the problem of water erosion has expanded to low-lying areas in a form of reservoirs, lakes and marsh sedimentation, damage to agricultural land and settlements, as well as other infrastructures.

Among the many consequences of ecosystem and land degradation in Ethiopia are: (i) loss of topsoil (the national soil loss rate is classified as 'moderate to high', which is estimated at 30-100 t/ha but could reach up to 300 t/ha per year depending on land use practices, Wright and Adamseged, 1986), mass movement and terrain deformation through water and wind erosion, (ii) the country's low and declining agricultural land productivity and ability to provide food and feed for the ever increasing human and animal populations, (iii) the persistent food and nutrition insecurity and the threat of losing the capacity for achieving national food and nutrition security, (iv) the devaluation and eventual loss of the country's land for agricultural purposes, and the high cost of restoring and maintaining integrated agricultural landscapes and natural environments, (v) the loss of soil and aboveground biomass carbon stocks, soil health, atmospheric carbon sinking capacity and ability of the land to contribute to the country's resilience, adaptation and mitigation efforts to climate variability and change, and (vi) the increased severity of the impact of drought and other stresses to crop and livestock production, and elevated risks to natural disasters. Indeed, Ethiopia's State of Environment Report (EPA, 2003) has now officially established that there is a close relationship between environmental and land degradation, drought, crop failure, malnutrition and increased level of rural poverty in the country. The report highlighted that land degradation especially accelerated soil erosion, soil organic carbon and plant nutrient depletion and the decline in water quality are critical environmental problems facing the country, and the major causes of the chronic food and nutrition insecurity widely experienced by Ethiopia's largely rural population. All of these factors contribute to increasing vulnerability of Ethiopia's resource poor smallholder farming communities. Therefore, of all the challenges facing Ethiopia, ending chronic food shortages and rural poverty, and achieving enhanced livelihood and long-term food and nutrition security in an environmentally and socially sustainable manner is the most pressing agenda for the country.

1.8 Climate variability and change context

The study by Intergovernmental Panel on Climate Change (IPCC) show that global average surface temperatures are likely to increase because of radiative forcing of greenhouse gases (GHGs) in the atmosphere by 1.1 to 6.4°C in the 21st century, depending on the region (Van Vuuren et al., 2007; IPCC, 2013;). Projected increases in global temperatures are likely also to lead to increased frequency and severity of extreme weather events such as droughts and flooding across the globe.

Ethiopia, as part of the global community is feeling the impact of this change. Historical trends show that Ethiopia's temperature increased by up to 1.3°C from 1900 to 2006. Future projections show that the country is becoming even warmer, with average projected increases reaching up to 2.2 °C by the 2050's and by 3.-6°C by 2100 (WB, 2013b; IPCC, 2013). This will be associated with heat waves and higher water losses from soil, plants and water sources affecting both crop and livestock system. In some areas, this means a real risk of more droughts that will constrain crop growth and yield or could lead to catastrophic failure and chronic famine. Although the changes in rainfall are more difficult to predict and thus more uncertain, most models suggest that rainfall is likely to increase in general across Ethiopia by anywhere between 1 to 10% by 2050's, and by up to 20% by 2100 (WB, 2013b; IPCC, 2013). However, the same model predictions show significant regional variation, with more rain in some areas and less in others exposing them to regular severe flood and drought events, respectively. Ethiopian agriculture is typically rain-fed and relies on predictable rainy seasons. The increasing unpredictability of future rains is, therefore, a key barrier to successful food production and could become a significant threat to food security. However, it is also likely that climate change will not only bring new risks and shocks but also it will worsen existing problems (WB, 2013b). In such cases, the normal weather shocks affecting people's livelihoods will become more severe, more frequent, and will come with shorter warning times. Drier conditions will mean there are likely to be more frequent or widespread challenges for Ethiopia's pastoralist communities to find enough water and grazing for their livestock. It is also possible that climate change impacts will cause more land degradation, making it harder for Ethiopia's smallholder farmers to grow crops and make a living. Such repeated exposure to more acute weather shocks, with no time to avoid or prepare for them could seriously degrade the resilience built around rural smallholder farming and pastoral communities, and could drive Ethiopia's rural poor deeper into food insecurity and exacerbate their vulnerability.

In order to respond to these climate change challenges, Ethiopia - despite the fact that it contribute only to 0.27% of the global emissions - has made an ambitious commitment to curb its greenhouse gas emissions between now and 2030. As one of Africa's most vulnerable nations to climate change, Ethiopia recently submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), where the country as part of its Climate Resilient Green Economy (CRGE) intends to limit its net GHG emissions in 2030 to 145 Mt CO_2e or lower. This would constitute a 255 Mt CO_2e reduction from the projected business-as-usual or the conventional economic growth emissions scenario in 2030. It represents a major shift, since the business-as-usual economic growth would more than double Ethiopia's greenhouse emissions by 2030 to 400 Mt CO2e. Ethiopia's INDC shows that 86% of the expected abatement potential is anticipated to come from the agriculture, forestry and other land use (AFOLU) sector, and calls for higher efficiency from the country's integrated agricultural landscapes to mitigate climate change.

However, Ethiopia's initial national communication to the UNFCCC, and its INDC indicate that the sector wise carbon dioxide (CO_2) and non- CO_2 GHG emission profile of the country is dominated by emissions from agriculture and forestry (NMSA, 2001; Shiferaw et al., 2013; UNFCCC, 2015). The initial estimate also shows that the sink capacity of Ethiopia's forestry, other woody biomass and grassland sectors is decreasing rapidly due to deforestation mainly for agricultural and energy use and overgrazing, respectively. Therefore, there is a great interest in the country - as part of its CRGE and Growth and Transformation Plan (GTP) that is now in its second phase - for initiatives that target to integrate the implications of climate change into agriculture, environment, energy and public health.

1.9 Significance of climate-smart biochar systems in Ethiopia

Ethiopia's future prospects to enhance productivity, food and nutrition security, and promote economic growth largely depend on initiatives aimed at - developing holistic approaches that promote synergy between agriculture, environment, energy, health, socio-economic and climate - to enable the country reduce its reliance on traditional wood-based fuel through diversifying the source by bring non-traditional agricultural and agro-industrial wastes with limited to non-competitive use minimizing the pressure on remnant forests, rehabilitate its degraded land and agroecosystems, enhance crop productivity, food and nutrition security, and better manage climate risks via promoting socially and environmentally sustainable economic growth and livelihood asset creation, even as the climate changes, to help its chronically food insecure rural farming population resist economic and climatic shocks.

This is clearly highlighted in Ethiopia's green economy strategy which has prioritized two programmers that could help to develop sustainable forestry and reduce fuelwood demand by reducing demand for fuelwood via the dissemination and usage of fuel-efficient stoves and/or alternative-fuel cooking and baking techniques leading to reduced forest degradation, and increasing afforestation, reforestation, and forest management to increase carbon sequestration in forests and woodlands. As part of this initiative, the Sustainable Land Management (SLM) program, initiated by the Government of Ethiopia in collaboration with its international developments partners (e.g. World Bank, Finland, EU and Germany etc.) and other stakeholders is currently making headways to reverse land degradation and improve agricultural productivity. Large-scale SLM activities in the Amhara, Oromiya and Tigray regions already started to show encouraging results where about 77,000 hectares of land have been rehabilitated, a further 79,000 hectares of forest are being maintained in accordance with participatory forest management principles, as well as some 50,000 households, have adopted sustainable land management practices. These green initiatives and programs could form the core of any local green economy – protecting the natural assets that underpin development and livelihoods. It is imperative to indicate that these climate-smart integrated agricultural landscape management approaches are also designed to achieve multiple objectives including goals to: (i) enhance the soil's organic matter content and its aboveground biomass coverage, s essential macro- and micro-plant nutrient contents and the soil's ability to hold and exchange nutrients, (v) reduce top soil removal via wind and water erosion and loss of physical, chemical and biological fertility, (vi) foster increased efficiency of inorganic and organic fertilizers and improved soils health, while sequestering carbon wherever possible and contributing towards building resilience, adaptation and mitigation potentials to climate variability and change in Ethiopia.

Ethiopia's effort aimed at restoring local environments degraded by years of overuse and unsustainable management and achieving the above objectives include implementation of a package of sustainable integrated watershed management interventions in accordance with Ethiopia's Agricultural Transformation Agency's (ATA) five year strategic plan for the transformation of soil health and fertility in Ethiopia and the country's Ministry of Agriculture and Natural Resources Management (MOANRM) procedures on community-based participatory watershed development (CPWD) (Desta et al., 2005; Berhane et al., 2011) in integrated agricultural landscapes.

These multiple sustainable watershed management interventions range from integrated soil and water conservation (ISWC) practices such as construction of stone and soil embankments, hillside terraces, deep water infiltration trenches, shallow wells and ponds and stream diversion for irrigation, digging drainage channels to reduce flood damage to farmlands to adopting suitable integrated soil fertility (ISFM) and crop management practices that involve the use of multi-nutrient blended inorganic fertilizer, organic amendments, improved varieties, diversified cropping systems, and the use of multi-purpose leguminous cover cops and multi-strata agroforestry systems that can protect farmlands while providing additional food and fodder and improving the sustainability of agroecosystem attributes. They also include degraded land rehabilitation and marginal land reclamation measures such as area closures and natural regeneration of indigenous grass, shrub and tree species and/or the establishment of woodlots and forests etc., (Mekuria et al., 2007, 2010, 2011, 2013) that can improve the qualities of both the natural environment and the neighboring agroecosystems. However, most of these initiatives provide little emphasis on integrating climate-smart approaches that aim to benefits from the potential nexus and co-benefits of integrating agriculture, environment, energy, health, socio-economic and climate. Therefore, it is against these backdrops that we propose the development of the next-generation sustainable biochar systems that help to reduce the alarming trends in land and ecosystem degradation, improve soil fertility and health, agricultural productivity and food and nutrition security, while also contributing towards reducing energy poverty, clean-up the living environment, and sequestering carbon in agriculture soils supporting the country's strategic policy where the AFOLU sector is expected to contribute towards adaptation and mitigation to climate variability and change. This report is prepared as part of the GeoSFF part measure "Potential analyses of biochar systems for improved soil and nutrient management in Ethiopia" financed by The German Federal Ministry for Economic Cooperation and Development (BMZ), and implemented by The Federal Institute for Geosciences and Natural Resources (BGR) to explore the "Socio-economic scenarios of low hanging fruits for developing climate-smart biochar systems in Ethiopia to improve soil fertility, agricultural productivity and food and nutrition security." The report explores how these goals can be achieved through identifying and more efficient use of the existing non-competitive agricultural and agro-industrial biomass waste streams in an environmentally and socially sustainable manner, while from the outset recognizing the multiple economic constraints and tradeoffs involved in agricultural, agro-industrial and other biomass residues in resource-poor smallholding farming systems of rural communities of Ethiopia.

1.10 Biochar production technology and biochar properties

Biochar is the solid carbon-enriched product of thermal decomposition obtained when non-competitive biomass residues are heated at relatively low temperatures (typically between 300 °C to 700 °C) under oxygen-deprived environment, a process technically known as "pyrolysis" (Lehmann and Joseph, 2009). Although the biochar production process often mirrors the production of charcoal, which is one of the most ancient industrial technologies developed by mankind (Harris, 1999), it distinguishes itself from charcoal in that biochar is produced with the intent to be applied to soil.

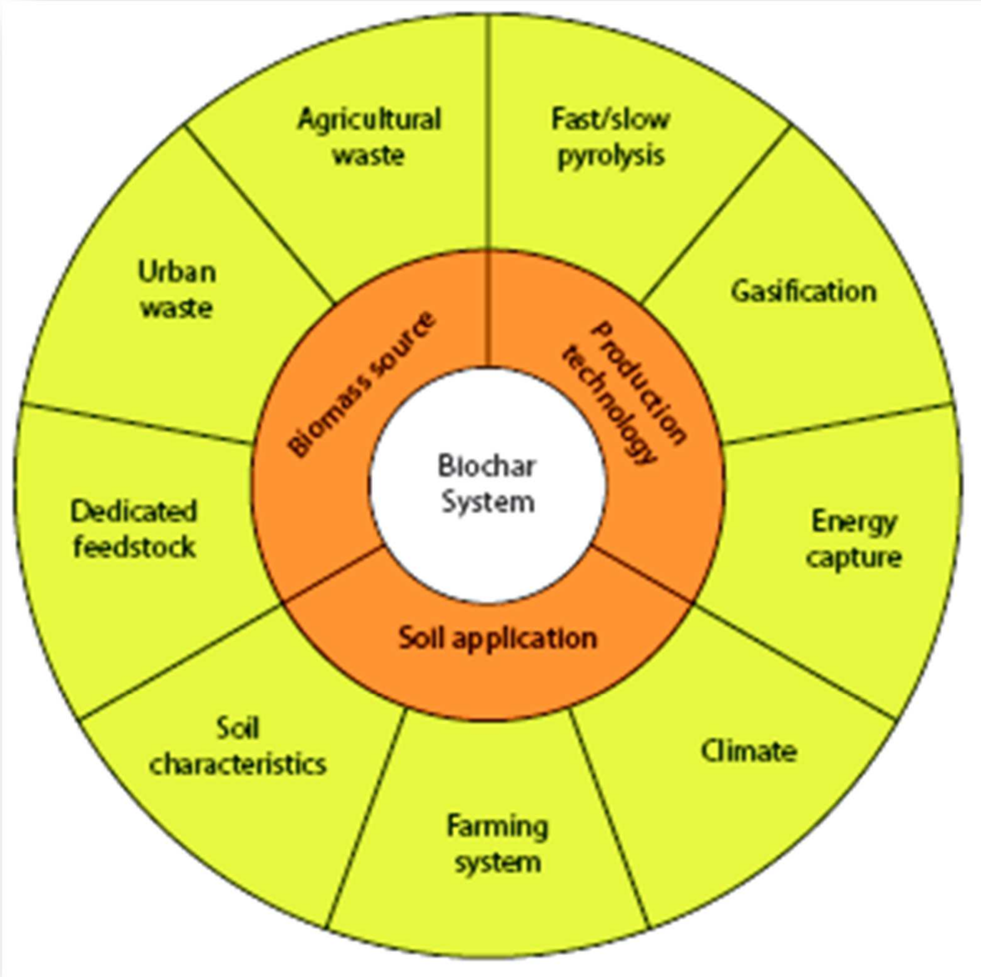

Figure 3. Biochar systems (Lehmann and Joseph, 2009).

The word "biochar" is a system-defined term referring to black carbon that is produced intentionally to manage carbon - with a downstream single sector-based or integrated application to soils - for sustainable agriculture, environmental management, and climate change mitigation purposes. It is often produced with the intent to be applied to soil as a means of improving soil productivity, carbon storage, or both. Although the term "biochar" has come into common usage only relatively recently, the practice of amending soils with charcoal for fertility management goes back millennia. Instances can be found in Africa, Asia, and notably in the Amazon basin where the historically managed highly fertile and carbon-rich dark earths (e.g., Amazonian and African Dark Earths) stand out next to the original highly weathered, infertile, yellowish- to- red tropical soils in the land scape (Glaser et al., 2002; Lehmann et al., 2003; Solomon et al., 2016).

Agricultural and agro-industrial biomass residues typically contains about 50% carbon, which is relatively quickly decomposed and reemitted to the atmosphere in the form of GHGs such CO_2,

CH_4 etc. upon decay in soil. The mean residence time of fresh biomass residue is in the range of months to years, with longer times for woody biomass and colder climates. Biochar retains between 10 percent and 70 percent (on average about 50%) of the carbon present in the original biomass and slows down the rate of carbon decomposition by one or two orders of magnitude, that is, in the scale of centuries or millennia. Although, in principle biochar can be made from any type of biomass, it is important to understand how different production conditions can result in different types of biochars, and how they interact with different soil types.

Three elements critical to every biochar system including the proposed one in Ethiopia are: (i) the source and availability of biomass, (ii) the means of biochar production at the envisioned scale, and (iii) whether and how it is applied to soil (see Figure 3). For each element there are a wide range of alternatives. In fact, theoretically the source for biochar feedstock can be almost any type of biomass. However, biomass is one of the most important resources in smallholder farms in Ethiopia. It provides rural households with ecosystem services such as soil organic matter, soil protection against erosion, nutrient recycling to crops, to other common usages such as source of fuel, building materials and animal feed (Torres-Rojas et al., 2011). Conversely, it is also important to realize the fact that although biomass in most cases come at a cost, it can also pose tremendous environmental burden often disposed in water ways polluting drinking water or allowed to decompose in open air releasing substantial amounts of GHGs. Therefore, the judicious choice of feed stocks plays an important role not only for matching biochar properties to soil needs but also for the sustainability and economics of biochar systems (Roberts et al., 2010; World Bank, 2011).

Biochar can be produced at various scales. In the envisioned biochar production system under the current report, the scale and complexity vary from small scale rural household cookstove hub-based to village or municipal-level pyrolysis systems to medium scale regional and national-level industrial pyrolysis plants-based bioenergy-biochar-soil application systems with benefits for soil health and productivity, farming economies, climate, and human well-being. Biochar, depending on the feedstock and production parameters such as pyrolysis temperature, can exhibit different physical and chemical characteristics ranging from surface area, porosity to pH, cation exchange capacity and level of carbon recovery and carbon stability as shown in Figure 4.

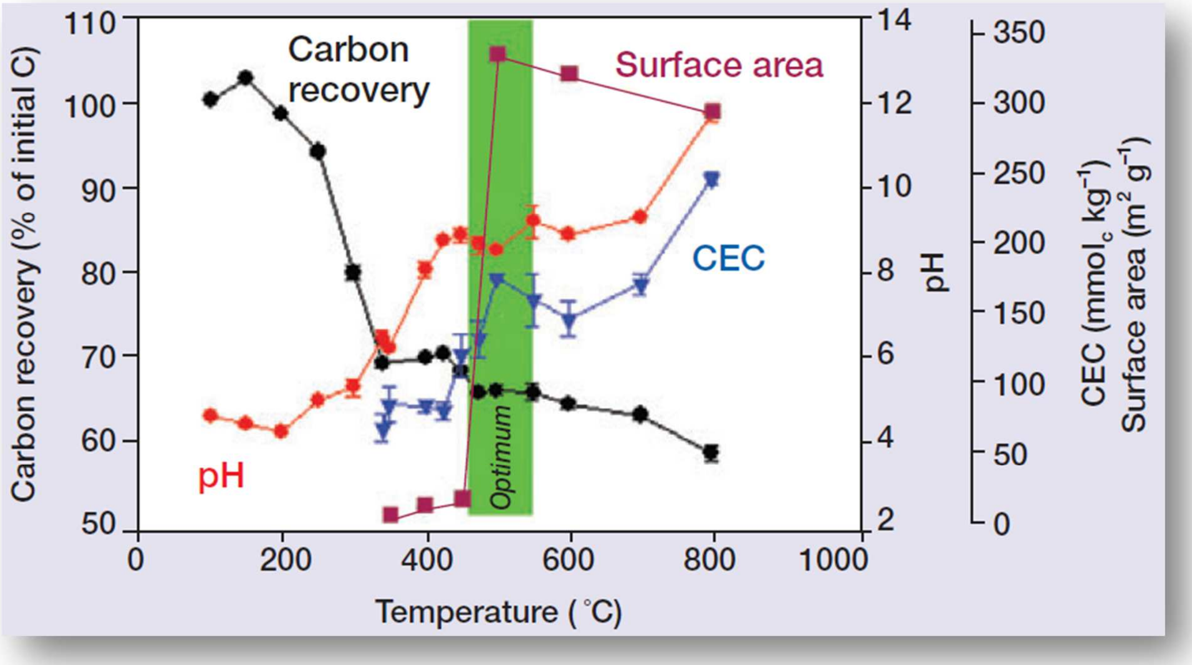

Figure 4. Physical and chemical properties at various temperatures during the various stages of pyrolysis of biochar produced from hard wood residue (Lehmann, 2007).

