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Faculty of Life Sciences

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Innovation-driven shift towards a sustainable energy consumption of smallholder farmers

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A case study on improved stove technologies and increased on-farm wood production in two regions of Tanzania

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Table of Contents

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List of abbreviations

ANOVA	Analysis of variance
ARI	Acute Respiratory Infections
ARI	Agricultural Research Institute
CBFM	Community Based Forest Management
CCT	Controlled Cooking Test
CGIAR	Global Agricultural Research Partnership
CSS	Case Study Site
CV	Calorific value
EUR	Euro
FAO	Food and Agricultural Organization
ICRAF	World Agroforestry Centre
ICS	Improved Cooking Stove
JFM	Joint Forest Management
KPT	Kitchen Performance Test
m. a. s. l.	meters above sea level
MNRT	Ministry of Natural Resources and Tourism
NAFORMA	Natural forestry resources monitoring and assessment
NGO	Non-governmental organization
PFM	Participatory Forest Management
PHC	Population and housing census
RCD	Root collar diameter
SC	Specific firewood consumption
SD	Standard deviation
REDD+	Reducing emissions from deforestation and forest degradation
TaTEDO	Tanzania Traditional Energy Development and Environment Organization
TFSA	Tanzanian Tree Seedling Agency
TZS	Tanzanian Shilling
UPS	Upgrading Strategy
URT	United Republic of Tanzania
WBT	Water Boiling Test
WHO	World Health Organization

List of figures

List of tables

Executive Summary

Since several decades forest degradation and deforestation is an ongoing problem in Tanzania. Inefficient means of cooking (3 stone fire stoves) are one among several reasons which contribute to deforestation in the country. Inefficient stove technologies directly affect the livelihood of poor rural dwellers in Tanzania who face increased walking distances in order to collect firewood.

This master's thesis analyses the impact of two innovation strategies, so called Upgrading Strategies (UPS), on the firewood consumption and production in the semi-arid region of Dodoma. The first UPS steers to implement and disseminate Improved Cooking Stove (ICS) technologies in the project villages Idifu and Ilolo (Case Study Sites, CSS) in order to reduce the firewood demand for cooking purposes. The second UPS "improved on-farm wood supply" targets to enhance the domestic firewood supply in order to reduce the dependency on external firewood sources and reduce the pressure on the already degraded forests in the area. The research took place one year after the UPS implementation.

A Kitchen Performance Test (KPT) was developed in order to demonstrate performance differences with regard to firewood consumption and cooking time between ICS and traditional 3 stone fire stoves. The tools of semi-structured interviews, focus group discussions and key informant interviews were used to provide insights into challenges and benefits induced by the ICS technology. Biomass growth assessments on trees planted allowed an estimation of the biomass production potential of the tree species *Gliricidia sepium* (*G. sepium*) in the semi-arid region of Dodoma. The combination of firewood savings induced by ICS and increased on-farm wood production emphasize the possibility to cover the firewood demand for cooking purposes of a village by local firewood production.

The results of the ICS performance assessment promise a reduction of firewood consumption of around 30 % and time utilization for cooking of around 20 % when ICS are used instead of 3 Stone fire stoves. The time savings during cooking were supplemented through a reduced frequency of collecting firewood. In total around 27 % of time can be saved when ICS instead of 3 stone fire stoves are used for cooking which reduces the labor duties mainly for women. Based on different cropping patterns around 2,170 ha to 60 ha in Idifu and around 1,442 ha to 40 ha in Ilolo of *G. sepium* need to be planted to cover the annual firewood demand for cooking purposes (1,816 plants per household).

1 Introduction

In Tanzania ongoing deforestation is a severe problem. It results in lower availability of firewood and increased walking distances for villagers to collect firewood. In 2005, the total forest cover in Tanzania amounted up to 35,257,000 ha. The annual forest loss is estimated to be approx. 400,000 ha (FAO, 2005; Blomley and Iddi, 2009). If forest degradation will continue it is most likely that remaining forest areas will be depleted (Kahimba et al., 2015).

The importance of forests and woodlands to human life is manifold. Forests are crucial as a source of livelihoods and provide direct benefits like firewood, charcoal, timber, fodder, human food, medical services among others. In addition, indirect benefits are observable. Forests are important to regulate the climate, mitigate the negative effects of climate change, conserve soil and water sources and provide living space for numerous animals and plants (URT, 2012). In Tanzania deforestation is a double-edged sword. On the one side, overexploitation of forest resources leads to forest degradation with multiple negative impacts for human livelihoods and the environment. On the other side, strict protection and regulation of forest product utilization harm the poorest in Tanzania who directly depend on forest products as a source of income. Woodfuels are the economic and social basis of hundreds of thousands of dwellers. Charcoal and commercial firewood used for cooking purposes generated approximately TZS 1.6 trillion (695.6 Mio. EUR)[1] in revenues for hundreds of thousands of rural and urban producers, transporters and wood energy sellers in 2012.

In sub-Sahara Africa, the domestic demand for wood is mainly driven by the factors income and population growth. The share of wood used as firewood compared to the total amount of wood harvested is substantial. More than 50 % of wood harvested in developing countries is used as firewood or for charcoal production (Scherr, 2004). Zein-Elabdin (1997) cites that over 80 % of all fuelwood consumption in sub-Sahara Africa (SSA) is caused by domestic cooking purposes. In the 1980s the FAO (1981) estimated that about 97 % of Tanzanian annual wood production is used as firewood and accounts for 91 % of the countries primary energy demand. Kassenga (1997) cites biomass to be the most important source of energy in Tanzania accounting for about

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[1] Note: The exchange rate between Euro (EUR) and Tanzanian Shilling (TZS) was assumed as following: 1 EUR = 2.300 TZS.

90 % of the total energy consumption; almost 90 % of that demand comes from the household sector (Camco Clean Energy Limited, accessed 18.11.2015). Other scholars cite that 95 % of the households are using firewood as a source of energy for cooking. 4 % rely on charcoal and 1 % on crop residues (NBS, 2013; Sander et al. 2013). Until the 21st century the dependency on woodfuels, especially firewood in Tanzania changed insignificantly.