While pyrolysis is not a new technology, the optimization of pyrolysis procedures with an intent to produce a specific type of biochar suitable to overcome the various soil-related productivity constraints, is a relatively new approach in soil sciences, allowing the potential opportunity to adjust the pyrolysis conditions and feedstock types as shown in Figure 4 to produce particular types of biochar with required physical and chemical properties to meet specific edaphic constraints to improve the health and fertility of soils, enhance agricultural production, and food and nutrition security in different ecoregions of Ethiopia, while sequestering carbon in soils. Various reports in the past showed that application of biochar to soils, if appropriately designed using the various production conditions, could serve a number of purposes for small-scale agriculture and help improve the food security, income, and nutrition of resource-poor rural households by: (i) moderating soil pH (Major et al., 2010), (ii) increasing water infiltration, soil water holding capacity and aeration (Glaser et al., 2002), (iii) improving nutrient retention and potentially reduce the need for mineral fertilizers (Steiner et al., 2008; Major et al., 2010), (iv) reducing leaching of nitrogen into ground water (Major et al., 2011), (v) increasing the efficiency of traditional organic fertilizers, (vi) improving proliferation of beneficial microorganisms through biochar applications (Lehmann et al., 2011), (vii) offer long-term benefits due to some biochars having half-lives of thousands of years (Zimmerman, 2010), (viii) reducing greenhouse gas emissions by avoiding emissions from land fill, through more efficient fuel use and lower generation of nitrous oxide from soil (Singh et al., 2010), (ix) enhancing uptake of CO2 by photosynthesis through improved soil fertility (Whitman et al., 2011), and (x) reducing deforestation due to the ability to switch from wood fuel to mainly residues (Whitman and Lehmann, 2009; Torres-Rojas et al., 2011; Whitman et al., 2011). These reports demonstrate that to ensure sustainability, judicious biomass selection, appropriate conversion technology and considerations of specific soil and crop needs are critical.

1.10.1 Integration of biochar into sustainable soil fertility management practices

Ethiopia is making a concerted effort to increase its agricultural productivity, and improve the livelihood of its rural population in an environmentally safe and sustainable manner. As part of this initiative and inspired by the kickoff-workshop of the GeoSFF, The Soil Fertility Improvement Directorate of Ethiopia's MOANR in September, 2016 organized an international conference where participants from BGR, Cornell University, Biochar Europe UG , MOANR, INGOs , NGOs , and from Ethiopia's Institute of Agricultural Research (EIAR) took part to explore the potentials of sustainable biochar systems and opportunities to integrate these climate-smart approaches into the country's sustainable soil management practices.

Among other things, the objective of the Soil Fertility Improvement Directorate effort was geared towards improving soil health and revitalize Ethiopia's depleted soils, improve the effectiveness of organic and artificial fertilizers and other agricultural management practices that may help to increase agricultural productivity of resource-poor Ethiopian farmers and rehabilitate degraded watersheds across the Ethiopian landscape through sustainable agricultural interventions that support agroecological intensification to achieve food and nutritional security at the household level. The conference concluded with the resolution to establish a National Soil Management Platform (NSMP) in Ethiopia, and also by indicating the need for preliminary information and data related to the potentials of biochar systems for improving soil and nutrient management in Ethiopia. The pressing issues in the conference include questions related to:

(i) What is the state of the art of biochar systems in Ethiopia?
(ii) What needs to be done to introduce climate-smart biochar technology to farmers?
(iii) What are the low hanging fruits when it comes to availability on non-competitive biomass resources that can fuel the technology and result in model pilot projects in the country that can garner support from Ethiopia's development partners?
(iv) What are the potential private and public sector partners?
(v) What type of business partnership could be effective implemented to develop socio-economically viable model projects that have potential for future scaling up?

Thus, the conference confirmed the necessity of the GeoSFF part measure goals to document the potentials of biochar systems for soil and nutrient management to provide the Soil Fertility Improvement Directorate of Ethiopia's MOANR with a basis for decision-making with respect to future integration of biochar systems in existing strategies for soil rehabilitation and nutrient management in agriculture. The GeoSFF part measure is thereby divided in the following parts: (i) the state of the art of biochar systems in Sub-Sharan Africa (by Biochar Europe UG), (ii) current status of biochar research and various biochar-related activities in the country (by Biochar Europe UG) (iii) the socio-economic scenarios of low hanging fruits for developing climate-smart biochar systems with potential for developing scalable pilot projects in in Ethiopia (by Cornell), (iv) Identification and characterization of two priority areas for a biochar system pilot project in Ethiopia (by Biochar Europe UG).

These studies are expected to provide the Soil Fertility Improvement Directorate of Ethiopia's MOANR with a basis for decision-making with respect to future integration of biochar systems in existing strategies for soil rehabilitation and nutrient management in agriculture, and therefore, will support the sustainable management of land in the long term.

1.10.2 Objectives of the current report

Despite the positive outlook for biochar systems, the introduction and adoption of new technology packages are often fraught with other things by lack of demonstrable success stories and models, detailed technical knowledge about the production system, resource availability, effective utilization of the end products, market development, as well as other prevailing socio-cultural and economic challenges and opportunities that both smallholder agricultural communities, and public sector enterprises time and again need to respond to. Therefore, the objective of this report are: (i) to conduct a rapid assessment to identify potentially available non-competitive biomass residues or “real waste” that can help incubate and fuel biochar systems-based technology targeting in a manner that aim to benefits from the potential nexus of integrating agriculture, environment, energy, health, socio-economic and climate by making use of the combination of previous studies in Ethiopia by Cornell Biochar Research Group, as well as follow-up survey, interview and other literature evidence-based approaches, (ii) to explore the socio-economic scenarios that help to develop straightforward fundable climate-smart model biochar systems pilot project portfolios with potentials for scaling up using the low-hanging fruits identified by the rapid assessment, and (iii) to identify potential biochar-based agricultural inputs or products associated with each biomass residue; and prospective beneficiaries who seems very likely to use the products generated from the biochar systems-based technology with special focus to alleviate various soil fertility, agricultural, food and nutrition security, as well as environment and climate-related constraints in Ethiopia.

2 Sourcing non-competitive biomass residue for biochar in Ethiopia

2.1 Brief overview of potential biomass residue sources

Biomass in the context of the current report refers to biological materials derived from living or recently dead biological materials, encompassing materials from both plants and animals that can be used as feedstock for the development of sustainable biochar systems in Ethiopia. Biomass resources include wood and wood wastes, agricultural crop residues and other farm wastes, by-products of flower production industry, household and municipal wastes, wastes from food processing, animal wastes, aquatic plants, weeds and algae etc.

There are competing uses for these resources in the country because of their economic and environmental value. Biomass can be used to generate power, heat and steam, for the production of transportation fuels, as well as for home cooking. It is also used as organic fertilizer, animal feed, and construction material etc. (see examples in Figure 5) for smallholder household biomass resource utilization in two Ethiopian ecozones).

Biomass residue utilization in Ethiopia varies with the size of the enterprise - whether it is farm or agro-industrial plant. For example, in subsistence farming context of the country, the relatively small amounts of residues produced in these farms could be effectively incorporated into the system as organic soil amendments, for construction purposes, and animal feed, for fuel - or they can be also disposed as unwanted nuisance and disposed as trash along with other household wastes. In large farms and agro-industries – the enormous amount of available residues produced at the site often cannot be used on-site due to a number of reasons including the sheer size of waste materials produced each day or season, the lack of available infrastructure for storage and handling, and the limited demand in the immediate vicinity. Similar to the small scale farms, these residues often tends to be disposed of wastefully, in a manner that creates both environmental and public hazard.

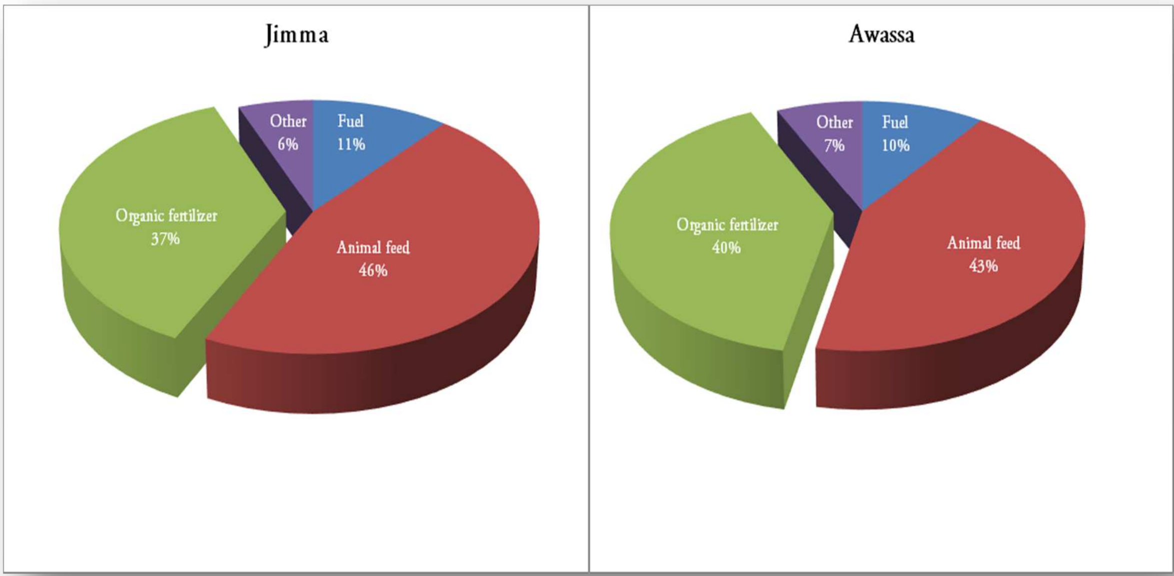

Figure 5. Competitive use and allocation of crop residues in smallholder faming households at Jimma (n=150 smallholder households) and Awassa (n=200 smallholder households) ecozones in Ethiopia (Data from Cornell-Jimma University first round socio-economic survey).

Agriculture, although, dominated by mostly small-holder and largely subsistence farming with low productivity on fragmented and highly degraded lands, is crucial for Ethiopia's food security. In fact the sector is the largest contributor to overall economic growth and poverty reduction. Therefore, it is understood that leading the sector to higher productivity and efficiency is not just fundamental to poverty reduction and food security, but can also contribute to meeting a number of other key development challenges that Ethiopia faces. The GOE recognizes the importance of agricultural development, and has shown a long-standing and strong commitment to this sector. However, there is also a general concusses in the country that the sector needs transformation, and Ethiopia together with its international development partners have started the process by designing its Agricultural Growth Program (AGP) - which is widely implemented in the country to drive the revival and long-term sustainability of this sector. Ethiopia is currently executing the second phase of this strategic program. The GOE's GTP also includes bolstering the productivity of both major staple and cash crops and the livestock sector: enhancing marketing systems, upgrading participation of private sector, increasing volume of irrigated land and curtailing amount of households with inadequate food among other things.

Table 1. Total area, production and yield of crops from Ethiopia's smallholder agriculture for the 2014/15 season (CSA, 2015).

Crop	Number of Holders	Area In Hectares	% Distribution	Production In Quintals	% Distribution	Yiels (Qt/He)
Grain Crops.......	**14,159,734.00**	**12,566,239.98**	100.00	**270,396,048.03**	100.00	
Cereals.................	**13,346,462.00**	**10,152,015.05**	80.76	**236,076,624.38**	87.30	
Teff..................	6,536,605.00	3,016,062.55	24.03	47,506,572.79	17.58	15.75
Barley................	4,095,273.00	993,938.74	7.92	19,533,847.83	7.23	19.65
Wheat................	4,614,159.00	1,663,845.63	13.26	42,315,887.16	15.66	25.43
Maize................	8,685,557.00	2,114,876.10	16.78	72,349,551.02	26.74	34.31
Sorghum..............	4,993,368.00	1,834,650.81	14.57	43,391,342.61	16.03	23.69
Finger millet.........	1,607,677.00	453,909.38	3.62	9,153,145.18	3.39	20.17
Oats/'Aja'...........	255,008.00	27,899.64	0.22	508,059.26	0.19	18.21
Rice..................	118,079.00	46,832.21	0.37	1,318,218.53	0.49	28.16
Pulses..................	**7,931,562.00**	**1,558,422.02**	12.42	**26,718,344.54**	9.89	
Faba beans...........	3,759,029.00	443,107.88	3.53	8,389,438.97	3.10	18.93
Field peas...........	1,663,488.00	230,667.20	1.84	3,426,367.80	1.27	14.85
White Haricot beans...	970,630.00	126,195.69	1.01	2,021,192.52	0.75	16.02
Red Haricot beans.....	2,242,178.00	197,131.58	1.57	3,116,055.55	1.15	15.81
Chick-peas...........	1,081,755.00	239,755.25	1.91	4,586,822.55	1.70	19.13
Lentils...............	768,748.00	98,869.15	0.79	1,373,542.40	0.51	13.89
Grass peas...........	744,321.00	136,883.77	1.09	2,514,390.03	0.93	18.37
Soya beans...........	109,055.00	35,259.76	0.28	721,837.45	0.27	20.47
Fenugreek...........	523,227.00	20,524.42	0.16	251,286.63	0.09	12.24
Mung bean/"Masho".....	62,377.00	14,562.00	0.12	140,676.54	0.05	9.66
Gibto................	93,390.00	15,545.36	0.12	176,905.80	0.07	11.38
Oilseeds................	**2,936,158.00**	**855,762.91**	6.82	**7,600,993.24**	2.81	
Neug.................	826,877.00	252,584.38	2.01	2,244,625.07	0.83	8.89
Linseed..............	810,657.00	82,325.78	0.66	831,305.05	0.31	10.10
Groundnuts...........	313,072.00	64,649.34	0.52	1,037,062.38	0.38	16.04
Sunflower............	131,813.00	5,625.81	0.04	63,250.64	0.02	11.25
Sesame...............	867,347.00	420,494.87	3.35	2,887,700.79	1.07	6.87
Rapeseed.............	478,727.00	30,082.74	0.24	537,049.31	0.20	17.85
Vegetables.............	**5,762,200.00**	**139,717.15**	100.00	**5,954,004.03**	100.00	
Lettuce..............	32,279.00	114.14	0.08	*	*	*
Head Cabbage..........	364,315.00	4,541.48	3.26	289,189.96	4.86	63.71
Ethiopian Cabbage.....	3,421,976.00	31,385.65	22.45	3,267,608.99	54.89	104.28
Tomatoes.............	220,506.00	5,026.68	3.58	306,999.50	5.14	61.12
Green peppers.........	1,039,383.00	5,889.02	4.20	367,926.32	6.17	62.69
Red peppers...........	1,691,480.00	92,455.73	66.21	1,707,656.64	28.69	18.48
Swiss chard...........	99,917.00	304.47	0.22	*	*	*
Root Crops..............	**5,903,835.00**	**216,971.05**	100.00	**54,615,540.22**		
Beetroot.............	333,072.00	1,949.77	0.90	182,079.42	100.00	93.39
Carrot...............	159,136.00	3,697.27	1.71	142,970.14	0.33	38.67
Onion................	705,877.00	22,771.88	10.52	2,307,451.89	0.26	101.35
Potatoes.............	1,288,146.00	67,361.87	31.13	9,218,320.70	4.23	136.85
Yam/'Boye'...........	314,237.00	3,717.39	1.71	*	16.90	*
Garlic...............	1,768,487.00	9,257.81	4.28	934,868.73	*	100.98
Taro/'Godere'.........	1,700,269.00	48,817.41	22.41	14,488,345.20	1.71	297.81
Sweet potatoes........	1,729,229.00	59,397.64	27.33	27,015,989.97	26.47	456.56
Fruit Crops.............	**9,478,920.00**	**1,298,590.13**	100.00	**30,009,711.12**	100.00	
Avocados.............	1,382,199.00	13,798.04	1.05	536,977.64	1.79	39.61
Bananas..............	2,574,035.00	53,956.16	4.12	4,782,510.44	15.94	89.41
Guavas...............	331,529.00	2,830.24	0.22	39,322.77	0.13	13.92
Lemons...............	222,942.00	1,238.77	0.10	79,038.14	0.26	64.11
Mangoes..............	1,146,419.00	12,860.54	0.97	905,613.94	3.02	72.30
Oranges..............	454,707.00	3,298.97	0.25	314,276.98	1.05	96.50
Papayas..............	572,313.00	2,434.14	0.18	404,350.56	1.35	171.89
Pineapples............	36,797.00	251.35	0.02	*	*	*
Chat...................	**3,066,655.00**	**249,358.02**	19.16	**2,758,345.28**	9.19	11.10
Coffee.................	**4,723,483.00**	**568,740.00**	42.76	**4,199,801.56**	13.99	7.57
Hops...................	**2,378,125.00**	**28,541.94**	2.18	**372,731.44**	1.24	13.20
Sugar Cane.............	**1,270,627.00**	**30,296.16**	2.32	**15,612,347.12**	52.02	519.41

Crop	Number of Trees Harvested	Production In Quintals			Yield(Qts/Tree)		
		Amicho	Kocho	Bula	Amicho	Kocho	Bula
Enset	98,002,435.00	22,929,729.96	26,219,341.21	1,022,800.30	0.23	0.27	0.01

* One quintal is 100 kg.

2.1.1 Ethiopia's agricultural crop subsector

Ethiopia's major crops (both staple and cash crops) include a variety of grains (principal grains include teff, wheat, barely, maize, sorghum, millet etc.), pulses (peas, beans, lentils, chickpeas etc.) and oilseeds (sesame, niger seed, flax etc.), as well as vegetables, root crops (potatoes, onion, enset etc.), and fruit (bananas, avocado, papayas, mangoes, oranges etc.) crops; while the cash crops include sweetener and stimulant crops (sugarcane, coffee, chat, hops etc.), pulse (peas, beans, lentils, peanuts etc.) and oilseeds (sesame, niger seed, soybeans etc.), flowers (roses, gypsophilia, hypericum, limonium, chrysanthemum, carnations, etc., fiber (primarily cotton) crops (see details in Table 1).

Table 2. Breakdown of the second socioeconomic survey participants in Ethiopia's for ecozones.

Survey location	Frequency	Percent
Jimma	130	25.1
Debre Zeit	139	26.8
Worer	119	22.9
Awassa	130	25.2
Total	518	100

The Cornell and Jimma University group recently conducted a second round expanded socioeconomic assessment survey where a total of 518 households were visited in four ecozones (See Table 2 for details). The locations were: Jimma (Oromia Regional State), Awassa (SNNPRS), Debre Zeit (Oromia Regional State), and Worer (Afar Regional State). The survey focused on certain areas in each of the survey locations. In Jimma the focus was on coffee producing areas, in Afar it focused on agro-pastoral areas with high levels of prosopis invasive weed, in Debre Zeit it focused on areas with wheat and teff production, and in Hawassa it focused on CARE intervention area where maize and sugar cane were grown. Four kebeles in each of the four study areas were surveyed.

As part of the socioeconomic survey the family size of the participant households was assessed (see Figure 6). The results show that the family size varies from 2 person house hold to 12 person households, where the majority of the households being within the 4 to 8 person. A vast majority 88.4% (458) of the sample reported they had land. The mean amount of total land for a household was 1.70 hectares, where households in Worer being with the largest average land holding (1.81 ha), followed by Awassa (1.69 ha), Jimma (1.67 ha), followed by those in Debre Zeit with the lowest average land holding (1.63 ha). In addition, as part of the current assessment, general economic activities of these households were conducted to get an idea of the dominant economic activity and farming system, and biomass residue associate with these major economic activities (see Table 3).

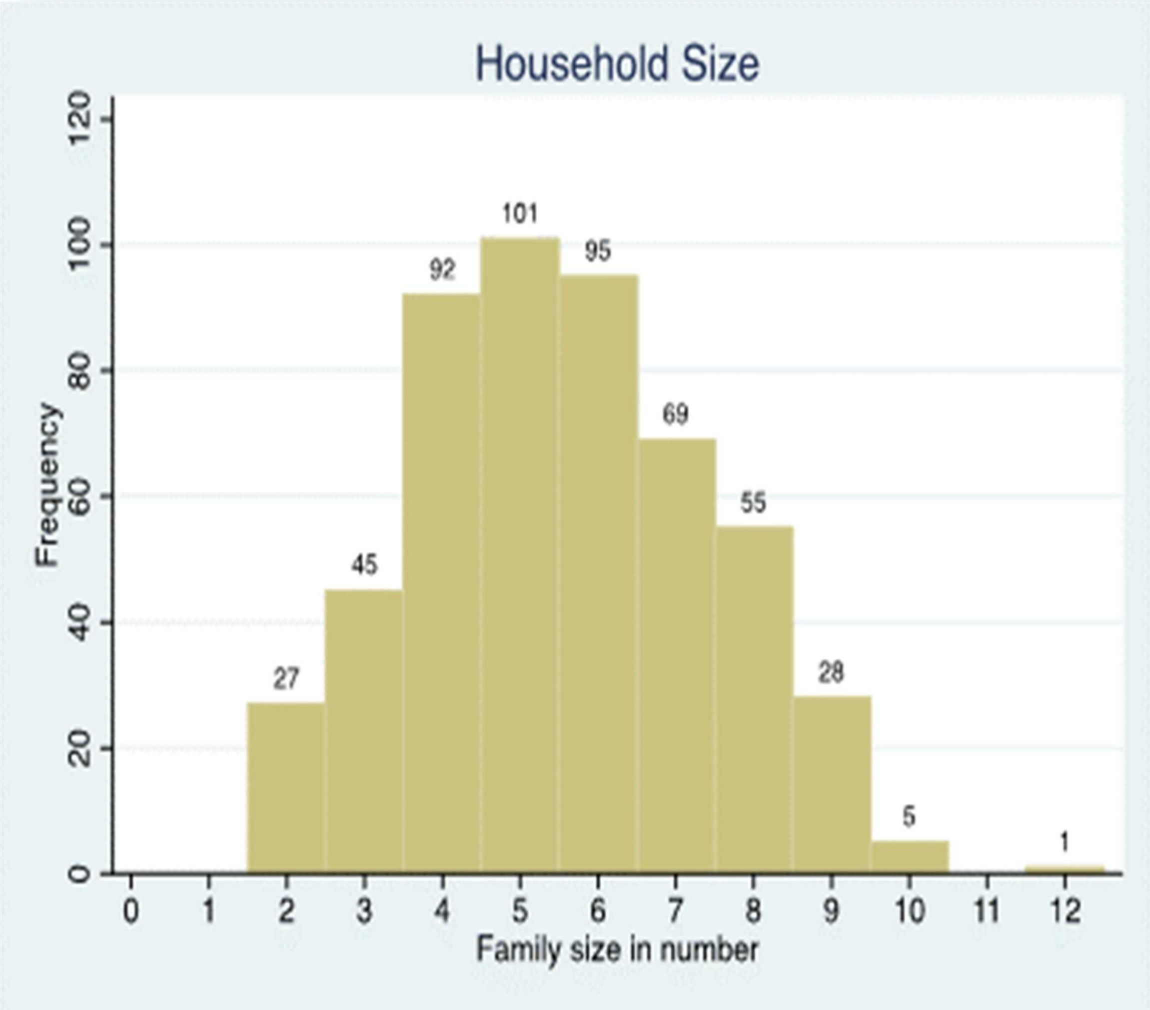

Figure 6. Histogram of the family size of the survey participants in four Ethiopian ecozones.

The results in Table 3 show that the majority (67%) of these rural farming households are engaged in mixed crop and livestock system as part of their major economic activities. Only 10% of the participants were engaged in farming systems involving only crop husbandry, while the while 23% of the participants were engaged in livestock husbandry, the majority which were from Worere - a region dominated by predominantly pastoral communities. The dominance of the mixed cropping system in Ethiopian smallholder communities provided a clear indication that any strategic approach that aims to utilize biomass residues for energy, sustainable agriculture, environment and human health management in a manner that considers socioeconomic viability and climate change mitigation, adaptation and resilience must integrate the livestock center.

Table 3. The main source of economic activities in four Ethiopian ecozones.

Survey location	Main Source of Economic Activity			
	Crops only	Livestock only	Mixed	Total
Jimma	10	0	120	130
Debre Zeit	5	14	120	139
Worer	2	77	40	119
Awassa	35	27	68	130
Total	50	118	348	518

2.1.2 Ethiopia's livestock subsector

Ethiopia is home to the largest population of livestock in Africa. According to the 2015 Ethiopian Government's Agricultural Sample Survey (ASS), the country has about 50 million cattle, 23 million sheep, 22 million goats and about 1 million camels. The total poultry population is estimated to be about 57 million. Livestock production is an important component of the national economy generating nearly 8% of the US$ 2.80 billion in export income, and it is expected to be an important component of the national export economy of the country for the future. Although informal livestock trade is difficult to quantify, some estimates indicate it accounts for additional $200 million per year. Furthermore, the livestock sector makes a major contribution to rural development in Ethiopia by producing food, enhancing crop production and providing additional economic goods and services. At the household level, up to 70% of all Ethiopians rely on livestock in some form to contribute to their family's livelihood. Sales of livestock products provide funds for purchasing crop inputs and for financing farm investments. Livestock as well confer a certain degree of security in times of crop failure, as they are a "near-cash" capital stock and also provides farmyard manure that is commonly applied to improve soil fertility and also used as a source of energy. On the other hand, draught animals provide power for the cultivation of the smallholdings and for crop threshing virtually all over the country and are also essential modes of transport to take holders and their families long-distances, to convey their agricultural products to the market places and bring back their domestic necessities.

Overall, the Livestock plays vital roles in generating income to farmers, creating job opportunities, ensuring food security, providing services, contributing to asset, social, cultural and environmental values, and sustain livelihoods. The subsector contributes about 16.5% of the national GDP, and 35.6% of the agricultural GDP (Metaferia et al. 2011). It also contributes 15% of export earnings and 30% of agricultural employment (Behnke 2010).

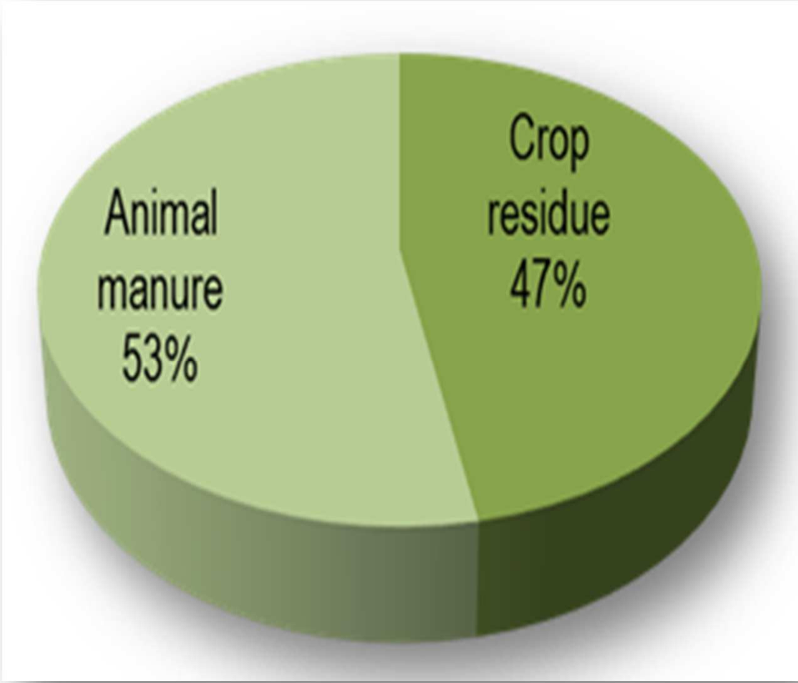

Figure 7. Proportional distribution of Ethiopia's national agricultural waste steam into crop residues and animal manure.

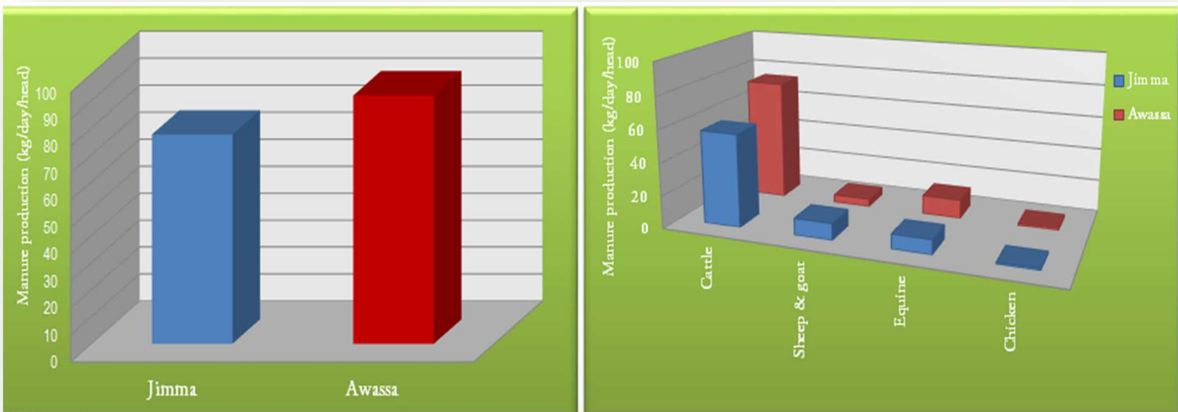

Figure 8. Potential manure production (8a) and source breakdown (8b) in smallholder households at Jimma (n=150) and Awassa (n=200) ecozones in Ethiopia (Data from Cornell-Jimma University socio-economic survey).

According to Table 1, Ethiopia's major staple and cash crops, along with its livestock sector that is believed to have the largest livestock population in Africa (CSA 2013), as well as with the GOE's renewed emphasis to bolster the country's agriculture and agro-industry segments, are all expected to genera significant amounts of residues and waste streams. Past national level agriculture estimates show that in fact the number for agriculture wastes could be as high as 51 million t/year (see Figure 7 for proportional distribution between crop residues and animal manure). The majority of animal manure is generated from cattle, followed by sheep and goat, equine and chickens manure in no order of importance (see Figure 8a and 8b). Hence, there is a clear need of options for effective waste management and conversion of waste streams into sources of renewable energy and useful agricultural inputs to suitably enhance food and nutrition security in the country; highlighting the many environmental and social complexities associated with economic development and growing waste production.

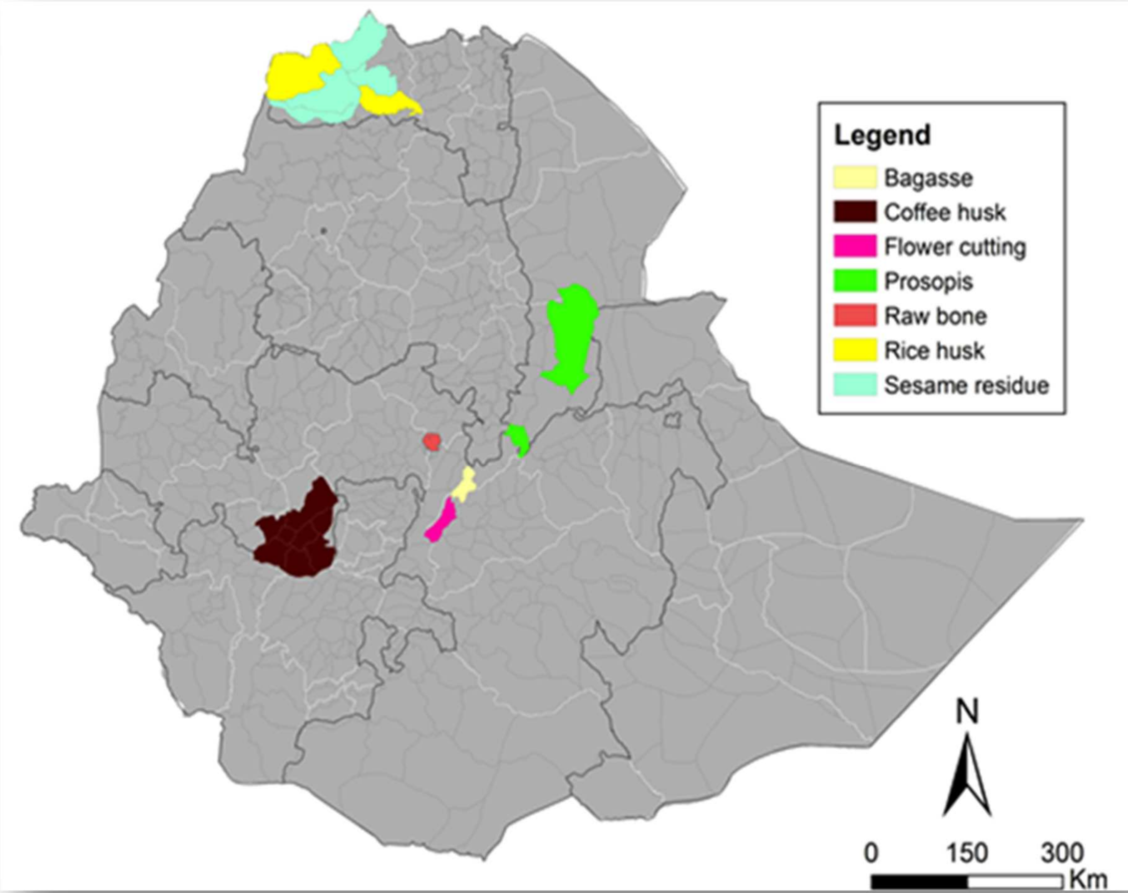

Figure 9. Geospatial map of potential low-hanging biomass resources locations by woreda for a potential private public partnerships model pilot project development of climate-smart biochar systems in Ethiopia.

Recognizing the close links between agriculture, environmental, energy and other development concerns, there is also a clear need in Ethiopia to integrate climate considerations into its broader agriculture and agro-industry development planning processes in a manner that effectively harnesses the waste stream associated with these sectors. Based on the results of these observations and studies, follow up discussions with private and public sector partners, and officials from the Ethiopia's MOANR in the aftermath of the September, 2016 international conference organized by the MOANR's Soil Fertility Improvement Directorate, a strategic decision was made to identify, report and focus on the below low hanging fruits where potential biochar systems projects that involve private and public sector business partnership, and to develop socio-economic scenarios for viable and scalable pilot model projects based on agricultural an agro-industrial waste streams from crops and livestock sectors. Hence, the next section of this report recounts the biomass resources, potential partnerships and socio-economic scenarios of around: (i) animal bones, (ii) coffee husk, (iii) flower cutting, (iv) invasive weed (prosopis), (v) bagasse, (vi) rice husk and sesame residues distributed across the country (see Figure 9 for geospatial distribution of these biomass resources along the various Ethiopia's regional states and woredas) for developing climate-smart biochar systems that take into account the synergy between agriculture, environment, energy, health, socio-economic and climate in Ethiopia.

2.2 Low-hanging biomass residue streams for climate-smart biochar systems

2.2.1 Private-public sector partnership development potential from animal bone waste stream in Ethiopia

The livestock subsector has a huge contribution to Ethiopia's national economy and livelihoods of many Ethiopians promising to rally round the economic development of the country. Livestock products and by-products in the form of meat, milk, honey, eggs, cheese, and butter supply the needed animal protein that contribute to the improvement of the nutritional status of the people. Livestock also plays an important role in providing export commodities, such as live animals, hides, and skins to earn foreign exchanges to the country.

Simons et al., 2014 reported that Ethiopia's animal herd produces 192118–329744 tonnes of bone residues every year, which contain 9-11% elemental phosphorus (see Table 4, Simons et al., 2014). This animal bones, byproducts of meat consumption and animal husbandry, contain as much phosphorus as 84,290-176,937 tonnes of chemical phosphorus fertilizers such diammonium phosphate (DAP) and triple superphosphate (TSP). Recycling of these bones waste streams could potentially help Ethiopia replace from 25%-52% of its annual imported phosphorus fertilizer supplies from the year 2014 (FAOSTAT, 2014). Importing an equivalent amount of phosphorus fertilizer costs Ethiopia approximately US$ 50 to 104 million.

With the exception of nitrogen, phosphorus is the most important nutrient in agricultural production. In crop development, phosphorus is critical for flowering, fruiting, maturation, root development and cell division. Unlike nitrogen, which can literally be pulled from the air, commercial phosphorus is derived almost exclusively from mined rock phosphate, which is finite and non-renewable. As demand for phosphorus is expected to double by 2050, there is mounting evidence that the world's supply of rock phosphate around is under threat (Chowdhury et al., 2017). If the supply of phosphorus fertilizer were limited, it would represent an existential threat to food security around the world, but most particularly in African countries such as Ethiopia where the poorest farmers face the highest fertilizer prices and the highest rates of food insecurity (Dana et al., 2002).

Table 4. Potential total raw animal bones that could be available from slaughtered animals in Ethiopia.

Livestock	Total animals*	Bone mass	Animals slaughtered	Bone residues	Total phosphorus†
		Kg/animal	%/year	Tonnes/year	Tonnes/ year
Cattle	50283000	20-30	16–17	160908–256447	
Sheep	23642000	4-5	19–34	17968–40192	
Goats	22070000	4-5	15–30	13242–33106	
Total	95995000			192118–329744	17279–36272

*Averages of total phosphorus from 2008–2011; †, Averages of total phosphorus from concentration in bones of 9–11% (Simon et al., 2014).

Over the last decade, improved agricultural productivity has been the principal driver of economic growth in Ethiopia, and increased fertilizer use has been integral in fueling productivity. Continued gains in fertilizer use and availability are vital if Ethiopia wishes to sustain its historic run of economic growth and poverty reduction. Adoption of commercial inorganic fertilizer, however, remains low. While imports have more than doubled in the last decade, only 30-40% of Ethiopian farmers use fertilizer, with applications significantly below recommended rates (Spielman et al., 2010). One in three farmers cite availability as the principal constraint to adoption while another 40% cite costs as the principal constraint. Improving access to phosphorus fertilizer in particular, may present the most daunting challenge, considering the current global constraints and outlooks described in this report. Ethiopia currently imports all of its phosphorus fertilizers and mineable phosphorus reserves around the world are quickly depleting (Beardsley, 2011). World phosphorus prices can be extremely volatile: in fact as recent as 2008, world phosphorus prices spiked by 800% (Cordell and White, 2013). The lack of mineable phosphorus and the prospect of future phosphorus shortfalls threaten growth and food security in Ethiopia, as in many countries world-wide. Securing an alternative and renewal source of phosphorus especially for resource-poor smallholder farming households from livestock waste stream involving discarded raw animal bones could be an excellent opportunity with immense, environmental and socio-economic potential; and currently considered in the country as one of the low hanging fruits where scaling up potential using private public partnership schemes should be investigated.

Figure 10. Spatial map showing the Addis Ababa region identified as a low-hanging raw bone waste stream source for medium (regional) scale model project to develop a commercially viable bone biochar-based indigenous phosphorus fertilizer. The region is also the site where the private and public sector partners are located.

Most developing countries such as Ethiopia lack mineable phosphorus reserves. However, in Ethiopia, agricultural and agro-industrial wastes represent an abundant source of phosphorus and other nutrients. With increasing urbanization and development in the country, more and more agricultural and agro industrial non-competitive wastes are being concentrated in cities and urban centers. Unutilized, these wastes pollute land and water and represent a significant solid-waste disposal problem and incur management costs to municipalities and central and regional abattoirs across the country. In fact, environmental pollution derived from domestic and agro-industrial activities is the main threat to the surface and ground water qualities in Ethiopia. It is reported that the majority of industries in the country discharge their wastewaters into nearby water bodies and open land without any form of treatment. Due to the absence of controlled waste management strategies and waste treatment plants, untreated wastes are dumped into water bodies and the surrounding environments. The streams and rivers into which waste is dumped are used for various purposes such as horticulture, drinking, washing and other domestic activities by downstream inhabitants (Fan, 2005). Identifying methods to capture the nutrients contained in these wastes and converting them into economically viable fertilizers could satisfy a significant fraction of phosphorus demands in Ethiopia (Simons et al., 2014).

Taking the Ethiopian livestock herd as an example, it is argued in this report that developing countries already have access to an indigenous supply of phosphate fertilizer, in the form of raw bone waste streams (Simons et al., 2014). It is suggested that by tapping into this resource, there is enormous potential to develop private-public partnership project which can benefit Ethiopia to secure a significant fraction of its smallholder rural and peri-urban agriculture phosphorus demands without relying on international markets or the support of international development partners, and could achieve greater autonomy by effectively recycling the phosphorus contained in agricultural waste products. As such, there is no commercial outlet for animal bone residues in Ethiopia, and the disposal of bones represents a real cost to businesses in the meat supply chain as described above. Bones were once used as animal feed, but the risk of spreading bovine spongiform encephalopathy (BSE, or mad cow disease) has ended the practice (Jeng et al., 2007). Many bones, improperly disposed of by butcher shops and restaurants, find their way into public green spaces, are burned in makeshift incinerators or else tossed, haphazardly into the streets. Capturing bone residues from the waste stream will not only provide fertilizer, but also improve public health via the removal of potential hazardous biological material from public areas.