Deforestation affects rural areas in Tanzania where livelihoods directly depend on the utilization of firewood for daily cooking. Other forms of cooking energy such as gas or electricity are not affordable for many rural dwellers in the country (TFSA, accessed 20.12.2015). Diminishing forest resources are closely connected to cooking habits with 3 stone fire technologies. 3 stone fire stoves are characterized by low thermal efficiency and have further negative impacts such as high smoke burden for those who sit close to the fireside during the cooking process and a high environmental pollution due to incomplete burning processes of firewood (Camco Clean Energy Tanzania Limited, accessed 18.11.2016). In comparison to 3 stone fire stoves, ICS technologies bear the potential to reduce the firewood consumption (figure 1) (Zein-Elabdin, 1997).

Figure 1: 3 stone fire stove used traditionally in Tanzania (left) and Improved Cooking Stove constructed in Idifu by Trans-SEC (right).
Photo credit: Adkins et al. (2010) (left), ZALF e.V. (right).

High pressure on forest resources showed the need for means to reduce the firewood demand and at the same time justifies further engagement in afforestation programs in the CSS. In this work, the two UPS of Trans-SEC, which aim to reduce the firewood consumption by using ICS technologies and at the same time increase the domestic firewood supply by “increased on-farm wood supply”, were analyzed. The tool KPT was used to assess to what extend locally built ICS contribute towards reduced firewood and time consumption during cooking. The biomass production potential of wood plantations and its potentials to cover the domestic firewood energy demand were assessed.

The first objective of the thesis is to quantify the firewood and time consumption patterns of ICS and 3 stone fire stoves. The second objective is to determine the area of afforested trees needed in order to cover the firewood demand for cooking purposes. The following research questions shall be answered in this thesis: How much time can be saved with regard to firewood collection and total cooking time by using ICS instead of 3 stone fire stoves? Do ICS and 3 stone fire stove performance differ with regard to different types and amounts of food cooked? Does the design shift of ICS during the project lifetime change the performance of "new" and "old" ICS? What are the perceived improvements of ICS compared to 3 stone fire stoves among the users? Are ICS able to contribute towards reduced deforestation in the CSS? What are the driving and hindering factors of ICS dissemination and its sustained use?

The thesis is structured in the following way: Chapter 2 of this work provides an overview on the current literature on ICS and its advantages and challenges. Different approaches in order to determine ICS performance and the question how do innovation processes come into place are displayed. Furthermore, the bioenergy consumption and production situation in Tanzania is highlighted. The results of the baseline survey conducted within Trans-SEC in 2014 provide an overview on the bioenergy situation in the CSS. Chapter 3 provides an overview of the methodological approach of the work. The KPT as a tool in order to gather quantitative and qualitative data on ICS performance and to identify driving factors of ICS dissemination and its sustainable usage is introduced. The procedure, on how the assessment on firewood production potential of *G. sepium* was done, is displayed. Chapter 4 provides the results of the KPT and the biomass growth measurements based on different cropping patterns and spacings of *G. sepium*. The results of the KPT and the biomass production assessment are extrapolated to determine the total hectare demand of wood plantations in the CSS. In Chapter 5 the findings of the thesis are discussed considering the current literature. In chapter 6 a conclusion is drawn and future implications of ICS on the CSS and beyond are discussed.

2 Background: Rural and traditional energy transition

2.1 Improved Cooking Stoves

2.1.1 Benefits

In the 1970s the promotion and dissemination of ICS has started being a beneficial solution instead of traditional 3 stone fire stoves because of the perceived link between deforestation and energy consumption for cooking purposes (Arnold et al., 2003). Dissemination of efficient stoves in Tanzania has been ongoing since the early 1980s with a first major effort being the adoption of the successful Kenyan stove (Hyman, 1987; Agbemabiese et al., 2012). After the millennium the promotion of ICS programs regained attention on donor organization and non-governmental organization (NGO) level. A meta-analysis in 2010 indicated that 160 stove programs were running around the world (Gifford, 2010).

Approximately 3 billion people worldwide depend on firewood, dung, charcoal and other biomass fuels for cooking (WHO, accessed 01.12.2015). Estimations assume that approx. 50 % of all households and 90 % of rural households utilize solid fuels for cooking or heating (Desai et al., 2004). The majority cook with 3 stone fire stoves. Poor burning processes lead to high emissions which contribute to global warming and at the same time have negative effects on respiratory systems of people surrounding the cooking site (Smith et al., 2004). Smoke and particle inhalation cause millions of respiratory infections each year. In 2012 WHO published that approx. 4.3 Mio. people die annually from the effects of indoor air pollution which is induced by 3 stone fire stoves. More than 50 % of deaths were caused among children below 5 years (WHO, accessed, 01.12.2015). Measurements on acute respiratory infections (ARI) showed that the prevalence of ARI among women and children is significantly lower when ICS technologies are used compared to 3 stone fire devices. Wafula et al. (2000) came to this conclusion after testing 200 ICS and 200 3 stone fire users in rural Kenya. Estimations of emission reductions from improving the efficiency of traditional cooking stoves are uncertain, since the underlying data are either unavailable or subjected to considerable fluctuation. Nevertheless, estimations in sub-Sahara Africa emphasize that emission savings from ICS vary between 52 and 190 Mio. tons (t) of carbon per year (FAO, 2010).

Recent studies indicate that the majority of people in East Africa still use traditional 3 stone fire stoves which consume more firewood compared to ICS. The introduction of more efficient ICS reduces the absolute amount of biomass used for cooking and at the same time minimizes adverse health effects of air pollution from indoor smoke (Jetter and Kariher, 2009; Rehfuess, 2006). Studies on the performance of ICS are widely available and exist for different stove technologies. Findings in East Africa on the performance of ICS compared to 3 stone fire are varying. The results on ICS performance with regard to firewood consumption are connected to the type of stove constructed. Stoves, which aim at fuel efficiency, can reach performance values using between 30 % and 50 % less fuelwood compared to 3 stone fire stoves (Still et al, 2011; Jetter and Kariher 2009). Other sources cite that compared to open fires, the use of more efficient biomass cooking stoves can reduce the demand of traditional fuelwood by a half (Chum et al., 2011). Results on time consumption of ICS and 3 stone fire stoves are not consistent due to individual stove testing procedures among the literature.