Therefore, in this section of the current report envisages a future scalable medium (regional) scale model project with socio-economic scenarios that involve a close collaboration of successful private and public sector institutions that will catalyze a path to a commercially viable fertilizer industry using locally procured bone residues in Addis Ababa federal capital district (see Figure 10). The team consists of Menagesha Biotech organic fertilizer Industry P.L.C (Private partner), The Addis Ababa Central Abattoir Enterprise (Public enterprise), Jimma University (Ethiopian Federal Government Entity) and Cornell University (Land-grant International Institution of higher learning) to launch the first bone biochar-based private-public indigenous phosphorus fertilizer production facility in Ethiopia. Cornell and Jimma University have developed a proven indigenous fertilizer development process in the country, and created the necessary infrastructure and appropriate-technology-based equipment to convert raw animal bones into a safe, cost-effective and farmer accepted indigenous phosphorus fertilizer called Abyssinia Phosphorus (see Figure 11). Bone biochar fertilizer produced in Ethiopia is sterile, contains 60% more elemental phosphorus than rock phosphate and nearly as much plant available phosphorus as industrially produced triple super phosphate (Zwetsloot et al., 2015). The technology required to produce bone biochar is inexpensive and can be built by local machine shops.

Figure 11. Proven capacity and scalable appropriate technology development in Ethiopia to turn bone into useful agricultural inputs (indigenous phosphorus fertilizer, Photo by Solomon D.)

The project partner, the Addis Ababa Abattoir Enterprise was established 60 years ago. The central municipal abattoir normally butchers 500 to 1,200 animals per day, with a significant increase during holidays where the number animals were butchered to meet the market demand for meat could reach up to 4000. Of the 4000, 2500 were castles while 1500 were sheep and goats. The Addis Ababa Abattoir Enterprise reports indicate that it produces about 15 tonnes of waste per day (bones, blood, manure and other wastes) that in lieu of finding a productive use, must be sent to the city dump. The Enterprise has currently in the process of upgrading its infrastructure capacity, and has already started building a new modern abattoir on 17400 square meters with a capacity to handle 14000 animals per day, a more than 11-fold increase from the current capacity of the old facility. There're a great deal of interest expressed from Addis Ababa Abattoir to include ways and means to address issue related to value chain in the meat industry in Ethiopia. By taking the current and future production potentials of the Addis Ababa Abattoir Enterprise, three scenarios can be developed: (i) scenario one involving old slaughter house capacity capped at 500 livestock per day where 62.5% of the slaughtered animals being cattle and the remaining 37.5% being primarily sheep, operating five days a week for a year, (ii) scenario one involving old slaughter house capacity capped at 1200 livestock per day where 62.5% of the slaughtered animals being cattle and the remaining 37.5% being primarily sheep, operating five days a week for a year, and (iii) scenario three involving the future potential of the new slaughter currently being built in Addis Ababa with the capacity to slaughter 14000 livestock per day where again 62.5% of the slaughtered animals being cattle and the remaining 37.5% being primarily sheep, operating five days a week for a year (see Table 5).

The results of the analysis show that the Addis Ababa Abattoir Enterprise has a potential to generate about 519, 1247, and 14543 tonnes of bone residue per year under scenario one, two and three respectively. These amounts transfer to about 177, 426, and 4965 tonnes of phosphorus as P_2O5 per year under scenario one, two and three respectively. Although hypothetical and assumes the utilization of 100% of the bone residue, this result show that significant amount of phosphorus, which is a critical plant nutrient element that can support agricultural sustainability in Ethiopia is wasted each year - potentially causing environmental pollution of rivers and other freshwater resources and associate health hazards. This result also demonstrate the potential that exists in the current private public partnership to turn this waste stream into renewable agricultural input, potentially reducing the dependency of the country's smallholder rural and peri-urban farmers on expensive imported phosphorus fertilizers.

Figure 12. International, as well as national and regional TSP price (from 2014-2017) sensitivity analysis.

By taking into account the current international, as well as national and local price of the most potent but also expensive phosphorus fertilizer (Triple Supper Phosphate (TSP) with 0% N, 46% P as P2O5, and 0% K) which is currently selling at $ 297 USD internationally and $855 USD (see the results of the price sensitivity analysis for the years 2014-2017 in Figure 12), the equivalent price of the bone char P_2O_5 have been determined (Bone char total P content is 14.5% and its P2O5 content is 34.7% (see Table 6 for the results of an independent fertilizer certification for Cornell's and Jimma Universities pilot project) to be in the range of $224 USD and $645 USD at the international and national markets. Furtheron the data using these prices were analyzed to determine the comparable total economic value of these alternative and renewable source of phosphorus in Ethiopia. The results of the analysis show that: (i) under scenario one capacity there is a potential to generate a product with a financial value of $39123 USD and $112627 USD using the international and national prices, respectively, (ii) under scenario two capacity there is a potential to generate a product with a financial value of $93895 USD and $270304 USD using the international and national prices, respectively, and (iii) under scenario three future potential capacity there is impending possibility to generate a product with a financial value of $1095441 USD and $3153541 USD using the international and national prices, respectively.

Table 5. Socio-economic scenario of bone waste stream for a private-public partnership bone biochar-based indigenous fertilizer production in Ethiopia

Livestock		Animals slaughtered		Total bone residue		Bone P	Bone P_2O_5	Equivalent P_2O_5 price#		Equivalent P_2O_5 price	
Slaughtered	Type	Animal/year	kg bone/animal	Kg/year	Tonnes/year	Tonnes/year		International (USD)	Total economic value	National (USD)	Total economic value
Scenario one*											
30000	Cattle	18750	25.0	468750	469	70	160	35310	39123	101648	112627
	Sheep	11250	4.5	50625	51	7.5	17	3813		10978	
Scenario two†											
72000	Cattle	45000	25.0	1125000	1125	168	384	84743	93895	243956	270304
	Sheep	27000	4.5	121500	122	18	42	9152		26347	
Scenario three‡											
840000	Cattle	525000	25.0	13125000	13125	1956	4481	988665	1095441	2846156	3153541
	Sheep	315000	4.5	1417500	1418	211	484	106776		307385	

* Scenario one – old abattoir slaughtering 500 per day with a 62.5% cattle and 37.5% sheep and goats.
† Scenario two – old abattoir slaughtering 1200 per day with a 62.5% cattle and 37.5% sheep and goats.
‡ Scenario three – new abattoir slaughtering 14000 per day with a 62.5% cattle and 37.5% sheep and goats.
# Prices are based on P2O5 equivalent values for TSP which is 46%; Prices and other calculations were adjusted to bone char P2O5 which is 34.17% or 14.9% P; TSP average international market price (2014-2017) 297 USD per tonne; TSP national and local market price (2014-2017) 855 USD per tonne 2015 calculated from Africa fertilizer and World Bank Commodities Price Data (The Pink Sheet).
†† The rate of conversion from raw bone to bone biochar is about 70%.

Table 6. Results of an independent fertilizing and soil conditioning potential test result of bone biochar produced as part of Cornell's and Jimma University's pilot project in Ethiopia.

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16-Sep-2016
Page 1 of 1

Report For: Cornell University
306 Tower Rd.
918 Bradfield Hall
Ithaca, NY 14853
Attn: Kelly Hanley

Sample Identification:

Bone Char Fertilizer, Sample #2
ID: Non-Pelletized Bone Char

Date Received: 30-Aug-2016

Laboratory Number: 397625

CERTIFICATE OF ANALYSIS
OFFICIAL ANALYSIS *

Method	Parameter	Result	Units
AOAC 958.01			
	Phosphate, Total (P2O5)	34.17	%
AOAC 977.01,958.01			
	Phosphate, Water Soluble (P2O5)	0.17	%
AOAC 2006.03(mod)			
	Calcium (Ca)	31.26	%
	Iron (Fe)	0.064	%
	Magnesium, (Mg)	0.54	%
	Manganese (Mn)	0.001	%
	Sodium (Na)	0.67	%
AOAC 955.01			
	Calcium Carbonate Equivalent	14.35	%
NFSA 1980			
	pH Value	8.44	
EU 2003/2003			
	Phosphate (P2O5), Soluble in 2% Citric Acid	24.75	%

The current analysis doesn't take into account or monetize the urban and per-urban environmental benefits (e.g., minimizing health hazard, effective waste recycling and reducing nutrient lode to aquatic ecosystems etc.), or sustainable agriculture benefits (e.g., tacking phosphorus deficiency, liming, soil conditioning and other agronomic and soil health potentials, and subsequent boost to cereal and vegetable crop productivity and enhance human nutrition as a result of bone biochar application etc.), nor the cost of updating the required capital equipment, (see Figure 11 for the current status of infrastructure including locally manufactured and imported equipment at the Addis Ababa Abattoir Enterprise) infrastructure, product branding and marketing schemes for the proposed private-public sector partnership scaling up project that build up on past achievements under the Cornell-Jima university partnership. These results, however, demonstrate a clear potential and a need to develop a more comprehensive scaling up business plan that takes into account the results of the current socioeconomic scenario analysis of the low hanging fruit in the livestock sector at the country's capital.

Figure 13. Showing the 2016 resource base and available infrastructure and capacity survey results showing massive accumulation of unwanted animal residue, as well as although ageing and requiring replacement - the availability of grinding, pelletizing and packaging potentials of the Addis Ababa Abattoir Enterprise. (Photo by Solomon D. during the 2016 survey ad site visit for the current report).

The proposed partnership will build capacity of public institutions (i.e. abattoirs) through investments and knowledge sharing to improve and expand their raw material production capabilities for bone char fertilizer production (see Figure 13 for various types of bone and other animal waste streams and available although ageing infrastructure at Addis Ababa Abattoir Enterprise useful for indigenous bone phosphorus fertilizer production) . During the 2016 survey and capacity building exchange by Cornell and its local partners to identify strategies for maximizing the efficiency of technological dissemination and production, it was observed that the Addis Ababa Abattoir Enterprise believe that these mutual beneficial activities are in line with its mandate and the government's desire for effective recycling of solid-waste into useful agricultural inputs. Menagesha Biotech Organic Fertilizer Company is currently serving about 120,000 clients in Ethiopia in the areas of inoculants production, distribution and marketing, and the proposed scaling up project will be benefit from the branding and distribution channels and also market reach through the already established this private sector partner. The success of the partnership with Menagesha Biotech will be determined by the extent to which a private-public business partnership capable of sourcing bones from abattoirs is build, converting the bones into high-quality, uniform fertilizer, and selling the fertilizer to farmers at a price that is lower than imported phosphorus fertilizers but greater than the costs of production and distribution. Cornell and Jimma Universities will provide technical support and backstopping, capacity building, as well as could develop solid data-based agronomic support through integrated demonstrative on-farm trials that will be conducted across different soil types, climates and cropping systems with various formulations and blends in the ecozones where the product will be sold.

Figure 14. Results of four years maize (a) agronomic and two years soybean trials showing the important role that bone biochar indigenous phosphorus fertilizer can play in enhancing creel and leguminous crop production in Jimma Zone in Ethiopia. (The recommended rate of phosphorus fertilizer in this graph refers to the value of P_2O_5).

Table 7. Selected physical and chemical properties, major taxonomy group, ^{15}N and ^{13}C natural abundance and total carbon contents of soil profile samples collected from Jimma ecozone in Ethiopia.

Ecozone	Depth	Sand	Silt	Clay	Texture	BD†	Drainage	Soil order‡	pH		CEC	^{13}C	^{15}N	C
	cm	%				g/cm³			H_2O	$CaCl_2$	cmole₊/kg‡ soil	‰		g/kg soil
Jimma	0-15	1.9	48.2	49.9	Silty clay	1.0			5.1	4.6	41.3	-19.5	7.1	31.3
	15-45	1.8	50.3	47.9	Silty clay	1.2	Good	Nitisols	4.9	4.5	42.7	-17.7	6.3	25.3
	45-100	1.4	68.0	30.5	Silty clay loam	1.1			5.3	4.8	39.9	-15.6	4.1	12.8

As the technology moves across the country, the results of these trials will be used to direct resources to high impact areas and aid Ethiopian institutions such as the MOANR, ATA, as well as NGO's in integrating bone biochar fertilizer into the nationwide fertilizer-blending and extension programs. In order to provide a proof concept for the pilot bone biochar indigenous phosphorus fertilizer project, Jimma and Cornell University conducted joint agronomic trails in Jimma Zone using cereal (maize) and leguminous (soybean) crops for four and two years, respectively (see Figure 14) The results of these on-going trials show that application of bone biochar-based phosphorus fertilizer help the resource poor rural farming communities of the Jimma Zone to enhance their cereal and leguminous crop productivity by 197% and 76%, respectively, compared to the control in acidic to moderately acidic soils (see Figure 14a and b, and Table 7) and could contribute to food and nutritional security of the community. The study seems to also provide preliminary evidence that the farmers application of this phosphorus and calcium rich bone biochar-based indigenous fertilizer, in addition to increasing crop productivity and the overall performance of the crop in the field (see Figure 14 c and d), could also take other ancillary advantages related to: (i) soil quality and health though enhanced soil nutrient content especially phosphorus and calcium and could also moderate soil acidity by acting as a liming agent as shown by its high calcium carbonate equivalent percent (see Table 7), (ii) reduced production cost and other socio-economic benefits through the ability to replace 60 to 100% P fertilizer without significantly reducing yield which translates to a saving of $112 to $186 USD per ha for each farmer considering the current recommendation rate of 100 kg/ha of P2O5 and the national and regional average price of 100 kg of TSP containing 46% P2O5 to be in the range of $86 USD (see national and local price taken from Table 5) , and (iii) environmental benefits in the forms of turning non-competitive agro-industrial wastes streams into useful agricultural inputs, as well as though the provision of means for effective recycling waste in Ethiopia.

2.2.2 Private-public sector partnership development potential using coffee waste stream in Ethiopia

Ethiopia, birthplace of Arabica coffee, grow a wide variety of high quality shade-grown coffees, mostly without chemical inputs by small-scale farmers. Coffee is a major commodity export-earner for Ethiopia, and the country ranks eighth in the world and first in Africa with an annual coffee production of 280,000 tonnes (Gemechu, 2009; GIZ, 2009).

Figure 15. A self-igniting and smoldering excessive accumulation of coffee husk at the back yard of dry coffee processing plant at the outskirt of Jimma, Ethiopia; posing danger to the nearby community and also contributing to atmospheric CO_2 and CH_4 emission and the country's GHG emissions. (Photo by Solomon D.).

Coffee beans from freshly harvested red cherries are process either in household or coffee processing agro-industries in two different ways: wet and dry processing. Both wet and dry processing of coffee - albite different processing procedures and quality of green beans - produces residues with very different characteristics. Wet or alternatively also called washed coffee processing, is the first type of coffee processing that involve gentle pulping of fresh cherries using wet pulpier to remove the outer most skin and a considerable amount of the mucilage. The pulped coffee cherries are then further processed by immersing and leaving them in the fermentation tank to ferment in for a definite period of time to remove the remaining mucilage, leaving coffee beans with intact parchment. Washed coffee processing generates two distinct types of residues. The first residue involves the wet coffee pulp consisting of the epicarp removed at the washing plants in the coffee growing regions. The thumb rule for this process is that for every 100 kg cherries that goes through wet processing, about 60% by mass ends up as washed coffee pulp with the remaining 40% consisting of the green bean and endocarp or as it is normally called parchment coffee. Following the sun-drying of the parchment coffee, only 50% of it or 20 kg remains as bean and parchment. The sun-dried parchment coffee is usually transported to where in some cases it will be further processing at coffee processing plants to remove the parchment from the green beans. Out of the 20kg parchment coffee further processing removes about 4kg in the form of dried parchment, resulting only in about 16 kg of washed green beans. The average residue production per tonne of wet red cherry is about 600 kg or, based on green coffee bean production, the residue potential would be 1.4 times the mass of green beans produced (ESMAP, 1986).

Table 8. Regional distribution of coffee residues for the year 2001 in Ethiopia (Kebede, 2001).

Coffee processing	Regional state	Processing plants	Green bean	Coffee residue
		No.	Tonnes/year	
Dry processing	Oromia	113	35060	49496
	SNNPR	273	94145	132911
	Gambela	2	1033	1458
	Others	N/A	112	158
Sub total		388	130350	184023
Wet processing	Oromia	309	6959	8421
	SNNPR	189	16533	20006
	Gambela	6	1519	1838
	Others	N/A	8	10
Sub total		504	25019	30275
Grand total		892	155369	214298

- The figures in this table are limited to coffee that was produced in 2001 and passed through the processing plants. The overall production could be much larger than this since significant amount of coffee that come to market is often processed in household environment.

The second type of coffee processing involve sun-drying of the red cherries after picking, which initially contain approximately 65% moisture content, until the berries reach approximately 10-12% moisture content. Following sun drying, the cherries will be subjected to dry mechanical pulping (or decorticating) process in which the green coffee bean is separated from the outer residue material (skin and husk) of the cherry. This dry process removes the upper hard cover (the husk) and the inner skin (parchment) in the milling process. This process can be conducted at coffee processing plant for mass handling or some farmers process the coffee at home using traditional equipment. The resulting coffee husk, especially in the case of large scale coffee processing agro-industrial plants where there is excessive amount of residue, accumulate often at the backyard of the processing plant, and following the introduction of moisture start to decompose or at times self-ignite and smolder as shown in Figure 15 becoming both great safety concern for the community where children often play close by and also an environmental hazard polluting the nearby rivers and waterways via the effluents and the atmosphere though the release of GHGs such as CO_2 and CH_4. When it comes to residue stream, a mass of 100 kg of red cherries with a 65% moisture content will result in approximately 40 kg of sun-dried coffee cherries (beans plus husk) delivered to the processing plant. Of this mass, about 17 kg will become sun-dried coffee beans while the remaining 23 kg will end up as residue at the processing plant, often called coffee husk.

Most of the coffee production areas and processing plants in Ethiopia are found in the southern and eastern parts of the country, notably in the Southern Nations, Nationalities and People's (SNNPR) and in the Oromia Regions, where each host about 500 coffee processing plants (see Table 8 for distribution in year 2001). In the case of dry processing, for the most part all residues are effectively available at the local processing plants, where as in the case of wet processing, the pulped residue is available at the primary processing plant, where as the remaining residue (the parchment) is available at about 10 central processing stations located in the environs of Addis Ababa. Currently, 84% of the coffee arriving at the central auction stations in Addis Ababa and Dire Dawa is dry-processed. The market share of wet processing, which results in a better quality of coffee, is limited although its market share in Ethiopia is expected to show a steady growth due to demand for high quality export coffee.

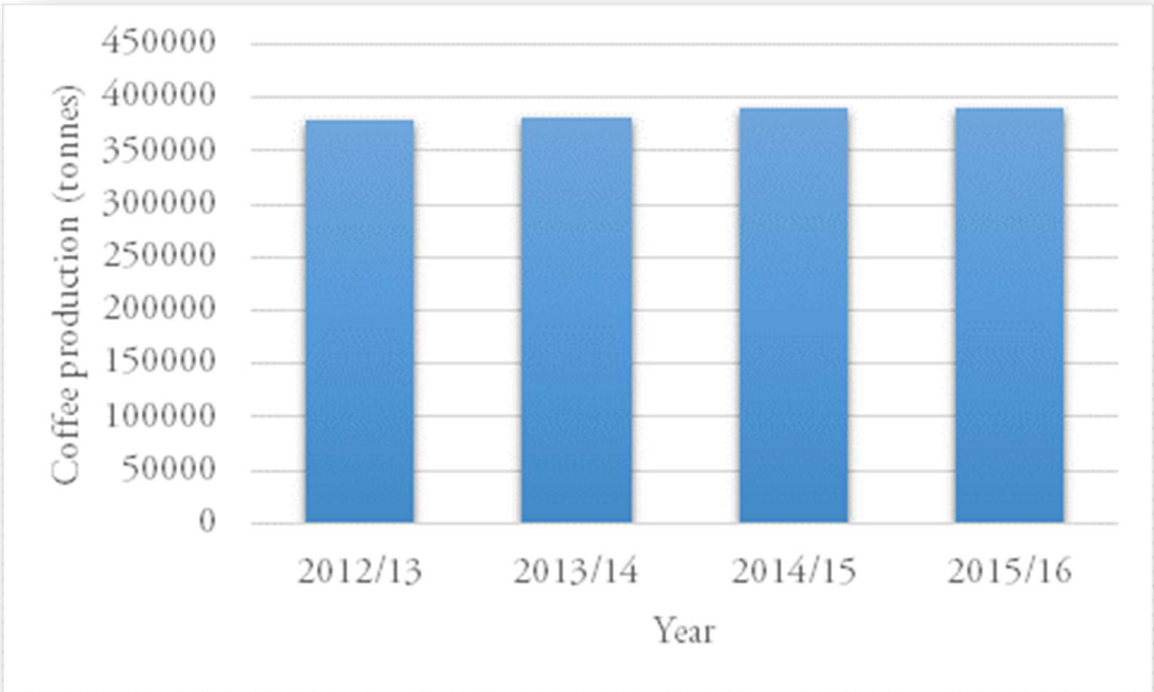

Figure 16. Annual coffee beans production in Ethiopia from 2012 to 2016 (USDA FAS, 2016)

A recent report by GIZ (2009) indicates that Ethiopia's coffee production system each year leaves about 100000 tonnes of coffee husk per year (note that this figure is lower than the theoretically expected value which is 161000 tonnes), and states that this waste stream is considered to be one of the major pollutants in coffee growing areas. According to this report, most of the decorticating stations where the dry husk and the pulp are removed from the beans are located near coffee growing areas. The report further elaborates that since firewood is usually not scarce in most coffee growing areas, the use of the coffee husk for cooking energy does not take more than 25 % of the available supply. Therefore, the remaining 75,000 tonnes of coffee husk for the year 2009 was potentially available annually at very low opportunity costs. Furthermore, at a national level there was a commitment and support to the existing and new coffee growers to enhance the annual coffee production within ten years. This commitment expected to increase the amount of coffee husk (a residue stream which is the focus of this report) that will be available as a residue. In fact, the numbers rose to from 2012 onwards approaching 390,000 tonnes of coffee beans by 2016 (see Figure 16), representing about 4.3% of the worlds coffee production and with potential to make 224250 tonnes of coffee husk waste stream. Hence, coffee husk could become a sustainable biomass feedstock source to develop climate-smart integrated energy, sustainable agriculture, environment and climate change mitigation and adaptation initiatives in the country, with a potential to enhancing the livelihoods of Ethiopian farmers to significantly increase their incomes and improve the quality of their lives.