ICS do not only save firewood and time during the cooking process but also secure a complete combustion of the firewood. During the combustion of firewood, greenhouse gases emerge. By-products such as black carbon (BC) are strongly connected to insufficient biomass combustion. BC has the potential to contribute towards global warming. Due to its improved combustion of BC ICS can contribute to mitigate climate change and reduce the indoor smoke burden (Bond et al., 2013).

2.1.2 Aspects of dissemination

Riedjik (2011) estimates that 3,800,000 ICS are used in Tanzania. One of the main organisations in Tanzania engaged in distribution of improved stoves is TaTEDO (Tanzania Traditional Energy Development and Environment Organization) which distributed 1.2 million charcoal ICS and 116.000 firewood ICS between 2000 and 2006 in the country (Angstreich and Jackson, 2007). Besides few examples, there have been low levels of uptake and sustained use of clean cooking stove technologies by poor communities across the globe. The adoption and sustained use of cleaner cooking technologies by poor communities are functions of social, ecological, and technological interactions (Rehfuess et al., 2014).

Efforts to design, build and promote ICS have been undertaken in many communities throughout the world in recent decades. This resulted in the development of a wide variety of stove types employing a range of materials, design features and production processes (Adkins et al., 2010). The empirical literature addressing the sustained adoption of cleaner cooking systems remain scattered and unstructured. Coherent analyses on driving factors of ICS dissemination are not available (Ruiz-Mercado et al., 2011). The lack of dissemination of ICS technologies can be caused by several factors.

Many scholars cite that the challenge of disseminating ICS is not confined to develop robust technical solutions, to reduce indoor air pollution and increase the effectiveness of cook stoves compared to traditional 3 stone fire stoves. The main challenge is to disseminate and implement cleaner cooking technologies and fuels in the context of various social, behavioral and economic constraints faced by poor households and communities (Kumar et al. 2016). Studies indicate that acceptance of ICS is high when fuelwood is scarce and the resource firewood is priced, speed of cooking is enhanced and the usability of cooking local dishes is met. Poor education patterns in Tanzania might be a reason not to adapt towards the ICS technology. The lack of knowledge of villagers concerning the usefulness of ICS and their benefits can hinder the dissemination. Miscommunication on benefits and challenges of ICS can be a driving factor reducing the speed of implementation.

Important drivers of ICS dissemination are easy installation, low maintenance and usability (Barnes et al., 1994). Poor quality of the ICS, high costs, lack of information and training about the stoves are major factors for the failure to adopt improved charcoal stoves in urban Zanzibar (Omar Makame, 2007). Hovmand (2014) indicates that the sustainable dissemination of ICS technologies in a village might result in a “bandwagon effect” pulling passive community members to adopt the new technology. Quantitative aspects such as increased efficiency or affordability are not the main drivers of adoption. Much less attention is laid on health related factors, like reduced smoke burden for the villagers. Further dissemination of ICS can only be realized if the stoves are widely adopted within social systems. It is essential to consider affordability and cultural issues when deploying new or improved energy technologies. The dissemination of improved designs of domestic stoves succeeds mainly when they are affordable, which is a critical factor for impoverished rural communities (Geoghegan et al., 2008). On the other side a highly subsidized product might hinder the acceptance of the ICS technology. If this is the case ICS programs fail because they lack business opportunities for local producers and lose their value in the perception of the villagers. It is reported that one potential reason for insufficient distribution of ICS technologies is a general lack of commercialization (Clough, 2012). Another driving factor, which determines the lasting utilization of ICS, is the availability of firewood and its pricing schemes. Where households need to purchase fuelwood to a large extend or its availability is connected to extensive walking distances, the acceptance of fuel-efficient stove solutions is much higher (Barnes et al., 1993). Dissemination of ICS technologies is cited to be low in areas where firewood is collected without any financial expenses from the household side.

There is a risk that the dissemination of ICS can be induced by the development projects itself and not be based on the villagers understanding that improved cooking solutions contribute towards improved health, environmental protection as well as decreased firewood and time consumption (Simon et al., 2014).

An interview with Marco Hülls who is the main responsible of Gesellschaft für Internationale Zusammenarbeit (GIZ) for the implementation of the program Energising Development (EnDev) in Tanzania emphasized that an amortization rate of the initial investment for an ICS should not exceed two to three months in order not to counteract the dissemination of the technology. Where opportunity costs for using 3 stone fire stoves as cooking devices are low, the dissemination probability of ICS sinks. The economic pressure has to be tangible; a transition from a subsidized program towards an independent business model has to take place.

2.1.3 Demand and supply driven innovation

In literature, two types of innovation processes are differentiated; demand side oriented innovation processes and supply side oriented innovation processes. ICS can be seen as an incremental innovation, which is a technical innovation based on an existing idea (Witt, 2000). Schumpeter (1911) distinguishes between three phases of innovation: An invention, an innovation and a diffusion phase.

Demand side innovation theory is based on the assumption that governments are the main drivers of innovation processes. If the state wants a certain type of technological development, it should support a successful dissemination of the technology by inducing sales promotion, subsidizing the supply or induce taxes on undesired behaviors. An introduction of a tax that limits the use of firewood after a certain amount of annual usage is one example. The subsidization and taxation indirectly could support the diffusion of more efficient stove technologies. Another possibility to induce innovation is to increase the knowledge of the villagers on the benefits and the usage of ICS. Studies showed that the implementation of a technology is strongly connected to the ability of users to operate a technology and understand its benefits. Arrow (1962) shows that sustained understanding of a technology is strongly connected to an integration of the innovation in daily life. This is seen as a prerequisite for the adoption and further dissemination of a technology. In early stages of the education process, e.g. in the kindergarten or primary school, education on ICS usage can induce a higher acceptance of the technology and increase the awareness of children in young age. Structural barriers, which slow down the dissemination of ICS, might exist and therefore have to be eliminated by a governmental subvention policy (Edler, 2006).

Supply side driven innovation follows the idea that innovations are directly induced by market actors who introduce innovations based on their own research and development of products (Weyer, 2004). Smith and Mehta (2003) suggest that the dissemination of stove technologies should focus on producers of ICS instead of subsidizing consumers.

The sustained usage of a technology is influenced by demand and supply side factors of innovation politics. Especially in the invention phase of a new stove technology users might hesitate to adopt a new technology due to uncertainty of quality and applicability (Kline and Rosenberg, 1986). Supply side innovation politics may induce the introduction of new inventions but may not be suitable for a further innovation and dissemination of a technology. Governmental activities are neglected during the innovation and dissemination process of ICS technology (Rothwell, 1986).

Governmental and research agencies play a key role in promoting the dissemination of ICS technologies. Demand driven innovation and dissemination politics are connected to additional budgetary strain with regard to ICS promotion but might induce humanitarian and environmental benefits, which are much higher than the initial costs (Gassler et al., 2008).

2.1.4 Stove performance assessment: Testing protocols

Compared to 3 stone fire, scholars emphasize that ICS have a potential to reduce firewood and time consumption for cooking. Literature recommendations with different levels of efficiency are cited for different stove programs around the globe. The stove design and the testing procedures of these stove programs were not always transparent and were conducted in different climatic conditions which influence the test results. In literature, ICS test results are related to special sites stove designs and materials. Every stove design has some unique features, which makes the results of stove efficiency of previous studies from other areas limited comparable (Wallmo and Jacobsen, 1997). Individual stove testing is pivotal in order to get clear information on how efficient ICS technologies work. It needs to be tested whether the ICS design introduced provides significant improvements compared to 3 stone fire stoves with regard to firewood and time consumption (Adkins et al., 2010).

In literature, three cooking stove tests are used to measure the performance of a stove, namely the Water Boiling Test (WBT), the Kitchen Performance Test (KPT) and the Controlled Cooking Test (CCT).

The WBT test is referred being a laboratory test while CCT and KPT are conducted in the field. Laboratory-based tests evaluate stove performance and quality in a controlled environment. The WBT is relatively short; a simple simulation of common cooking procedures is possible. It measures how efficient a stove uses fuel to heat water in a cooking pot and the quantity of emissions produced during the cooking process. While laboratory testing is a helpful guide to test the efficiency of stoves with regard to firewood and time consumption, an evaluation in the field provides more resilient information on stove efficiency. The CCT is a field test that measures the ICS performance in comparison to a 3 stone fire stove of a pre-determined local meal. The CCT is designed to assess the stove performance in a controlled setting using local fuels and pots. It reveals what is possible in households under controlled conditions but not necessarily what is actually achieved by households during daily use. Compared to the WBT, where the testing procedures are fixed and rigid, the CCT is more variable with regard to the types of meals cooked, the stove design and the application of the stove, which varies between users. To ensure the comparability of results from the CCT it is required that the test series is conducted under the exact same conditions following the exact same procedures.

The KPT is a field test that is used to evaluate stove performance in real-world settings. A field-based test is the best way to understand the stove’s impact on fuel consumption, general household characteristics and behaviors because it occurs in the homes of stove users (Lillywhite, 1984). It is designed to assess actual impacts on household fuel consumption of different types of stoves. In order to enhance the reliability of the collected data 10 % of households of a village should be part of the study (Bailis et al., 2007). The downsides of the KPT testing scheme is that the execution of the test is expensive, time consuming and labor intensive. The execution of the test requires logistics and field research skills. The KPT is an invasive testing method, which might influence the cooking process (Global Alliance for Clean Cookstoves, accessed 30.03.2016; VITA, 1985). The KPT measures the relative rate of fuelwood and time consumed within the household environment. Compared to the WBT and CCT it is emphasized that the KPT can provide a reliable indication concerning ICS performance. The KPT test results on fuelwood savings tested are reliable and increase the trust of users in the new technology. Realistic test results are required to develop a marketing label of the ICS in order to indicate the benefits of the tested ICS.

2.2 Solid bioenergy: Consumption and production patterns

2.2.1 Global and Tanzanian perspectives

Biofuels and waste[2] products play historically a non-negligible role in the global energy mix. In 1973, the total consumption of primary energy counted 6,106 Million tonnes of oil equivalent (Mtoe) per year. The share of biofuels and waste of the primary energy consumption of 1973 was 10.5 %. Biofuels and waste consumption amounted up to 640.06 Mtoe. In 2012, the total consumption of primary energy amounted up to 13,371 Mtoe per year. The share of biofuels and waste of the primary energy consumption remained at approx. 10 %. The total amount of biofuels and waste used amounted up to 1,340.71 Mtoe (IEA, 2014a).

Sub-Sahara Africa accounts for 13 % of the world’s population, but only 4 % of its energy demand. Analysis show that households in sub-Sahara Africa tend to use a variety of fuels to meet their energy demands (Van der Kroon et al., 2013). The bioenergy use in sub-Sahara Africa is mainly based on solid biofuels (firewood and charcoal) and outmatches the demand for all other forms of energy combined. Approximately four out of five people in sub-Sahara Africa rely on the traditional use of solid biomass; mainly fuelwood for cooking. Even with rising income the changeover to another energy source

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[2] Biofuels and waste comprise solid biofuels, liquid biofuels, biogases, industrial waste, municipal waste, woodfuel and by-products (e.g. charcoal) and animal materials.

is low (Zein-Elabdin, 1997). Making reliable and affordable energy widely available is critical for the development of the region (IEA, 2014a). An expected rise of 40 % in demand for bioenergy in sub-Sahara Africa up to the year 2040 might cause increased pressure on forest endowment of the countries. It is estimated that Africa's population growth will continue, with its inhabitants doubling from 1.2 billion to 2.4 billion between 2015 and 2050. Forecasts of the IEA predict that 650 million people in sub-Sahara Africa will still cook with biomass in an inefficient and hazardous way in 2040. Between the 1960's and the 1990's the global wood demand grew by more than 50 %. Wood is an economic tradable good, which cannot only support domestic demands but also generate income and contribute to poverty alleviation.

The immediate need to take measures to reduce the biofuel consumption in sub-Sahara Africa is obvious. Firewood and its sub products are the most-used energy sources for millions of urban and rural households in Tanzania. Firewood and its subsidiaries are used by all groups throughout the society ranging from the poorest to the upper class which emphasizes that its usage is not largely connected to income. In recent years biomass energy utilization of firewood and charcoal has increased dramatically due to population growth of both urban and rural areas in Tanzania (UNICEF, 2014). An increased pressure on wood resources is observable and caused severe problems in some areas of Tanzania such as desertification and deforestation. Increased demand for woodfuels for cooking coupled with the use of 3 stone fire stoves and dwindling supply led to environmental degradation and created woodfuel scarcity to rural and urban dwellers (Felix and Gheewala, 2011).