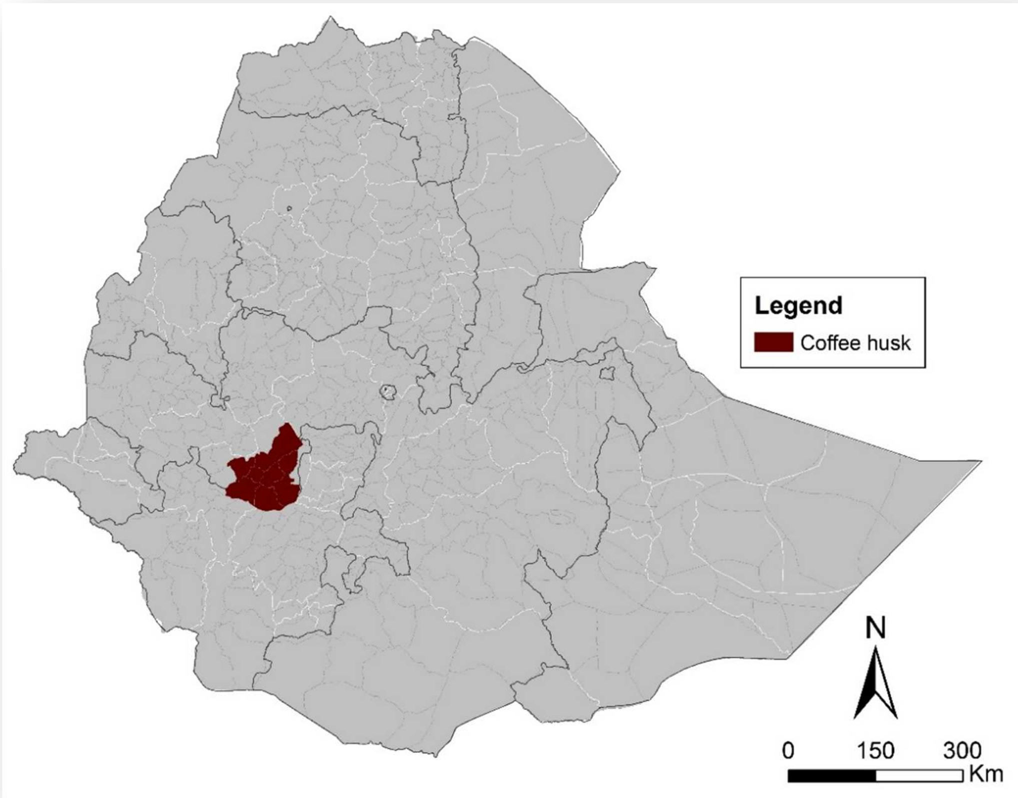

Figure 17. Spatial map showing the Kersa , Dedo , Seka Chekorsa , Mana, Limmu Kosa , Tiro Afeta and Omo Nada, and Goma woredas in Jimma zone, Ormoia region identified as a low-hanging coffee husk waste stream source for medium (regional) scale model project to develop a commercially viable coffee husk biochar-based soil conditioner. The region is also the site where the private and public sector partners are located.

In this section of the report socio-economic scenarios are explored to develop a future scalable medium size coffee husk biochar-based soil conditioner model project that involve private-public sector partnership in Kersa , Dedo , Seka Chekorsa , Mana, Limmu Kosa , Tiro Afeta and Omo Nada, and Goma woredas in Jimma zone, Ormoia region. The team consists of coffee processing agro-industries close to Guddeta Bulaa locality in Jimma Zone (see Figure 17) and Jimma University (public sector partners), Jimma University (Publick secto partners) and Cornell University (Land-grant International Institution of higher learning which can provide technical support and backstopping) to kick start commercially viable coffee husk biochar-based private-public sector partnership to develop a soil conditioner and fertilizer production facility for dissemination to farmers in the Jimma zone of the Ormoia regional state of Ethiopia.

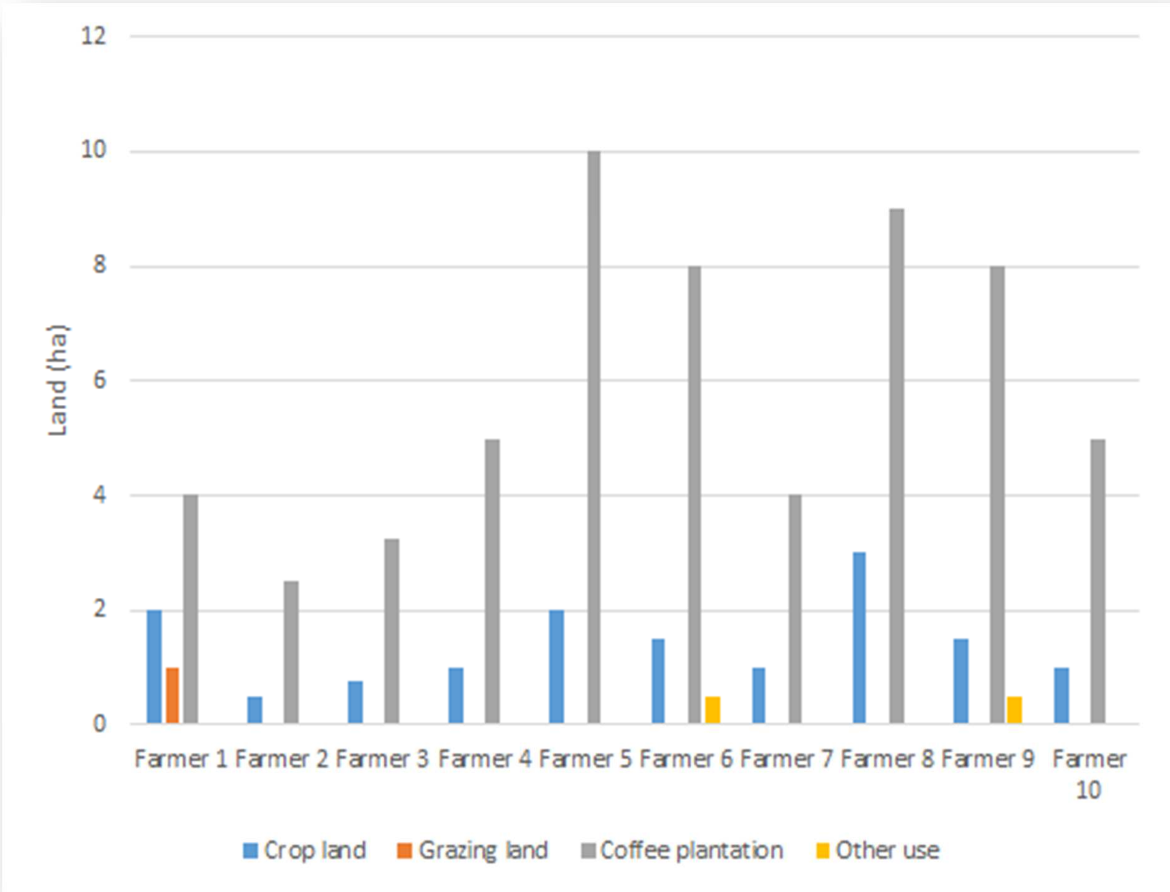

Figure 18. Total agricultural landholdings and utilization or various crops by small-scale coffee farmers that supply the coffee cherries to processing plants in Guddeta Bulaa at Jimma Zone.

In order to establish the frame work for the suggested model project, in 2016 a survey at Jimma Zone in Oromia Regional State was conducted to assess the most suitable coffee processing agro-industries and contacted individual operators from the region: (i) to explore interest in establishing joint private-public sector partnership to alleviate the current problem that these processing plants are facing from the ever accumulating coffee husk waste stream, (ii) to jointly develop a project with a potential to convert this waste stream into useful agricultural input (in this case as soil conditioner) with potential to address the nearby smallholder farming communities at Jimma Zone, and also (iii) to create an entrepreneurship opportunities for the operators. As part of this survey it was also looked at the use of agricultural land for various cropping systems by the smallholder farming communities that produce and sell the matured coffee cherries to the partnering coffee processing plants from where it is planned to secure the coffee husk waste stream (see Figure 18). The results show that from 57 to 83% of the agricultural landholding in the surveyed area is used to produce coffee crop, guarantying a steady supply of coffee cherries for the coffee processing plants.

The survey result (see Figure 19) also showed that the majority of the coffee grown by the smallholder farmers (up to 96%) is produced primarily to supply the market, and only a very small proportion is used for household consumption. This limited but indicative socio-economic scenario data clearly show the intent, consumption partner and potential supply base of the primary coffee crop producers in the region, and provide an indication that there is sustainable supplier base for establishing coffee husk biochar-based soil conditioner project by tapping into potential waste streams currently available at the coffee processing agro-industries in the region.

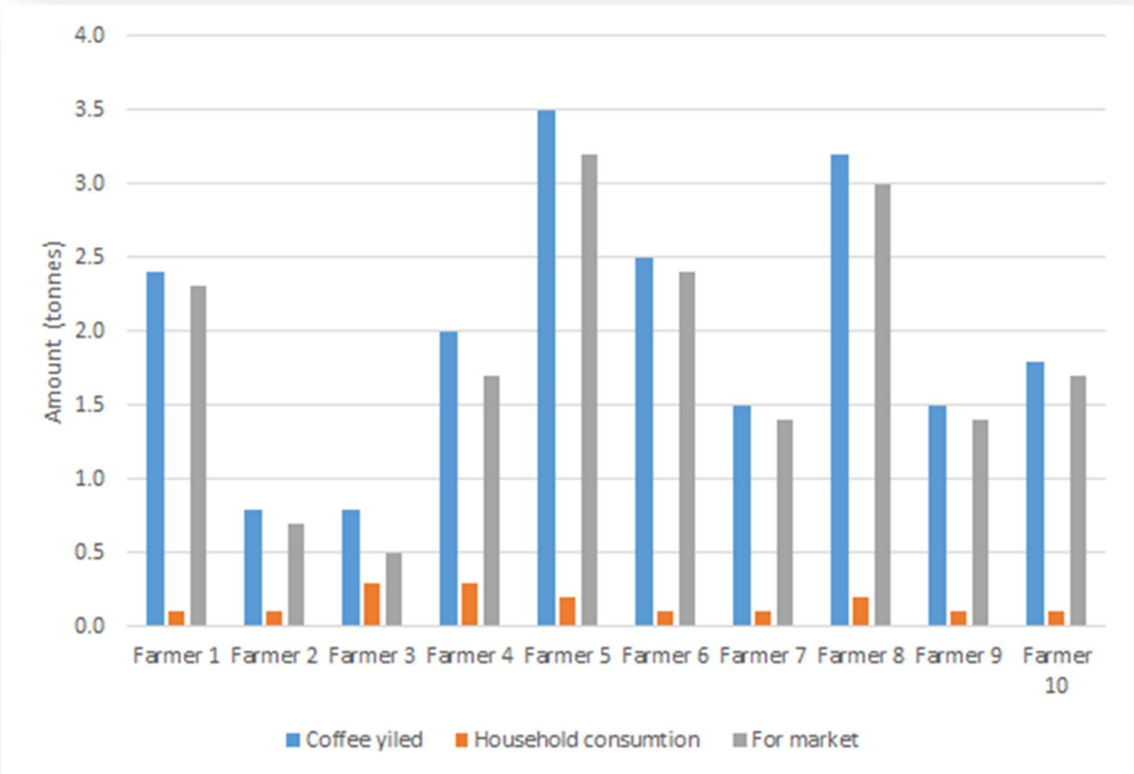

Figure 19. The use of coffee crop yield by small-scale farmers that supply the coffee cherries to processing plants in Guddeta Bulaa locality in Jimma Zone.

The second part of the survey was focused on assessing the potentials of the coffee processing plants under high and low coffee production seasons, in order to establish the socio-economic scenarios for the availability of biomass feed stock to develop a medium scale coffee husk biochar-based soil conditioner production model project in a private-public sector partnership setup in Jimma Zone (see Table 9). The results show that under the high production scenario these processing plants process 8500 tonnes of sun dried coffee cherry per year generating about 4888 tonnes of coffee husk. If 100% of this coffee husk is used for biochar production, at 30% recovery rate, the partnership is potentially capable of producing about 1466 tonnes of coffee husk biochar per year which can be used directly as a soil conditioner on 367 ha of land at 4 t/ha rate. Currently a new approach is being tested at using a 4 years and two years on-going agronomic trials at Jimma Zone by Cornell and Jimma University (see Figure 20), where coffee husk biochar at 2 t/ha is being used in a co-composting process also involving bone char, manure and plant residue and applied as pelletized organic soil conditioner into the soil. If co-composting approach is implemented, the total area of smallholder agricultural land coverage that could benefit from this renewable agricultural input could in fact be doubled to (733 ha) with the potential to helping smallholder farmers in Jimma zone to enhance soil fertility, agricultural productivity, food and nutrition security, while also sequestering carbon and potentially reducing the release of nitrous oxide from composing process - contributing to climate change mitigation efforts of the country. What is, however, beyond the scope of his socio-economic scenario analysis at this juncture but a timely needed future investigation is - the possibility to conduct full lifecycle analysis followed up by a pilot project involving a complete product branding and marketing exercise to understand the full cost of production, market potential and profit margins; and develop effective business model to develop entrepreneurial opportunity in a manner that addresses gender, as well as with a social consideration to engage unemployed youth to curve the courtiers massive unemployment problem to enhance social stability and support Ethiopian Government’s effort to create stability and vibrant CRGE.

In addition, carbon markets support a wide range of GHG emissions reduction projects, only some of which are in the AFOLU sector. Whereas significant research and discussion has been focused on the potential for carbon markets to spawn investments in climate change mitigation and adaptation activities in developing countries, for example the work of Jirka et al., 2015 involving an analysis of carbon finance trends for food security related programs shows that this has yet to crystallize. Therefore, in this report the financial potentials for mitigation for using biochar-based soil conditioners and indigenous fertilizers was not highlighted. However, this is another socio-economic scenario that needs proper investigation using initial, business as usual and project scenarios and a proper monitoring reporting and validating mechanism needs to be put in place - considering the fact that post Paris COP 21 developments started to highlight capture of carbon in soil a one of the formal part of the global response to the climate crisis. It will also help provide information about this sector’s contribution to Ethiopia’s INDC and contribute towards the country’s preparedness for potential 2020 or post 2020 opportunities in the area of climate financing.

Table 9. Survey result from three dry coffee processing plants in Jimma Zone showing the processing capacity for sun dried coffee at different coffee production seasons, as well as the potential amounts of coffee husk and coffee biochar capacity.

Dry coffee processing plant	Sun dried coffee cherry processed		Coffee husk produced†		Coffee husk char‡	
	High production*	Low production*	High production	Low production	High production	Low production
	Tonnes/year		Tonnes/year		Tonnes/year	
1	3000 to 4000	2500 to 3000	1725 to 2300	1438 to 1725	518 to 690	431 to 518
2	1500 to 2000	1000 to 3000	863 to 1150	575 to 863	259 to 345	173 to 259
3	2000 to 2500	1500 to 2000	1150 to 1438	863 to 1150	345 to 431	259 to 345
Total	6500 to 8500	5000 to 8000	3738 to 4888	2876 to 3738	1122 to 1466	863 to 1122

* These results are based on the data collected from the three processing plants for seasons conducive for coffee growth and where coffee production and matured coffee cherry supply was high and also for seasons where production was low and the processing plant was operating at low capacity

† The conversion from sun dried coffee beans to coffee husk was conducted as per the description provided in this section (pulping of 40 kg sundried coffee cherry yield 23 kg of coffee pulp and 17 kg of sun dried coffee beans).

‡ The conversion from coffee husk to coffee husk biochar yields 30% char

To provide clear evidence about the soil conditioning and agronomic values of biochar made from coffee husk (with pH H_2O and $CaCl_2$ values of 9.95 and 9.51, respectively), however, the Jimma and Cornell University research team conducted trials on maize and soybean crops. The results show that application of co-composted and pelletized coffee husk biochar along with 60% recommended N and K rates in addition to increasing the smallholder farmers yields of maize and soybean crops by about 208% and 98%, respectively, it could also enable them to gain: (i) soil fertility and health benefits through enhancing soil macro and micro nutrients, CEC, and moderating soil acidity effects, (ii) socio economic benefits via the potential in replacing 100% P and 40% N and K fertilizer and saving the cost for purchasing nutrients, (iii) environmental benefit by turning agricultural and agro-industrial wastes into useful soil conditions, as well as (iv) climate change mitigation and adaptation in the form of soil carbon sequestration and less dependency on highly expensive fossil fuel-based inorganic fertilizers.

Figure 20. Results of four years maize (a) agronomic and two years soybean (b) trials showing the important role that biochar made from coffee husk indigenous phosphorus fertilizer can play in enhancing creel and leguminous crop production in Jimma Zone in Ethiopia. (The recommended rate of phosphorus fertilizer in this graph refers to the value of P_2O_5).

2.2.3 Private-public sector partnership development potential using sugarcane bagasse waste stream in Ethiopia

Ethiopia has a conducive environment and potentially extensive cultivable land (about 1.40 million ha) out of which about 485,115 ha is marked as suitable for sugar cane plantation. The 1986 World Bank and UNDP comprehensive bagasse energy survey show that the country had a well-established sugar industry, owned and operated by the Ethiopian Sugar Corporation (ESC) that at the time effectively managed three operating sugar factories Metahara, Wonji, and Showa, which together used to process about 1,640,000 tonnes sugar cane, producing 186,000 tonnes of sugar per year (these factories are operational only between October to June). The amount of bagasse - a waste product from the sugar industry - produced following extraction of sugar from cane - at the time was approximately 470,000 metric tonnes (which is just about 28.7% conversion rate at 47.3% moisture content despite potential variability depending on variety, ecosystem and pressing efficiency) at an average moisture content of 47.3%. The report (UNDP-WB, 1986) show that except for the amount used for the filtration and start-up processes, most of the bagasse was burned "wet" (about 47.3% moisture content) as it emerges from the processing mills, with a small amount going to storage to take care of the fuel supply during occasional short mill stoppages time (mostly between July to September). Hence at the time, industrywide there was only a 17,000 t/year out of which about 10,300 tonnes was used annually by the ESC to operate its lime kiln. These competitive needs for this waste stream left approximately about 7,000 tonnes of wet bagasse per year that is equivalent to 3,690 t/year of bone dry bagasse as available sugar cane waste stream.

Since then, the domestic demand for sugar has been increasing at a faster rate than anticipated due to the combined effect of increase in population and urbanization, expansion in micro and small-scale food processing sector, etc., and it is currently becoming difficult for the existing sugar mills to satisfy the need - necessitated the country to take at times drastic measures including planned expansions of the existing sugar factories, establishing new plantations and factories and cutting down export to mention the few. Notable developments include for example the commissioning of the Fincha sugar factory in the year 1998 that has an average annual production capacity of 110,000 tonnes of sugar with a sugar cane crushing capacity of 4500 tonnes cane per day.