2.2.2 Forest situation in Tanzania

Miombo woodlands reach from South-West Africa to the east of the African continent. Miombo consist mostly by trees of subfamily Caesalpinioideae, particularly miombo (Brachystegia), Julbernardia and Isoberlinia, which are rarely found outside of miombo woodlands (Chidumayo, 1997; Frost, 1996). In Tanzania, miombo forests are the main source of firewood and consist of heavy and slow burning firewood (Gauslaa, 1988). Estimations propose that around 90 % of Tanzania's forests consist of Miombo. Fuelwood extraction, shifting cultivation and harvesting of trees for different purposes contribute to the degradation of miombo woodlands in the country. Malimbwi et al. (2005) emphasize that most miombo woodlands are subject to low legal protection, which allows an easy exploitation of these forests.

In Tanzania, the extent of forest resource available as well as their mean annual production of biomass is not known exactly. These figures are an important prerequisite for policy formulations regarding the sector (Mgeni and Malimbwi, 1990; Vahlne and Ahlgren, 2014). The existing information on total forest area as well as deforestation and afforestation measures is inconsistent and outdated. Reliable information on Tanzanian forest resources is mainly constrained by the lack of institutional capacity and priority. According to the FAO, the total forest cover of Tanzania amounted 35,257,000 hectares (ha) in 2005 compared to 41,441,000 ha in 1990. It is assumed that Tanzania faces an annual loss of forest area of 403,000 ha (FAO, 2005).

Reasons for deforestation are manifold and mainly human made. Some scholars pledge that population growth and enhanced space needed for livelihoods in sub-Sahara Africa reduce the availability of firewood resources. The underlying causes of deforestation are rapid and uncontrolled population growth, poverty, market failures, unsecure land tenure and general policy failures coupled with inefficient consumption patterns (Cleaver and Schreiber, 1994; Anderson and Hazell, 1994). Direct agents of deforestation are agricultural expansion, commercial charcoal and fuel wood production, overgrazing, uncontrolled fires, shifting cultivation and illegal logging (Foley, 1985; Hosier, 1993).

Tanzania relies to a large extend on forest products as a source for cooking energy. Hoek-Smit (1991) and Van der Plas (1995) argue that around 85 % of deforestation is directly caused by cooking purposes. Makundi (2001) attributes 70 % of total net forest loss in Tanzania towards charcoal and firewood consumption. Scholars cite that approx. 80 % of woodfuel consumption results directly in deforestation (Zein-Elabdin, 1997). Local buildings are mainly based on timber which further increases the pressure on forest areas. Wood resources are commanded by weak property rights and are regarded as open pool resources by many citizens in Tanzania. Due to unclear land ownership and trees being a natural product the depletion of forest resources is ongoing and its governance is weak although management schemes exist. Extreme poverty can be seen as another reason for households, which stops them from moving along the energy ladder. The energy ladder is a theoretic approach that appeared in the mid 1980’s assuming that people with higher income move towards cleaner and more efficient energy technologies. Early stages of economic growth are closely linked to a rise in woodfuel demand where alternative energy sources are unavailable (Baldwin, 1986; Smith, 1987).

Analyses of existing data regarding growth of miombo forests in Africa are rare. Growth measurements done in Kitulangalo which is located in the semi-humid region of Morogoro in Tanzania (annual precipitation of 800 mm) suggest a growth rate of miombo forests of 2.3 m^3 per ha and year. A study by Ek (1994) reported a biomass increment growth equivalent to 1.88 - 4.35 m^3 per ha and year for an old growth Miombo at Kitulangalo. In Zambia, mean annual biomass increment of a dry Miombo was 1.96 m^3 per ha and year (Chidumayo, 1988). Taking into account that the CSS sites are located in an area of around 500-600 mm of annual precipitation the regrowth of trees might be below the proposed values for Kitulangalo and more close to the data gathered from the biomass growth measured in Zambia. Compared to other regions in Tanzania, which receive more rainfall, the average annual growth increment of trees in Dodoma is low. Data on regrowth of miombo forests have to be treated carefully, a high variation may exist among different areas suggesting a limited transferability of gathered results to other study sites (Malimbwi et al. 2005). Due to the high degradation of miombo woodlands especially in the semi-arid areas of Dodoma, existing miombo woodlands are not sufficient to cover the firewood demand, considering the demographic development in Tanzania. Plantations of exotic species have high mortality rates and are characterized by slow growth rates due to a lack of nutrients, inadequate drainage and vermin. Fast growing species with an annual firewood increment of 25 m^3 per ha and year in wet areas of Tanzania, only produce 3 m^3 per ha and year of firewood in semi-arid areas like Dodoma (Adegbehen, 1982).

In order to combat deforestation in the country, it is vital that especially the local population develop afforestation schemes to reduce their dependency on external wood resources. Tanzania started large-scale plantations development in the 1950s. During the 1970s, the Tanzanian government encouraged individuals and communities to establish woodlots and trees on farms in order to meet the increasing demand for wood as well as improve other environmental services (URT, 2012).

Afforestation measures on national level are done by the Tanzania Forest Service Agency (TFSA). TFSA is a semi-autonomous government agency that was established in 2011 within the Ministry of Natural Resources and Tourism (MNRT). TFSA announced that within the five years of its existence 39,776 ha of new trees have been planted.

24,685 ha have been planted on areas that have been cleared and 15,080 ha were newly planted (MNRT, 2016).

Currently, there are 19 state owned industrial plantations covering around 89,000 ha of wood plantations, mainly planted with softwoods and a few hardwood species. There are nearly 70,000 ha of privately owned plantations. The total area of forest plantations, which is about 150,000 ha, is low compared to the annual rate of deforestation, given high domestic and export demand for forest products. On average the planting of new trees done by government agencies amount up to 8,000 ha per year (MNRT, 2016). Up to 2014, the total area replanted in the country is estimated to be 553,000 ha.