The sugar production from the three factories (Metahara and Fincha, as well as Wonji Showa sugar factories - which is the result of the amalgamation of Wonjie and Showa now collectively called Wonji Showa sugar factory) in Ethiopia by the year 2009 reached about 275000 tonnes, which translates to 2424731 tonnes of sugar cane and to 694892 tonnes of 50% wet bagasse or to 193096 bone dry bagasse; and despite the enhanced production shortage in the domestic market was felt. However, some investment documents showed that by 2011/12 the demand for sugar was forecasted to be 420,000 tonnes surpassing the production capacity of the three factories and thus registering a deficit of around 145,000 tonnes. Socio-economic analysis show that for Ethiopia, in order to meet these demand, there is a need to produce about 3,703,226 tonnes of sugar cane crop, and this will have a potential to produce 1,061,290 tonnes of wet sugar cane industry waste stream in the form of bagasse.

Since then, in accordance with the country's GTP which is currently in its second phase, Ethiopia in fact has started to further expand the existing three sugar mills; and is working to establish additional four new sugar factories with a future total cane crushing capacity of 65,500 tons of cane per day. These potentially means that these sugar processing factories will have a potential to process 17,947,000 tonnes of sugar cane crop per year working for 9 months, producing 2,035,452 tonnes of sugar. As a result the country will be producing a steady stream of 5,143,348 tonnes of wet sugar cane waste residue or about 2,711,279 tonnes of bone dry bagasse. However, the new caveat to these expansions is that these processing plants will need to have a cogeneration and an ethanol production plants. Sugar and ethanol productions are energy intensive processes requiring both steam and electricity, and despite the huge potential and intensive interest to develop a private-public partnership schemes for bagasse biochar-based soil conditioner - there is a possibility for competition between the steam and electricity and biochar production systems for the available sugar cane bagasse feed stock.

The present report clearly highlights the potential for utilizing sugar cane waste residue streams for bagasse biochar-based soil conditioner production and also to develop a private public partnership scheme around it to explore possible entrepreneurship and market-based opportunities by taping the rapidly expanding sugar industry sector. In order to explore this opportunity in scalable pilot project setup, following intensive discussion with private sector investors Wonji-Shoa sugar factory has been identified, which is located at Wonji in the rift valley region of the Oromia region in Ethiopia, as potential public sector partner (see Figure 21).

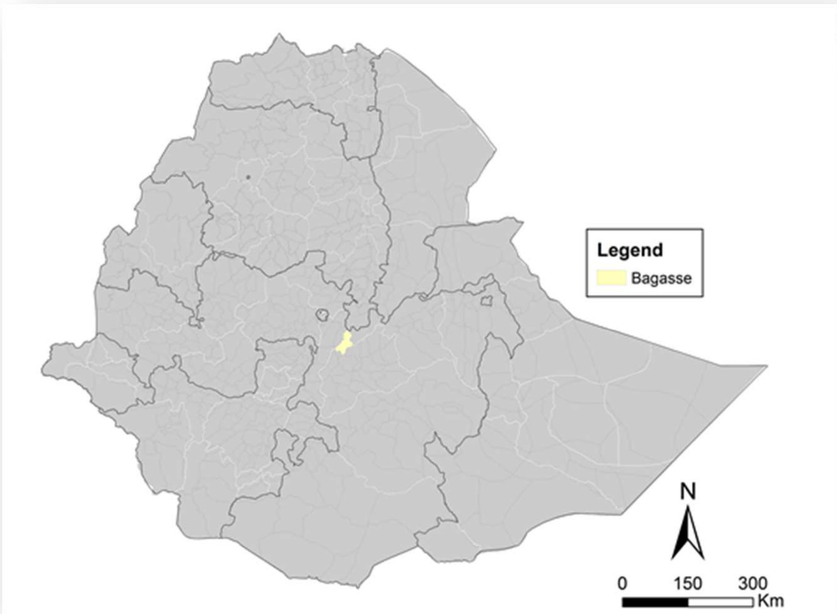

Figure 21. Spatial map showing Adama Zuria woreda in East Shewa Zone of the Oromia region where Wonji Sugar factory and plantation are located. The region is identified as a low-hanging sugar factory waste stream source for medium scale model project to develop a commercially viable bagasse biochar-based soil conditioner.

Figure 22. Photo of bone dry bagasse waste accumulation at the Wonji sugar processing factory site in Ethiopia (Photo by Amsalu Mitiku).

Wonji sugar factory commenced production in 1954, and is the oldest and also pioneer pant in the history of Ethiopia's sugar industry, whereas Showa sugar factory which is constructed in 1962 is the second oldest. The oldest sections of both sugar factories became obsolete and stopped production in July, 2012 and July, 2013 respectively, and were replaced by the new and expanded version of the joint Wonji-Shoa sugar factory plant in July, 2013. Accordingly, the newly built and modern Wonji-Showa sugar factory has a design capacity of crushing 6250 tonnes of cane a day (1,712,500 tonnes of sugarcane) and producing 194,223 tonnes of sugar, and about 490,777 tonnes of wet bagasse (258710 tonnes of bone dry bagasse) per annum in 2017 (see Figure 22 for bagasse accumulation in factory ground). Further expansion are expected to push the capacity to potentially reach 12,500 tonnes of cane a day as part of the country's GTP to maximize the output of the country. The factory is also planning to finalize a new ethanol plant, with a capacity to producing 12800 meter cube. The Wonji-Shoa sugar factory is also currently contributing 20 megawatt electric power to the national grid in addition to satisfying its own demand, which is around 11 megawatt. The information gathered by the current group indicate that up to 10,000 tonnes of the bone dry bagasse is considered as surplus to the requirements or not effectively used for the production of steam and electricity and present in the premises as a component of sugar industry waste stream.

The other partners in this pilot effort include Jimma University from public sector, as well as Soil and More Ethiopia - a new, innovative, private sector social enterprise established by Soil and More International from the Netherlands and Farm Organics International from Ethiopia. As part of the mid-size private-public partnership model project development strategy, it is proposed to start by conducting: (i) tradeoff analysis on bagasse for energy, steam and biochar production and collect the necessary data on the availability of wet and bone dry bagasse for these sectors, (ii) analysis on the synergy between energy, steam and biochar production from sugar cane bagasse at Wonji sugar factory, (iii) explore entrepreneurship, scaling and socio-economically viable business model development opportunities around the production and sale of sugar cane bagasse as soil conditioner for smallholder farmers and also for private sector and public sugar cane producers, as well as carbon financing prospects that exist around bagasse biochar-based soil carbon sequestration to mitigate climate change. It is expect that such study will help carve a clear path for developing future socio-economically viable bagasse biochar-based private-public partnerships, and help support to enhance the food and nutritional security of Ethiopia's resource poor smallholder community, and the country's effort to develop a CRGE.

2.2.4 Private-public sector partnership development potential using flower industry waste stream in Ethiopia

Driven by the ability of flowers to enhance the quality of life and influence human feelings, and the ever growing demand from globalization that is allowing extensive cultural exchanges, and celebrations enhancing both religious and social fraternity – there is an increased use of flowers and ornamental plants making this industry among the most lucrative business opportunities across the globe. The majority of cut flowers feeding this global demand are produced in countries with dedicated infrastructure and major distribution centers. The Asia/Pacific region leads in flower production with a total production area of 244263 ha, followed by Europe (54815 ha), Central/South America (45980 ha), North America (26135 ha), Africa (5,697 ha) and the Middle East (3845 ha) involving about 100000 companies and $60 billion USD per annum in value terms (Belwal and Chala, 2008). The key markets for flower industry are Western Europe (e.g., Germany, France, Netherlands, and Switzerland), North America (e.g., US) and Asia (e.g., Japan). However, EU countries - especially Netherlands and Switzerland account for nearly 80 percent of global imports.

The increased global market demand for cut flowers and its potential for agricultural diversification attracted increasing numbers of developing countries including Ethiopia into the fresh flower trade. Extensive floriculture for commercial purposes started as late as the 1980s under the Horticulture Development Corporations in collaboration with GIZ by importing planting materials from Canary Islands and Holland. At the time the government was responsible both for regulation, production and even for marketing (Ethiopian Horticultural Strategy, 2007). Production operation of fresh cut flowers for commercial purpose commenced at Zwai, Debere Zeit and Tibila state farms in 1981/82 production season. However, this agro-industry is experienced "a new boom" in the country as a result of the more favorable investment condition and the enabling environment for private sector development in the floriculture sector resulting in about 65 private sector enterprises operating in the country by the year 2006.

Following the increased interest both from domestic and foreign investors, the Ethiopian Government formulated a comprehensive development strategy for the period 2005/06 – 2009/10 called "Plan for Accelerated and Sustained Development to End Poverty (PASDEP)" to attain the Millennium Development Goals (MDGs) by 2015. Under PASDEP, the Government of

Ethiopia set program targets for intensification of the recently initiated flower production especially in regions with altitude between 1600 – 2600 meters above sea-level, and leased more than 2031 ha of land to the privates investors, out of which about 1600 ha were under greenhouse or other forms of shelter. As a result, the total area under flower production (roses, cuttings, summer flowers) further rose from 519 ha in 2005/06 production season to almost 2000 ha in 2009/10, making Ethiopia the second largest flower exporter in Africa, with over 100 flower growers.

The sector's socio-economic contributions in the form of generating employment and hard currency from export revenue have been also progressively increasing over the last few years. According to the report from Ethiopian Flower Producer Association (EFPA, 2007), 35000 to 50000 workers were employed in this economic sector - out of which about 60 percent were women - opening up new employment opportunities particularly with enhanced women's participation in labor market. The industry still remains attractive sources of employment as it provided stable income in the context of economic vulnerability, high youth unemployment and few available livelihood alternatives in rural areas. The floriculture industry also contributes significantly to the national economy of the country. In 2007, the sector's export earnings were about $100 million USD, which is an increase of five-fold from what it used to be in 2005. In 2008, Ethiopia has earned $186 million USD from horticulture exports out of which 80 percent was generated by flower (Getu, 2009). The Ethiopian Horticulture Development Agency in 2016 reported that the Ethiopia exported 49,000 tons of roses and 714.5 million cut flowers - earning $225 million USD and showing a 10.7% increase compared to the performance of the 2015 production cycle. Most of the flower production is largely confined around the vicinity of Addis Ababa, particularly in the West Shewa, East Shewa and Oromia Special Zones close to the Rift Valley and the Awash River Basin systems (Laws, 2006).

Ethiopia's flower cut flower agro-industry, despite the favorable climatic and edaphic factors, availability of labor, and the enabling policy environment and the accompanying rapid expansion, is still at its infancy compared to other global leaders of this industry. There is an expectation in the country that the sector will continue to expand and its contributions to the national economy will increase. However, there are a number of challenges that must be addressed for the sector to continue to grow and develop in a sustainable manner and to establish strong market acceptability of Ethiopia flower export worldwide. These challenges include both social and environmental impacts of the sector that need to be addressed via (i) industry-wide environmental legislative framework and pesticide registration system, and (ii) code of Conduct at sectorial level to demonstrate compliance with general standards (environment, workers‟ welfare, etc. - Ethiopian Horticultural Strategy, 2007).

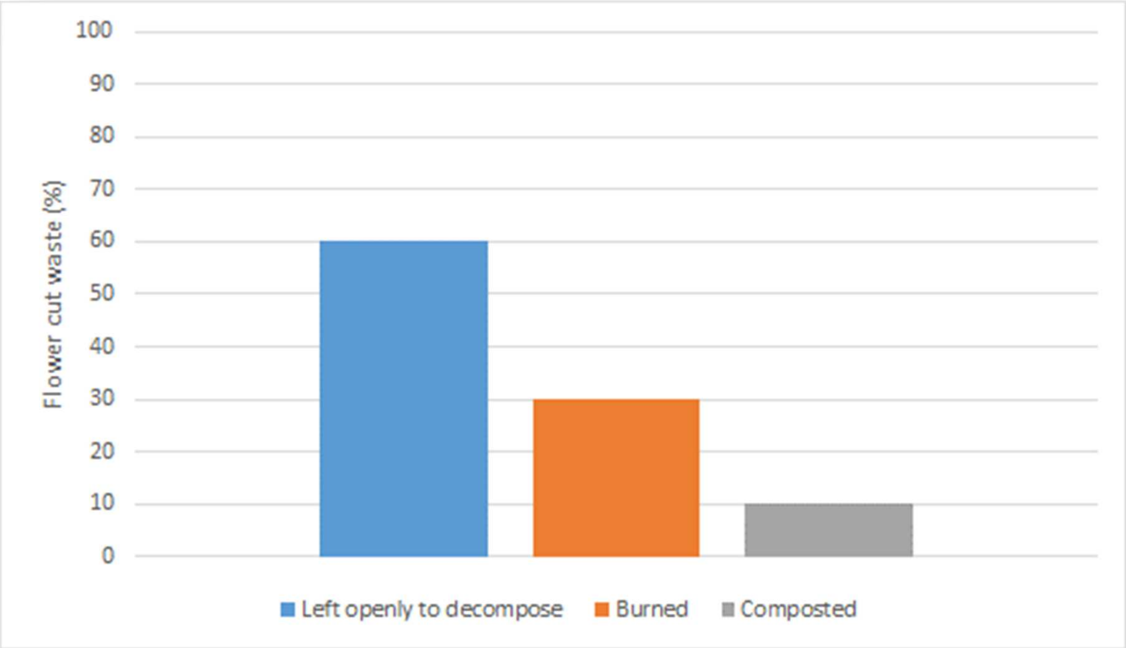

Figure 27. Flower cut green solid waste disposal mechanism at a flower farm in Ezha Woreda, Guraghe Zone Southern Nations Nationalities and Peoples Region (SNNPR), Ethiopia.

The rapid expansion of this agro-industry sector also comes with a huge amount of cut flower green solid waste stream (e.g., recent analysis by Seitz et al., 2017 for West Shewa, East Shewa and Oromia Special Zones flower farm clusters put this figure as 61,818 tonne) that is being generated each year and the need for an environmental and socio-economically acceptable solid waste recycling or disposal strategy. Although not much have been done in this area, the relatively scant available literature (see Figure 27 redrawn from Nigatu, 2016) show that there is no nation-wide strategy for effective flower waste disposal - especially when it comes to converting this non-competitive agro-industrial waste stream into useful agricultural input. For example, according to Nigatu (2016), the majority of the flower cut green solid waste was disposed 60% of the time in open fields and neglected to simply decompose, while 30% of it is burned. From the total amount of flower waste stream generated in the studies farm, only 10% of the waste is composted and used as organic amendment, while the remaining 90% of the waste is either burned or freely decomposes releasing GHGs to the atmosphere and also becoming health hazard - clearly showing the need to address this nation-wide problem, which will be expected to exacerbate with the expected growth of this agro-industry bin Ethiopia. This report propose exploring opportunities for a future scalable medium (regional) scale model project with socio-economic scenarios that involve collaboration between private (Soil and More Ethiopia private company) and public (Jimma University with technical support from Cornell University) sector institutions that will develop and facilitate a way to commercially viable soil conditioner entrepreneurship opportunity that aims to utilize the current flower cut green waste solid waste stream and convert it into useful agricultural input or soil conditioner.

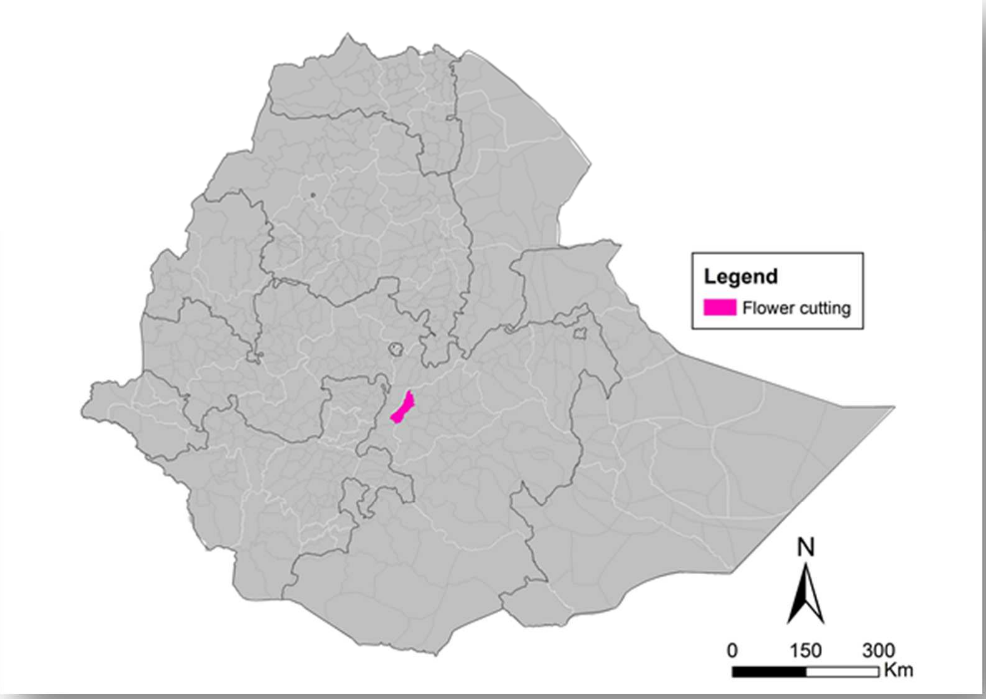

Figure 28. Spatial map showing Zewaye woreda in East Shewa Zone at Oromia region identified as a low-hanging flower cut waste source for medium scale model project to develop a commercially viable flower cut biochar-based soil conditioner.

Soil and More-Ethiopia is a private for profit social enterprise working on environmentally sound and sustainable business in the areas of agriculture in the country greatly positioned to alleviate the current unsustainable flower cut solid waste disposal problem. This private sector enterprise is already active in the proposed project site (Zewaye woreda in East Shewa Zone at Oromia region see Figure 28) using a fee for receiving solid flower cut waste scheme from the various flower farms. Soil and More Ethiopia aggregates the massive amount of flower waste (up to 44532 tonnes per year if the waste from Sher Ethiopia is taken into consideration see Table 10) from several flower producing farms of the region, and covert it in to useful agricultural input.

Table 10. Socio-economic scenario of flower cut solid waste stream for a private-public partnership bone biochar-based soil conditioner production in Ethiopia. Soil and More receives cut flower waste from the farms identified in this table on regular bases.

Flower farm	Flower waste†	Flower waste suitable for biochar‡	Flower waste biochar#
	Tonnes/year		
Sher Ethiopia*	23504	7051	2115
AQ Rose	4315	1294	388

Hurburg Rose	7546	2264	679
Ziway Rose	5974	1792	538
Braam Rose	2555	766	230
Florensise	638	191	57
Total	44532	13360	4008

* The arrangement for flower waste delivery by Sher to Soil and More for fee may not be currently operational. Data used only to show potentially available amount and the prevailing socio-economic scenario under full waste supply from all farms in Table 10

† Flower cut green waste stream includes leaves, stems and root stocks

‡ 30% of the flower waste is composed of hard woody and root material and deemed difficult to compost but suitable for biochar production

The rate of conversion from flower waste to biochar is about 30%

Soil and More Ethiopia's activities are generally focused developing and implementing large scale composing operations, and currently manages a number of large scale flower waste composing sites. However, this private sector enterprise is facing problem since about 30% of the flower cut solid waste stream (about 13360 tonnes per year) is composed of hard woody and root material and deemed difficult to compost or if composted takes very long period of time thus creating: (i) unprecedented amount of flower waste accumulation at site, (ii) if composted taking substantial amount of time to mature and often producing poor quality compost full of undecomposed woody residues not judged fit for application on farms, or (iii) incurring high cost related to labor for handling and processing of the composted end product from such poor quality waste for this private sector enterprise. As a result, Soil and More Ethiopia approach the Cornell and Jimma University consortium to explore the more efficient conversion of the more woody portions of the flower cut wastes, as well as roots using pyrolysis technology into biochar for use as a commercial grade soil conditioner. During follow-up discussion with the Cornell and Jimma University consortium, this private sector enterprise clearly highlighted the advantages of joint private public sector partnership to tackle the immense need for capacity building in pyrolysis technology, infrastructure development needs, as well as resource mobilization and leveraging needs. Considering the fact that there will be a sustainable supply of about 13360 tonnes of flower cut solid biomass feedstock for 4008 tonnes of biochar per year (at 30% biomass feedstock conversion rate efficiency) to guarantee a viable medium scale private-public partnership that can provide soil conditioner for 1002 ha land occupied by smallholder farmers in Zewaye woreda in East Shewa Zone of the Oromia regional state at 4 t/ha rate or to 2004 ha of land at 2 t/ha rage in a co-composted scheme described above in this this report. Hence in this report it is proposed to develop a future scalable medium (regional) size model project with socio-economic scenarios that involve collaboration between private (Soil and More Ethiopia private company) and public (Jimma University with technical support from Cornell University) sector institutions that will develop and facilitate a way to commercially viable soil conditioner entrepreneurship opportunity that aims to utilize the current flower cut green waste solid waste stream and convert it into useful agricultural input or soil conditioner. Considering the vast amount of Soil and More Ethiopia flower cut solid waste stream currently available in the country, Ethiopian

Government's effort to foster future expansion of this agro-industry sector, as well as the existing well established demand-driven supply system and branding efforts already in place, the proposed private public could be among the most promising opportunity to develop a socio-economically viable pilot project in the region.

2.2.5 Private-public sector partnership development potential using rice and sesame crop waste streams in Ethiopia

Rice - Rice (Oryza sativa L.) has supported greater number of people for a longer period of time than any other crop since it was domesticated between 8000 to 10000 years ago (Fairhurst and Dobermann, 2002). Because of its socio-economic and nutritional significance, rice still remains among the most important crops grown in the world. The largest producers of rice are concentrated in Asian, followed by South and North American countries. However, rice is becoming an important staple food crop in Africa with a growing demand that poses an economic challenge for the continent. Annual rice production in Sub-Saharan Africa was estimated at 14.50 million tonnes, comprising 15% of the continents cereal production. The Food and Agriculture Organization of the United Nations (FAO, 2013), forecasts that the world's largest proportionate increase in rice consumption over the next 10 years is expected to occur in Sub-Saharan Africa.

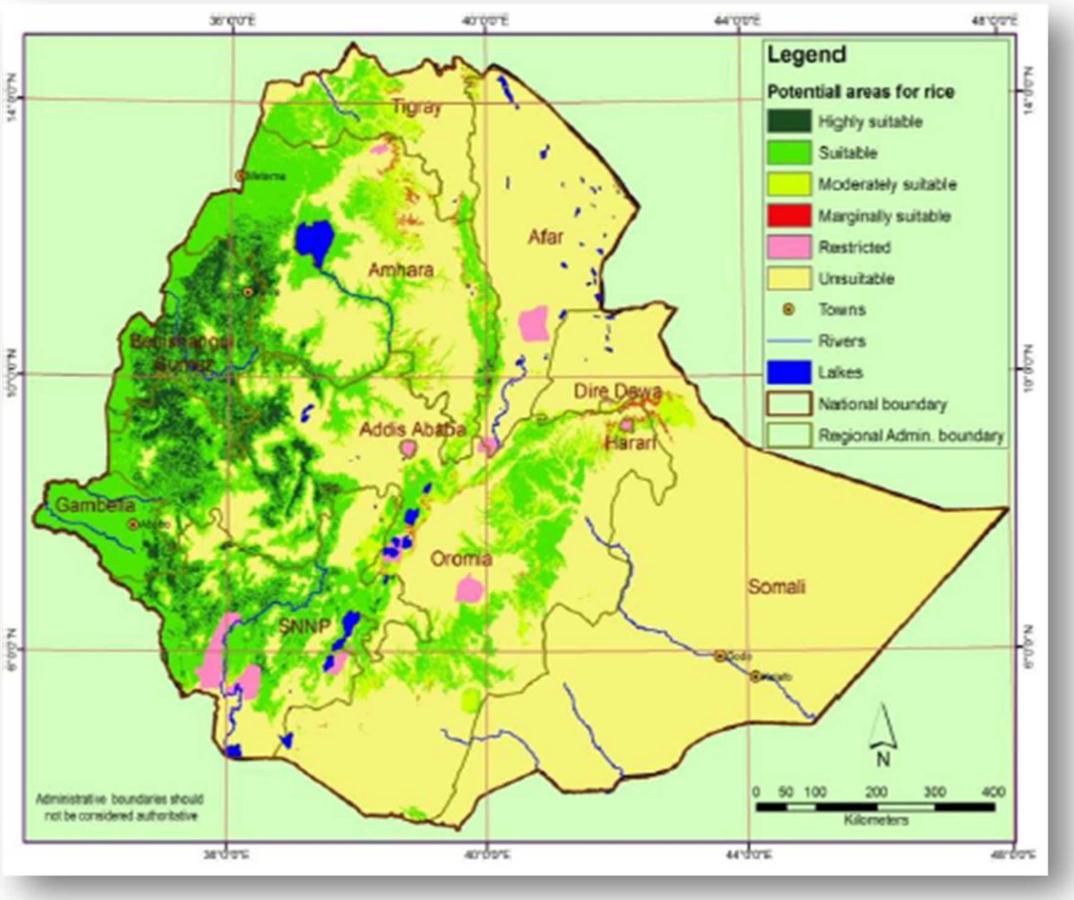

Figure 29. Rain feed rice suitability map of Ethiopia. (Source MoANR, 2010).

Rice is a relatively new crop for Ethiopia. Kebede (2011) reported that before 2009 there were in fact no recognizable large-scale commercial rice farm in the country. Although rice has just been recently introduced to Ethiopia, however, recognizing its importance as a food security crop and a source of income and employment opportunities, Ethiopia is now emerging as one of the potentially largest ice-producing countries in sub-Saharan Africa. In fact the government of Ethiopia has named rice as the "millennium crop", and has ranked it among the priority commodities of the country. Rice production in Ethiopia areas rose from 6000 ha in 2005 to nearly 222000 ha in 2010. Rice production increased from 15460 tonnes to nearly 887,400 tonnes, while the number of rice farmers increased from 18,000 to more than 565000 for the same period of time. The country has already identified vast suitable ecologies for rice production (see Figure 29) along with the possibility of growing it where other food crops do not do well. Currently there are about 30 million ha of land identified as highly suitable for rain feed rice production in the country, out of which 5.60 million ha were recognized as highly suitable and the remaining 24.4 million ha were identified as suitable. In addition there are about 3.70 million ha of land suitable for irrigated rice production in the country.

Cognizant of the afforested importance of rice and the existing potential for its production, a national steering committee was established to promote research and development activities on rice in the country and in 2010 developed the National Rice Research and Development Strategy of Ethiopia (NRRDSE) to make sure that the country will maximize benefit from this crop. Accordingly, the NRRDSE envisages seeing the existing limited area and subsistence dominated rice sub-sector progressively transformed into commercially profitable and viable production system, while addressing issues related to small- and large-scale rice production systems, gender, value chains in the various agro-ecological zones and also ensuring the socio-economic viability and environmental sustainability of rice production systems in the country.

Ethiopia's commitment to increase rice crop production both in terms projected increase in the total area of land allocated to this crop and to rice grain yield from what was shown in 2009 to what is expected by the year 2019 is summarized on Table 11. According to this Table the country's strategic effort is expected to further increase the total area of rice production from 155886 ha in 2009 by 396% to 773504 ha by 2019. Likewise, the total rice production is expected to increase by almost 8 times from 498332 tonnes from in 2009 to 3958323 tonnes by 2019. This expansion is expected to create a huge amount of rice waste residue stream. Considering the fact that most rice varieties are composed of roughly 20% rice hull or husk, 11% bran layers, and 69% starchy endosperm, also referred to as the total milled rice, for example the planned future expansion of rice is expected to generate about 791665 tonnes of hull or husk.

This waste stream could create both socio-economic and environmental side impacts as it has been demonstrated in this report or it could also create an opportunity to develop a sustainable system focused on converting this agricultural and agro-industrial waste stream into useful input. One of the main thrusts of Ethiopia's national rice development strategy is the promotion of postharvest technologies such as rice threshers and rice mills to reduce post-harvest loss and also enhance the value chains of rice crop. Such stagey could effectively address by designing effective waste stream management strategies in order to effectively utilize this available biomass resource. Hence, as part of the current socio-economic scenario analysis and based on follow-up discussion with representatives of the region, private sector parties and field visit, Tselemeti and Kafta Humera Weredas in Western Tigray Zone, Tigray regional state (see Figure 30a) have been identified to be ideal sites to incubate private and public sector partnership to develop successful commercially viable rice husk biochar-based soil conditioner enterprise.

Table 11. Projected rice crop area and production in Ethiopia by region and rice ecology from 2009-2019 (MOA, 2010)

Region	Year	Area (hectares)				Production (tons)			
		Upland rain-fed	Lowland rain-fed	Irrigation	Total	Upland rain-fed	Lowland rain-fed	Irrigation	Total
Amhara	2009	38,430	30,000		68,430	103,761	96,000	-	199,761
	2014	81,769	63,833	13,624	159,226	261,662	255,330	74,932	591,924
	2019	124,662	97,316	27,248	249,226	436,317	486,580	190,736	1,113,633
Oromiya	2009		12,940		12,940		41,408	-	41,408
	2014		30,805		30,805		123,220	-	123,220
	2019		34,743	15,570	50,313		173,715	108,990	282,705
SNNPR	2009	1,475	27,681		29,156	3,983	88,578	-	92,562
	2014	3,680	69,044		72,724	11,775	276,177	-	287,952
	2019	5,526	103,687	7,785	116,998	19,342	518,434	54,495	592,271
Tigray	2009	3,950	1,200		5,150	10,665	3,840	-	14,505
	2014	18,580	5,965		24,545	59,457	23,859	-	83,316
	2019	32,823	11,117		43,940	114,880	55,586	-	170,466
Gambella	2009		3,350	10,000	13,350		10,720	40,000	50,720
	2014		53,530	20,000	73,530		214,120	110,000	324,120
	2019		93,710	40,000	133,710		468,550	280,000	748,550
Benshangul Gumz	2009		10,080		10,080		32,256	-	32,256
	2014		58,670		58,670		234,680	-	234,680
	2019		102,260	5,000	107,260		511,300	35,000	546,300
Somali	2009			16,780	16,780			67,120	67,120
	2014			43,984	43,984			241,912	241,912
	2019			71,807	71,807			502,649	502,649
Afar	2009			-	-			-	-
	2014			120	120			660	660
	2019			250	250			1,750	1,750
Total	2009	43,855	85,251	26,780	155,886	118,409	272,802	107,120	498,332
	2014	104,030	281,846	77,728	463,604	332,895	1,127,385	427,504	1,887,784
	2019	163,011	442,833	167,660	773,504	570,538	2,214,165	1,173,620	3,958,323

The information collected in 2016 from Tselemeti woreda indicated that there is currently about 1862 ha of land where rice crop production is practiced. Rice production in this woreda ranges from about 3 to 6 t/ha, which show that on the average (by considering 4.5 t/ha to be the average rice crop yield for this woreda) this woreda produces about 8379 tonnes of rice crop per year. Considering 20% of the rice yield is husk, this woreda produces about 1676 tonnes of rice husk per year. If 100% of this rice husk is used for biochar production, at 30% recovery rate, this woreda is capable of potentially producing about 503 tonnes of biochar per year, with the capacity to be used directly as a soil conditioner on 126 ha of land at 4 t/ha rate or on 251 ha land if it is used as an additive in co-composting process at a rate of 2 t/ha.

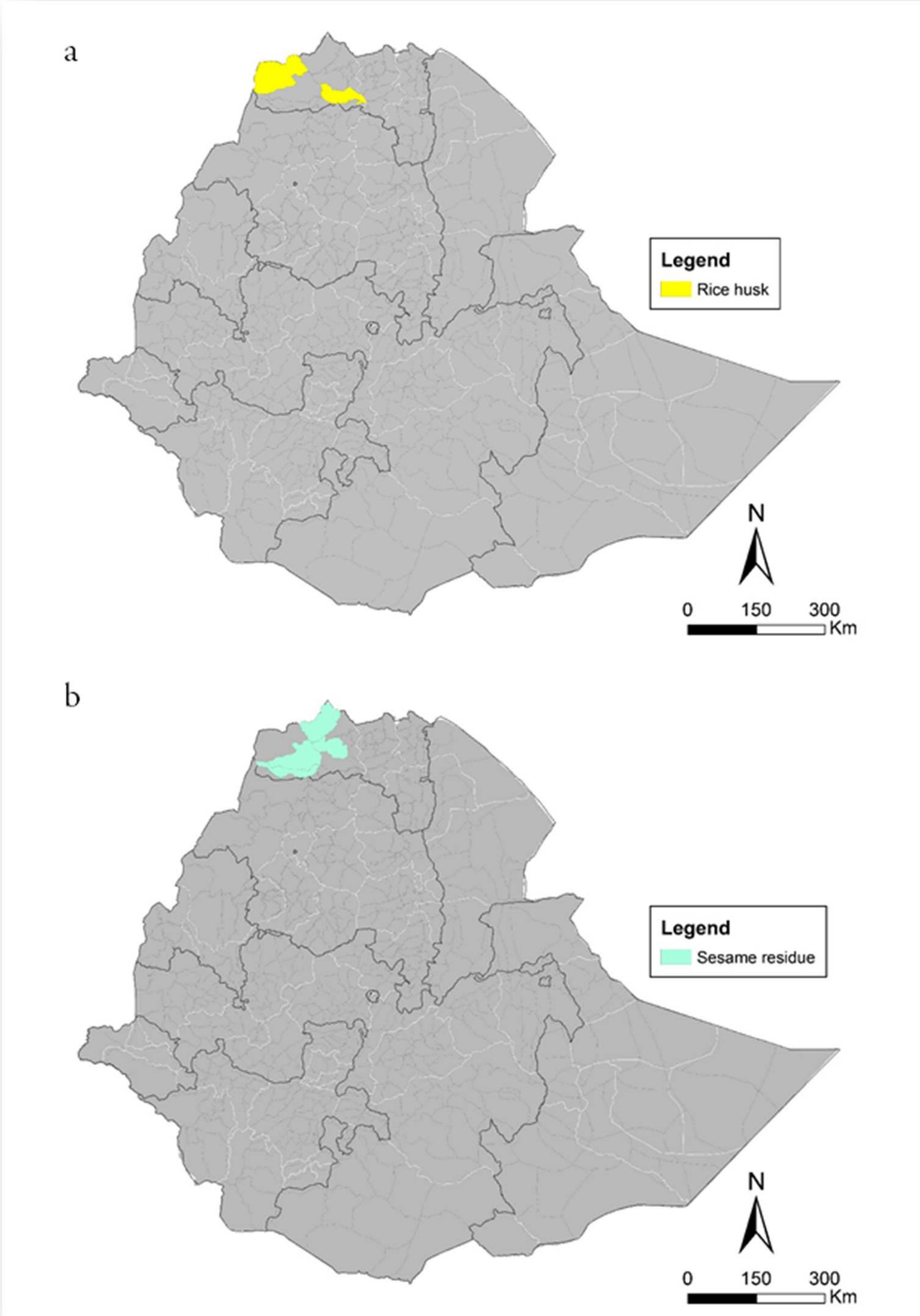

Figure 30. Spatial map showing Tselemeti and Kafta Humera (a) and in Kafta Humera, Wolkayit, Asgede Tsimbila, Tahtay Adiyabo and Tsegede weredas (b) in western Tigray zone in Tigray regional state identified as a low-hanging rice and sesame crop residue sources, respectively, for medium scale model project to develop a commercially viable flower cut biochar-based soil conditioner and organic fertilizer production.

Sesame - Sesame (Sesamum indicum L. Pedaliaceae) is one of the oldest oil crops in the world. In fact sesame production was recorded in the Middle East and India since 4000 years ago. Ram et al. (1990) reported that the origin of this crop would be in Africa. Whereas Bedigian (1985) narrowed it down to East Africa and India as the two geographical zones for the early origins for sesame. Although there is no definite information about the origin of sesame (Zeven and Zhukovsky, 1975; Hawkes, 1983), overall Asia (India and China), as well as Africa (especially Ethiopia) are identified as the most important centers of genetic diversity for this crop. The seed edible oil content ranges from 50-60%, containing high proportion of natural antioxidants such as sesamolin, sesamin and sesamol. Other industrial uses of sesame oil include pharmaceuticals in preparation of antioxidants, cosmetics and synergists for insecticides. Sesame is also used as a spice and direct food source and it is an excellent source of vitamin E and minerals such as calcium and phosphorous. After oil is extracted the remaining meal contains 42% protein rich in tryptophan and methionine, which makes it an excellent feed for animals (Hatam and Abbasi, 1994).

Sesame is widely grown in tropical and subtropical regions of Asia, Africa and South America. Its production is often concentrated in marginal and sub marginal lands (Ashri, 1998). FAO reports (FAOSTAT, 2008) show that the total world sesame production of this crop in 2008 was about 3.54 million tonnes, and it was grown on about 7.42 million ha of land. The world's largest producers of this crop were India and China, followed by Myanmar, Sudan, Uganda, Ethiopia, Nigeria, Tanzania, Pakistan and Paraguay. For example, about 60% of the world's sesame production during the year 2011 was from Myanmar, India, China, Ethiopia and Nigeria; and Ethiopia was ranked among the top 5 world's sesame seed producers for that year, along with other oil crops such as linseed and Niger seed (Ayana, 2015). Currently, the oilseeds sector is becoming one of Ethiopia's fastest growing and important economic sectors, both in terms of its foreign exchange earnings, and as a main source of income for over three million Ethiopians – and as a result sesame is designated as among the high-priority oil crops in the country. The major sesame seed producing regions of the country are situated in the northwestern and southwestern parts of Ethiopia (Wijnands et al., 2007; Dawit and Meijerink, 2010; CSA, 2011). Sesame production especially in these regions is increasing driven especially by high market value and suitable environmental conditions in these parts of the country (Wijnands et al., 2007).

In Ethiopia, the production of sesame is both by small and large scale farmers. In 2006 the total number of farmers engaged in this crop reached 601229, covering about 205153 ha of land and producing 148861 tonnes of sesame seeds (see Table 12), where the productivity per unit ha hovered around 0.73 t/ha. The total area production and productivity of this crop during 2013 increased further by 0.46% and 48% to 299000 ha and to 220000 tonnes, respectively, while the production per ha remained almost the same (CSA, 2008; 2013), making this crop ranks first in total area and production from all the oil crops produced during 2013 cropping season. Due to its importance as a major export commodity the area coverage and production has increased in the last consecutive years in Ethiopia and by the 2014/2015 season, total number of farmers engaged in this crop further rose by 44% to 867347, while the total area covered by sesame doubled to about 420495 ha of land, producing 288770 tonnes of sesame seeds registering a 94% increase in production of this economically important crop (see Table 12) compared to what was recorded in 2008.

Table 12. Sesame seed production in the various Ethiopian regional states. (CSA, 2006).

Regional state	Number of farms	Total area	Production	Yield
		ha	Tonnes	Tonnes/ha
Tigray	104680	60148	49215	0.82
Amhara	210344	62279	48970	0.79
Oromia	210010	57745	36998	0.64
Benesahngul	66446	23280	13131	0.56
Others	9749	1701	547	0.32
Total	601229	205153	148861	0.73

There is an enormous potential for further expansion of sesame seed production in Ethiopia through cultivation of additional new land and also via enhancing the crops productivity. The prevailing suitable of environmental condition for sesame crop production, and the presence of enormous genetic diversity in Ethiopia are expected to provide potential for improvement. The proximity of the country to international market and the high market demand for Ethiopian sesame seed also augments the above argument by providing a socio-economic driver and opportunity. The relatively good quality and demand for oil produced from Ethiopian sesame crop varieties currently under production is also factor that creates a fertile ground very encouraging dimension for attracting further investment and to expand this economically important crop in the country. However, in spite of the growing demand for sesame seeds and oil in Ethiopia, the productivity, production and oil extractions methods are traditional and require upgrading. Lack of improved and high yielding varieties for different agro-ecologies with desirable agronomic qualities including shattering of capsules at maturity, non-synchronous maturity, profuse branching, and low harvest index and poor stand establishment; poor seed supply system; low soil fertility and pH status; lack of organic and inorganic soil conditioners and amendments, as well as low response to these inputs, and diseases and insects seem to still affect agronomic performance of this crop (for example the average crop yields of sesame in the country was still 0.69 t/ha in 2014/2015 cropping season see Table 1), and the overall sesame production in the country (Ashri, 1994; Ayana, 2015). In addition, although Ethiopia is among the top five sesame seeds producers in the world, the potential benefits that could be obtained from this crop are still well below the optimum due to high post-harvest loss and lack of modern sesame oil seed processing and efficient seed oil refining agro-industries in the country. The Government of Ethiopia is currently committed to change this narrative and enhance investment in the oilseeds sector with an extensive package of incentives. In fact there is heighted expectation by the private sector, smallholder farmers and the country's government that with the transfer and implementation of best management practices and technology, and with the provision of the required organic and inorganic amendments and other inputs, the current low productivity and sesame yield gap for sesame crop can be effectively addressed; and that the various stakeholders in the country including smallholder farmers could realize the full potential of this crop and rip the associated economic benefits.