Reasons which might explain the low rate of tree planting are the unavailability of seeds and other planting material. Further issues, which hinder large-scale afforestation, are extreme weather conditions which occur throughout the year. These are droughts, floods, extreme temperatures and winds. Another factor which limits the tree planting is the large area of unsurveyed land. The lack of defined property rights leaves the tenant of the land in the uncertainty of appropriate the benefits from trees planted. Vulnerable property rights provide room for other stakeholders (e.g. the government) to claim the land for other uses (Scherr and Hazell, 1994; Uronu et al. 2014). Uronu et al. (2014) provide several reasons on why afforestation in Tanzania is at a low level. One issue is the lack of knowledge about trees with regard to their utilization (fodder, medicine, soil fertilizer) and their ecological requirements (environment, soil quality, temperature and precipitation). Especially in rural areas villagers are not aware of the importance of trees. When trees are planted, they are grown in environments which are not suitable for their growth. Due to a lack of understanding, planted trees often do not meet the requirements of the users. It is vital to understand the growth patterns of planted trees in order to determine their biomass production potentials. The growth rate of trees is influenced by numerous environmental and climatic variables such as soil quality, drainage, water availability, properties of the plant and light exposure. Other factors such as plant spacing and silvicultural treatment influence the growth of the plants. The factors tree height as well as root collar diameter (RCD) determine the growth of a plant. Different species may also react differently. Generally, height growth precedes any diameter growth. The amount of height growth in one season depends on immediate past and present environmental conditions (Popescu et al., 2003).

The need for local afforestation solutions in Tanzania is evident. Assistance on village level is required to increase local wood production. Skutsch (1983) found that villagers who perceived fuelwood scarcity and who had to walk significant distances to collect wood are more likely to establish plantations.

2.2.3 Forest Management in Tanzania

Land in Tanzania is divided into three categories as defined in the Tanzanian Land Act of 1999: Reserved land, village land and general land. URT (2012) cited that the total forest area of 35,257,000 comprised of 18 million ha of reserved forests and 17.26 million ha of unprotected forests defined as village or general land.

Reserved land includes protected or designated land such as national parks, land for public utilities, wildlife reserves and land classified as land whose development plays a pivotal role within the ecosystem. Although around 50 % of forests marked as reserved land, scholars emphasize that forest protection under this land title is low or non-existent (Johnsen, 1999). Village land includes registered village land, land demarcated and agreed to as village land and land that villages have been occupying and using as village land for 12 or more years under customary law. This type of land is under governmental observation as it plays a central role for vital industries of the country. The third type of land is general land. General land includes woodlands, rangelands and urban and peri-urban areas that are not reserved for public use (URT 1999, accessed 07.12.2015).

Although management guidelines for village and general land exist, these types of land are subject to degradation because of insufficient forest monitoring. Village and general land does not dispose clearly defined property rights and therefore possess properties of a common pool resource, characterized by unsecured land tenure, shifting cultivation, harvesting of woodfuel, poles and timber. Village land is exposed to rivaling land use systems such as agriculture, livestock grazing, settlements and industrial development and therefore being highly affected by forest degradation.

By the mid-1990s, a global shift towards decentralized forest management was taking place, with delegation of forest management rights and responsibilities to a local level which led to a major review of forest policy and legislation. This was one strategy which led to general changes in forest management. Many governments were intensifying their efforts to tackle the numerous regulatory and political barriers that were holding back investments in the domestic energy sector. However, inadequate energy infrastructure slows down the development of the sector (IEA, 2014b; UNICEF, 2014).

Also in Tanzania legal changes in forest management took place. The national government imposed several laws and policies to guide the management of natural resources with special emphasize to forest resources. The Tanzanian Forest Act of 2002, as one example, transfers the ownership of forest resources and management responsibilities to local communities. Other national laws and policies which guide the management and extraction of wood products are the National Forest Policy of 2008, the Environment Management Act 2004 (Ministry of Natural Resources and Tourism), Land and Village Act 1999, National Land Policy 1997 (Ministry of Lands), National Environmental Policy 1997 (Vice President's Office) (Sander et al. 2013). The laws and policies were introduced by several ministries within Tanzania which indicates that the task of forest management remains scattered among several ministries.

There are efforts like Reducing Emissions from Deforestation and Forest Degradation (REDD+) and the national forestry resources monitoring and assessment (NAFORMA) initiative to combat deforestation in Tanzania (IEA, 2014b). Since 2002, Participatory Forest Management (PFM) was legally proclaimed under the Tanzanian Forest Act of 2002 which included Joint Forest Management (JFM) and Community-based forest management (CBFM) as a major strategy for managing natural forests in order to maintain sustainable use and conservation of forest areas. PFM focuses on improving rural livelihoods, conserving and regenerating forest resources and promoting good governance. PFM schemes are cited to have a positive impact on forest endowment in the country (Blomley et al., 2008). The concept of PFM includes the local population in the decision-making process concerning forest management and the collection and distribution of forest benefits. PFM participates people who have a direct stake and a personal interest in the management of forest resources. PFM can be applied in unreserved forests defined as village or general land as well as in national forest reserves or forest reserves owned by local authorities at district level. It is characterized by divided responsibility and puts a focus on implementing property rights especially on the forests with de-facto no or low ownership. In Tanzania, the main sources of finance for forest management schemes are charges levied on forest products and services, state budget allocation to the forest administration and grants from development partners for forest projects. Limited financial resources are compelling Tanzania to identify innovative financing mechanisms to attract new sources of investment in forest management outside of traditional channels.

Through CBFM, villagers or private persons can manage certain types of land on their own. JFM is a mechanism to execute mutual ownership and responsibilities. Returns are divided among national and local authorities. JFM is an approach to manage state owned forests with shared management responsibilities and is characterized by the fact that returns are divided between the state and the communities. Villagers typically enter into agreements to share management responsibilities with the forest owner (URT, 2003; Blomley and Ramadhani; 2006).

Tanzania has benefited from the implementation of initiatives to protect forests but tangible outcomes are not presented. Programs like PFM benefited communities by integrating them into forest management. Nevertheless, the development in the fuelwood sector cannot be regarded as sustainable. There is no balance in demand and supply of forest resources and a risk of complete depletion of forest areas in some parts of Tanzania. In 2012, the Tanzanian government urged that the issue of deforestation cannot be solved solely by governmental efforts (URT, 2012).