The current production of sesame crop, as well as its expansion is expected to generate a substantial amount of agricultural waste stream. The quantity of dry matter of sesame crop residue is usually estimated by converting grain yield to fibrous residues using multiplier of 1.2 developed for oil crops with a utilization factor of about 90% (FAO, 1987). By taking this conversion factor in the 2014/2015 cropping season alone 346524 tonnes of sesame was produced in the country. The study conducted on the utilization of sesame crop residue by smallholder farmers from different socio-economic strata in the two woredas (Kafta Humera and Metema) in Ethiopia by indicated that about 68% and 75% of the sesame straw produced in in these woredas is not utilized for any form of economical purposes is generally burned potentially. This study show that the remaining amount is used either as animal feed or mulch or in a very few instances also sold at market for various household uses. According to this study the main reason for burning sesame straw was to eradicate insect pests particularly sesame seed bug, the predominant pest attacking this crop in the study sites. Moreover, burning of the straw was also considered as a quick and labor saving strategy for effective sesame straw disposal. This ineffective agricultural waste stream management strategy clearly constitutes not only loss in terms of considerable amount of organic residues which could have other economically important applications, but also relates to loss of important plant nutrients, organic matter that could be returned to the soil, release of GHGs to the atmosphere

The current report attempts to change the current set-up by looking at this low-hanging biomass feed stock and develop a socio-economic scenario whereby the current ample amount of sesame residue can be converted via pyrolysis process to develop sesame residue-based biochar system where by the end product can be used as a soil conditioner to help remedy some of the edaphic related to low soil fertility and pH, lack of organic soil amendments, as well as low response to inputs. The application of sesame residue-based biochar system in the smallholder agricultural system will also build the soil carbon stock and will also contribute towards reducing GGHs from the court and contribute towards its INDC supporting the country CRGE and policy commitments to UNFCCC.

As part of the current socio-economic scenario analysis in 2016 an exploratory survey have been conducted where there is a fertile ground in Ethiopia for the opportunity to combine both rice and sesame waste residue streams to develop a medium sized rice- and sesame residue-based biochar systems. The survey results show that western Tigray Zone in Tigray regional state can provide such opportunity. In the previous section it had demonstrated that dealt with rice that Tselemeti and Kafta Humera Weredas are ideal for rice crop residue waste stream-based biochar systems (see Figure 30b). Similarly, for sesame Kafta Humera, Wolkayit, Asgede Tsimbila, Tahtay Adiyabo and Tsegede weredas in western Tigray zone (see Figure 30b) seem to be the best localities for private and public sector partnership to develop commercially viable sesame crop reside waste stream-based biochar soil conditioners and fertilizers for dissemination to the western Tigray zone farming communities and households to alleviate edaphic constraints, enhance productive and whenever possible sequester carbon to mitigate for climate change.

The preliminary survey and data collection from these localities show that in the Kafta Humera, Wolkayit, Asgede Tsimbila, Tahtay Adiyabo and Tsegede woredas of the western Tigray zone sesame crop is grown in about 300000 ha of land. The sesame crop yield in these woredas also vary across socio economic status of the producers. Relatively poorer farmers with poor crop stand and maximum pest infestation get about 0.70 t/ha, farmers who implement recommended management practices and relatively good crop stand could get up to 2 t/ha from their land. Under exceptional situations, where farmers have excellent cop stand and pest and disease management practices, yield levels of up to 3.0 t/ha was also reported. By taking a more conservative approach and implementing the most recent (for the 2014/2015 cropping season) national average sesame crop yield which is about 0.69 t/ha, the five woredas in the western Tigray zone could potentially produce about 288000 tonnes of sesame crop seeds. Using the FAO conversion factor (FAO, 1987) for grain yield into fibrous residue, the five woreds could potentially produce about 345600 tonnes of sesame biomass feedstock for biochar production. If make an assumption where 100% of this sesame crop waste stream can be used for biochar production, at 30% biomass to biochar conversion rate, these wordas are capable of producing about 103680 tonnes of sesame waste stream-based biochar per year, that can be used directly as a soil conditioner on 25920 ha of land at 4 t/ha rate or on 51840 ha land - if this sesame residue biochars is used as an additive in co-composting process and used as organic fertilizer at 2 t/ha rate.

As part of the 2016 survey of the region and particularly the western Tigray, farmer's cooperatives active in each woreda have also been identified, Best Practice Association (BPA), Institute of Sustainable Development (ISD) and Participatory Ecological Land Use Management (PELUM) Ethiopia as potential private sector partners, as well as Shire Agricultural Research Center, Aksum University with technical backstopping by Jimma and Cornell University as the public sector parties to develop the envisage private public partnership to develop commercially viable rice and sesame crop reside waste stream-based biochar soil conditioners and fertilizers for dissemination to farmers in the western Tigray zone, in Tigray regional state of Ethiopia.

2.2.6 Private-public sector partnership development potential using invasive weeds (Prosopis species) in Ethiopia

Non-native plants, which are synonymous with alien or non-indigenous plants, are plant taxa that are introduced to areas beyond their native range through human activity. The introduction of such plants could be accidental or purposeful due to their economic, environmental or aesthetic values. Nonetheless, introduction of new species is not always a success and brings about the possibility of invasiveness of the species, which in turn result in negative economic, environmental and social impacts. This is due to the ability of these species to produce large number of offspring, effective long-distance dispersal mechanism, and thus have a potential to spread over a considerable area in relatively shorter time span - thus in most cases invasion by non-native species is among the most critical threats to natural ecosystems worldwide.

In the late 1970s and early 1980s, concern about deforestation, desertification, fuelwood shortages and the need for new tree species for integrated soil water conservation and watershed management among other things prompted a wave of projects that introduced exotic grassy, woody and tree species to new environments across the world (Mwangi and Swallow, 2005). During the introduction from their native environment, indigenous knowledge and information about the management and use was seldom transferred along these exotic plants, and as a result these newly introduced species either still remained under-utilized and unmanaged (Pasiecznik et al., 2013), or became problematic as invasive species. Prosopis species as such belong to some of the most highly invasive plants (e.g., parthenium weed, Parthenium hysterophorus; water hyacinth, Eichhornia crassipes; cactus, Euphorbia stricta, and lantana weed, Lantana camara) in the world, dominating millions of hectares of arid and semi-arid lands in Africa, Asia, Australia, and the Americas. Prosopis species is in effect now registered as one of the first top 100 invaders rapidly spreading in several southern and eastern African countries. Among the 44 recognized Prosopis species, however, Prosopis glandulosa, Prosopis velutina, Prosopis juliflora, and Prosopis pallida are the most invasive.

In Africa, Prosopis species are estimated to have invaded over four million ha, threatening crop and range production, blamed for desiccating limited water resources, and displacing native flora and fauna. Prosopis species have been also implicated to increase the mortality of Acacia erioloba, one of South Africa's important species, by depleting water resources. Hybrids of Prosopis species in South Africa are in fact expanding at alarming trend, where their coverage is growing in its range at a rate of 18% per annum, doubling its extent every five years. In other parts of the world (e.g., Australia), hybrid Prosopis species are believed to be having dramatic ecological impacts by forming extensive dense stands, and completely excluding native herbs, grasses, and shrubs (Wakie et al., 2014). Historical records show that, Prosopis species were first introduced to Eastern Africa (Kenya, Somalia, Eritrea, and Ethiopia) in the 1970s through collaborative projects involving local governments and international organizations. Nowadays, Prosopis juliflora and Prosopis pallida are found widely distributed in Kenya, whereas only Prosopis juliflora has been mostly reported in Ethiopia most commonly in Afar regional state and but rapidly spreading to Oromia, Amhara, Somali, and Dira Dawa regions. By the year 2006, over 700000 ha of land had been taken over by Prosopis juliflora in Ethiopia, out of which more than 490000 ha (70%) is located in the Afar region (Admasu, 2008; Ryan, 2011).

Prosopis species is a paradoxical exotic invasive plant in Ethiopia among the agro-pastoralists, pastoralists, mechanized farmland owners, economists and ecologists (Berhanu and Tesfaye, 2006). It has been reported to offer significant ecosystem and livelihood services such as microclimate regulation, improvement of soil fertility, reclaiming saline and alkaline soils and income and livelihood diversification (Bhojvaid and Timmer, 1998; Berhanu and Tesfaye, 2006). These are particularly important for the arid lands of Afar, where up to 50% of the regions soils are not coved in biomass, and believed to be exposed to erosive actions of wind and water (ANRS, 2010). Kahi et al. (2009) found that soils under Prosopis juliflora have higher organic carbon and total nitrogen content than soils in the open areas. Similarly, Kahi et al. (2009) reported that although soils under Acacia species have higher organic carbon and total nitrogen than soils under Prosopis juliflora, Acacia species survival capacity in the Afar region is much lower, while Prosopis species have a much deeper root system and a demonstrated higher coppicing ability that helps them to tolerate and thrive in the adverse arid and semi-arid conditions of the Afar region (Ayanu et al., 2015, see Figure 23). These characteristics benefits the resource poor community since the can use the Prosopis cuttings as an alternative source of energy for cooking and a means to secure additional resources to enhance their livelihood from the sale of Prosopis charcoal production. In addition, the pods from Prosopis juliflora serve as source of human nutrition (Choge et al., 2007), and as a less costly alternative ingredient for livestock feed - an important attribute in Afar pastoral communities with acute shortage of animal feed.

Figure 23. Prosopis invasion near the Awash River in Afar regional state of Ethiopia (Photo by Tewodros Wakie in West et al., 2016).

The expansion of Prosopis species, however, is not always viewed as positive development, and it is often reported as one of the most problematic invasive tree species in the Afar region, as well as in the rest of the country). In line with this assertion, recent studies by Ayanu et al. (2015) and Haregeweyn et al. (2013) have shown that the invasion rate by this tree species is increasing rapidly suppressing the growth and development of indigenous tree species and crop plants, and negatively influencing human health, as well as livestock production. In many instances, discussions with local residents and stakeholder highlights the aggressive colonization of useful habitats and agro-ecosystems, as well as its ability to inflict injuries and negatively influencing animal and human health by Prosopies species. Prosopis juliflora is also associated with creating a conducive environment for mosquito breeding and malaria incidents, limiting access to animal watering points and grazing lands, and provision of cover for major predators attacking cattle (Pasiecznik et al., 2013). As a result, members of the Afar pastoralist communities dubbed Prosopis species in some instances as the “Devil Tree” and want it to be eradicated from their environment. A recent study by Farm Africa also linked the invasion of Prosopis juliflora in the Afar region revealing serious potential impacts on people’s food security and livelihoods. The contrasting vie about by different community groups about Prosopis species where one groups advocates for the survival of this multipurpose tree/shrub species whereas other groups is desperately looking for systems that can eradicate the species from the area has led to conflicts of interest among the community, as well as by implementation agencies and policy decision makers. Such conflicts are compounded by the general complexity arising as a result of lack of long term socio-economic and environmental impact analysis particularly in developing countries like Ethiopia, where there is no considerable capability in handling such challenges and support rural livelihoods in the dry lands (HDRA 2005a; HDRA 2005b; Mwangi and Swallow, 2005). These approaches will in the long term significantly contribute towards controlling its spread. In order to address these problems, there are currently in studies analyzing impacts of economic exploitation of Prosopis juliflora in controlling the existing expansion rate in Gewane Wereda, Afar regional state with the specific objectives to: (i) analyze the economic contribution of Prosopis juliflora, (ii) compare the net value among other major alternative land uses with and without the presence of Prosopis juliflora, and (iii) determine the extent to which an economic exploitation (e.g., via promoting utilization of pods for human nutrition ingredient for livestock feed or use of cuttings for charcoal production as renewable cooking energy source etc.) in planned and regulated ways that provide economic incentives to local people and reduces the existing spread and present policy recommendations.

The current report examines the socio-economic scenarios to develop scalable medium scale Prosopis biochar-based soil conditioner model project that involve a private and public sector partnership involving a potential private partner with a capacity to put together a pyrolysis plant that can aggregate the supply of Prosopis from individual smallholder farmers, and consequently process it into pelletized soil conditioner. The public sector partners (in this case Jimma University) and the technical support unit (Cornell University) would involve as technical partners who provide both the technology and capacity building, as well as backstopping support to the private sector partners.

The importance of Prosopis biochar for use as a soil conditioner in Ethiopia's Rift Valley ecozone was investigated in 2012 by the Jimma and Cornell University team. The study found that subjecting this invasive species to a pyrolysis temperature as low as 350 °C could produce biochar with pH (CaCl2) of 6.7, which is ideal to remediate the more saline soils of Gewane and Awash Fentale woredas in Gabi Rasu Zone of Afar region (see Figure 24).

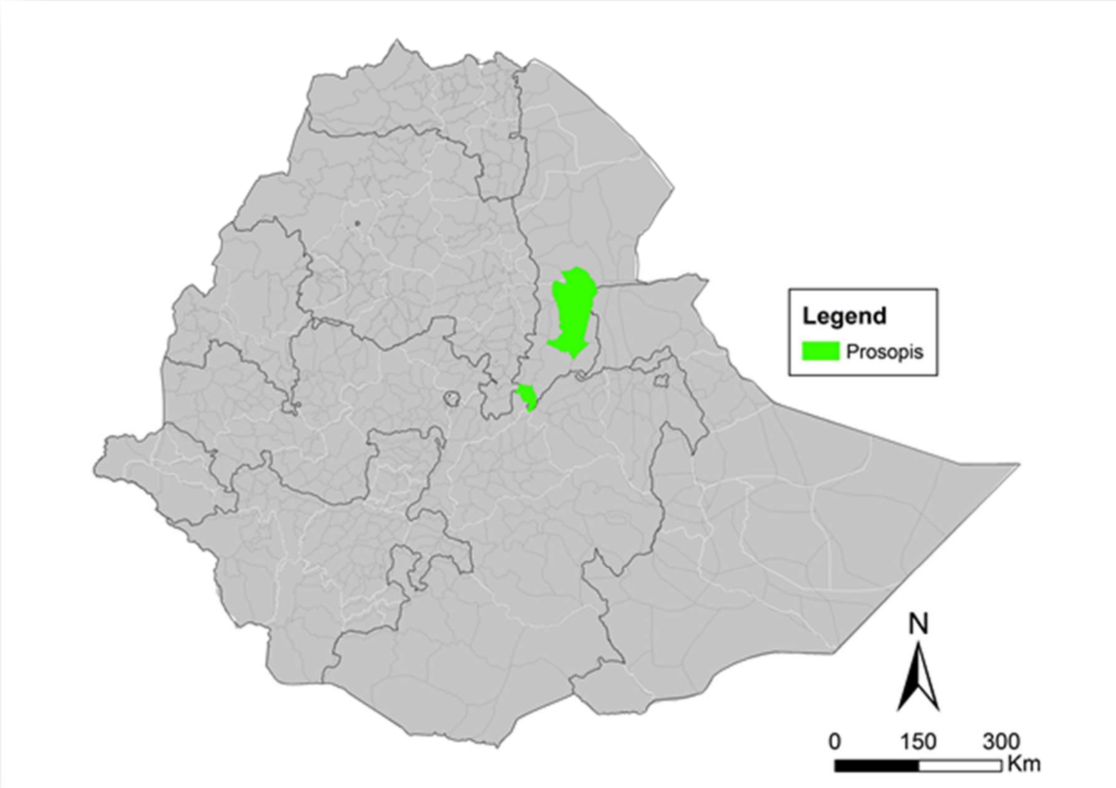

Figure 24. Spatial map showing Gewane and Awash Fentale woredas in Gabi Rasu Zone at Afar region identified as a low-hanging invasive species (Prosopis juliflora) tree source for medium scale model project to develop a commercially viable Prosppis biochar-based soil conditioner.

The study show that Prosopis biochar along with 60% recommended NPK and Prosopis biochar and compost along with alternative sources of phosphorus and potassium (bone char 40% P, Ash 40% K) and inorganic fertilizers (20% P and 40% K) provided the best result in terms of plant biomass, plant height and grain weight compared to control and commercial fertilizers alone. Although finding pertinent information about the dry matter yield of Prosopis juliflora is difficult past investigations indicate that the three has a potential to produce 12.6 t/ha. Considering the fact that this invasive tree species covers more than 490000 ha land in 2006 in the Afar regional state alone (Admasu, 2008; Ryan, 2011), without considering the capacity of this tree species for rapid expansion, the three is a potential to produce each year 6.17 million tonnes of dry matter for biochar production each year in the region. By considering 30% conversion rate from Prosopis dry matter to Prosopis biochar, this will provide about 1.85 million tonnes of Prosopis biochar each year for use as soil conditioner. . By considering 30% conversion rate from Prosopis dry matter to Prosopis biochar, this will provide about 1.85 million tonnes of Prosopis biochar each year for use as soil conditioner. If we consider a socio-economic scenario where by only 25% of this resource can be utilized, it could yield in about 462,500 tonnes of biochar.

Figure 25. Photo showing two field sites present side by side, where the first one show a site where Prosopis removal was practiced and the second one showing a site covered by Prosopis (Photo Dawit Solomon, Woolf et al., 2015).

At the current 4 tonnes per ha rate, this can potentially help to ameliorate soil fertility and productivity related problems in about 115750 hectares of land in the Afar region. If the biochar is used for composting at 2 t/ha rate, there is a potential to double the total smallholder farm area coverage into 231500 ha of land to tackle massive basic soil fertility and productivity constraints of the resource poor farming communities in the region, while also sequestering carbon in agricultural soils and contributing to climate change mitigation.

Figure 26. Result of greenhouse trial evaluating the impacts of Prosopis (invasive weed species) biochar, Prosopis compost, combination of Prosopis biochar and compost, as well as Prosopis biochar, compost and alternative sources of phosphorus (bone char) and potassium (ash) on maize crop biomass, plant height and grain yield in soils collected from Afar regional state.

These preliminary results, combined with the recent Jimma and Cornell University effort to develop appropriate technology to pelletize co-composted biochar to improve handling and improve ease of application, show: (i) the potential for converting this invasive species into useful agricultural input that could contribute to enhance soil fertility and agricultural crop productivity, as well as (ii) develop business models for scalable private-public partnership-based pilot projects to test the socio-economic viability of such approaches in the region and build entrepreneurship opportunities that could empower women and unemployed young people in the region.

Prosopis juliflora redeeming qualities, however, are not only restricted to being soil conditioner. In the recent investigation, it was found out that the increased vegetation cover and carbon stocks, could be particularly useful in GHG mitigation since its presence in the otherwise relative bare landscape is related to increased soil, as well as belowground and above ground biomass carbon sequestration (see Figure 25 and Woolf et al., 2015). In fact clearing of Prosopis juliflora and conversion into cultivated fields in the Afar region was linked to increased emissions of GHGs. In addition to the increased biomass cover and carbon stock, the addition of Prosopis biochar, sourced from well plan and executed management of woodlots, that is reach in highly pyrolyzed black carbon, which is resistant to decomposition and with potential half-life of up to hundreds of years could encourage investment and financial incentives to the community from future carbon financing and payments for ecosystem services and benefits related opportunities to the resource poor communities with special emphasis to women and unemployed youth as the main beneficiaries as shown at Jimma Zone in the Oromia region of Ethiopia, as well as to the entrepreneurs engaged in biochar-based soil conditioner production in the Afar region.

The socio-economic scenarios that identified the low hanging fruit in terms of noncompetitive biomass feedstock, and the proposed medium scale pilot project: (i) fits very well and support the current scenario where significant capital and effort is invested in the region both by the Ethiopian Government and international development partners to finds ways for effective economic exploitation of Prosopis juliflora, and (ii) helps to understand the net value land uses with and without the presence of this species by presenting new and climate smart economic incentives and opportunities for the local communities and support NGOs, regional state and federal government policy makers effort to come up with new policy recommendations to abate the uncontrolled spear of this invasive species in the Afar region, as well as in Ethiopia as a whole.

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