Tanzania is putting efforts in addressing drivers of deforestation and forest degradation through adoption of legal frameworks and implementation of different forest management schemes. Although laws and policies are in place the biomass energy sector in Tanzania is cited to be largely informal, poorly regulated and unorganized (Sosovele, 2010). Up to today, national policies and acts are often uncoordinated and cross-sectoral among Tanzanian ministries. Responsibility and accountability of individual ministries is lacking. Although policies and acts are established to govern forest resources in Tanzania, the World Bank (2009) stated that a coherent policy framework governing the value chain along the firewood and charcoal production as well as trade does not exist and reliable statistics on the sector are not available. Unavailable or ineffective forest management schemes contribute to ongoing deforestation in Tanzania (Mwampamba, 2007). Economic sustainable extraction and equitable distribution of benefits generated from forest products is lacking because of a missing coherent policy framework which governs the firewood and charcoal sector.

The restrained use of expensive alternative energy sources such as kerosene and electricity encourage further usage of biomass.

2.3 A scientific approach for evidence based fostering of Upgrading Strategies

2.3.1 Trans-SEC

Trans-SEC “Innovating strategies to safeguard food security using technology and knowledge transfer: A people-centered approach” is a research project launched on 01.05.2013. It is a multicultural large-scale food security project supported by the funding initiative "Securing the Global Food Supply– GlobE” and embedded in the German framework program "National Research Strategy BioEconomy 2030.” Seven German research institutes, two CGIAR research centers from Kenya and USA as well as five Tanzanian institutes are involved in Trans-SEC. Trans SEC aims at improving food security for the most-vulnerable poor rural population in Tanzania. Trans-SEC is designed to identify successful food securing UPS along local and regional food value chains. A joint stakeholder and scientist driven decision process was set up to determine which UPS’s were most promising for further testing. A participatory approach secured that all stakeholders could contribute to an equitable way to increase the local ownership of the UPS identified. The participative process resulted in 11 UPS determined for practical testing in four CSS across sub-humid (Morogoro) and semi-arid (Dodoma) Tanzanian regions. The action research approach of Trans-SEC combined a scientific approach with direct implementation of UPS.

2.3.2 Bioenergy situation in the project villages

Before the implementation of the UPS ICS and “improved on-farm wood supply” in 2015, a baseline survey was conducted in mid-2014 in the CSS. The baseline survey was done to determine the firewood production and consumption patterns in order to compare the situation in the bioenergy sector before and after the implementation of the UPS in the CSS. During the baseline survey 295 households in Idifu and Ilolo were asked on how the firewood situation had changed compared to 5 years ago. Around 73 % of the households responded that the firewood situation had worsened in terms of time spent to collect firewood. 156 households responded that they had to spend more or much more time to collect firewood. 49 households (16.6 %) saw no changes in the time spent to collect firewood and 24 persons (8.1 %) claimed that they spent much less or less time to collect firewood compared to five years ago.

During the baseline survey, 220 households in Idifu and Ilolo quantified their time consumption for collecting firewood. The walking distances to collect firewood are substantial (Household survey Trans-SEC, 2014). The walking distances in Idifu reached 286.8 min (Standard Deviation (SD) 225.4 min) (go and return). In Ilolo the walking distances were slightly reduced compared to Idifu. Around 196.79 min (SD 172.36 min) was spent (go and return).

Analysis of 110 households in Idifu and 109 households in Ilolo showed that firewood for cooking purposes is mainly gathered from miombo woodlands (table 1). The majority of the villagers (more than 90 % in Idifu and Ilolo) use firewood from forest areas around the villages (forest areas, community land and others). Only seven households (6.4 %) in Idifu respectively eight households in Ilolo (7.3 %) claimed to collect their firewood grown on own farms or plantations. All other households gather their firewood from public forest areas and community lands, which are de-facto under low legal supervision.

Table 1: Distribution of firewood collection sites in Idifu and Ilolo

	Idifu (N =110)	**Ilolo (= 109)**
Forest area	66	70
Community land	28	22
Own plots	7	8
Others	9	9

Biomass is the main source of energy in the CSS Idifu and Ilolo. Commonly firewood or charcoal is used to meet households' energy demand for cooking purposes. In the research villages ICS devices were almost non-existent (table 2).

Table 2: Type of cooking devices used in Idifu and Ilolo

	Idifu (N =150)	**Ilolo (N = 110)**
Charcoal stove	1	1
Improved charcoal stove	1	1
3 stone fire stove	148	108

2.3.3 Upgrading Strategy: Improved Cooking Stoves

The ICS design of Trans-SEC follows a two-pot design, which allows cooking two dishes at the same time (figure 2). The stove possesses one combustion chamber which is located under the first pot. The first pot is directly heated by the combustion chamber below. The second pot is heated via hot air which is channeled through the stove. The stove possesses a chimney, which creates the draft in order to pull the air from the wood entry slot via the first and the second pot towards the exit. When the fire is lighted, the wood entry slot can be covered with a stone to slow down the combustion process of firewood when no extensive heat is needed (Bryden et al., 2005).

The ICS stove design follows the rocket stove principle. The rocket stove science has been available since the 1980’s. The rocket stove owns its name from its combustion features where the flame burns inside a combustion chamber. The hot air is channeled through the vertical duct towards pot one and two. Rocket stoves are well-insulated cooking devices which increase the thermal efficiency compared to 3 stone fire stoves. Scholars assume that at least half a million rocket stoves are being in use worldwide. The combustion chamber has a height of approx. 30 cm to make the rocket principle work. This allows a complete combustion of the firewood (Bryden et al., 2005; Ochieng et al., 2013). A complete combustion during the cooking process lowers the emission of particles contributing to global warming. MacCarty et al. (2008) examined several types of cooking stoves performing a laboratory test on specific emissions. The authors concluded that greenhouse gas emissions of rocket mud stoves are lower compared to 3 Stone Stoves with special emphasize on carbon monoxide, methane and emissions from unburned hydrocarbons.

During the planning phase of the ICS program, special emphasize was put on enabling the villagers to construct the stoves without support from external sources. Trans-SEC focuses within its ICS approach on locally manufactured stoves along the complete stove value chain. Locally available materials such as mud, dried-grass and anthill or soil are used to secure that the stoves can be locally constructed without external inputs, especially after the end of the Trans-SEC project in 2018. This led to a continuous change of the design of stoves constructed. Artisans changed the stove design based on their own experiences. These self-determined continuous changes might increase the ownership of the villagers and support further engagement in the ICS technology. The ICS dissemination followed the train-the-trainers concept. All members of the initial ICS groups were trained to construct stoves on their own. This was done to anchor the knowledge on constructing stoves within the village and enable the group members to scale-up the construction of ICS into a business model to create income. Follow-up works like maintenance, repairs and replacements create employment and income for the stove artisans.

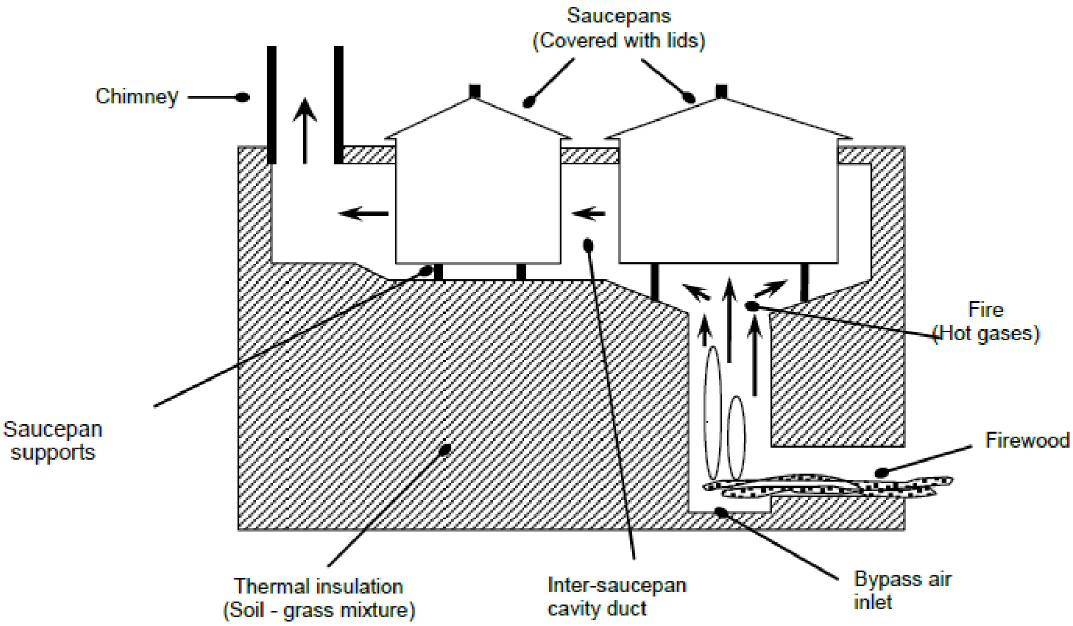

Figure 2: Archetype of an Improved Cooking Stove introduced by Trans-SEC.
Source: Simonis et al., accessed 01.04.2016.

The adoption process of ICS dissemination works independently of Trans-SEC. A random selection process was conducted to determine the initial group members in Idifu and Ilolo. The initial ICS users (23 households in Idifu and 25 households in Ilolo) were trained on how to construct a stove by themselves in order to disseminate the technology within the village without external input.

The ICS constructors built additional 80 ICS within Idifu. 37 additional ICS were built by local ICS constructors in Ilolo. Up to March 2016, 165 ICS (Idifu 103 ICS and 62 ICS in Ilolo) have been constructed in Idifu and Ilolo (figure 3). The first ICS were constructed in February 2015. Up to March 2016 the ICS dissemination of ICS among all households in Idifu was 7.4 % (103 households using ICS / 1,386 households in Idifu) and in Ilolo 6.7 % (62 households using ICS / 921 households in Idifu). Between November 2015 and January 2016 the new adopters in Idifu and Ilolo amounted up to 42 households (14 new ICS per month). This equaled a higher uptake rate of the technology than in the previous months. Between February and October 2015 only 66 adopters of ICS in the CSS (approx. 7 new stoves per month) were registered. From January up to September the villagers are mostly occupied by farm works (planting, harvesting and processing of harvest). This might have contributed to the slow implementation of

ICS in the CSS during that period.

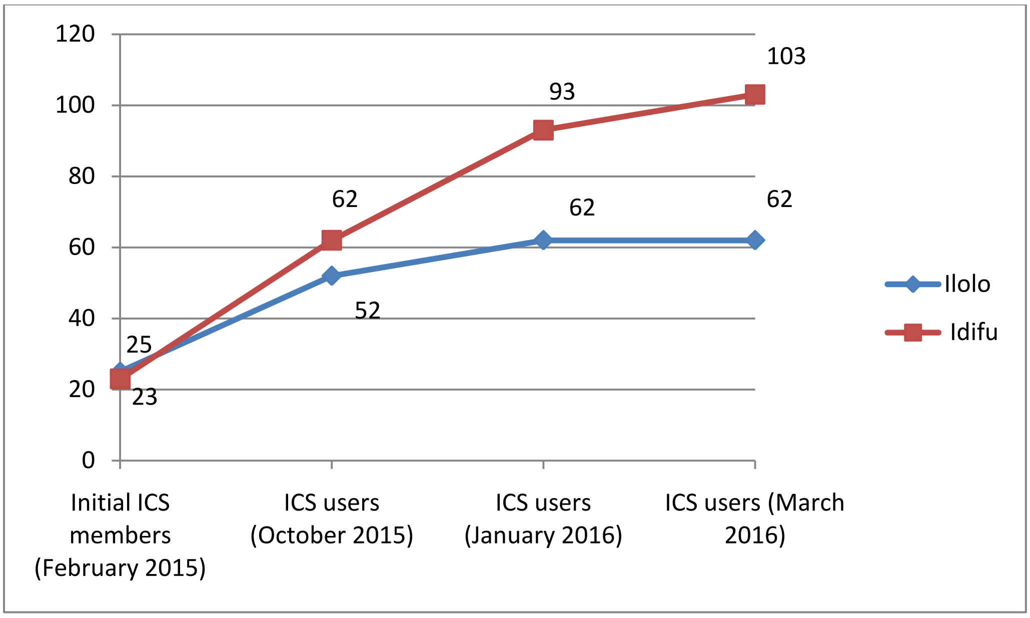

Figure 3: ICS dissemination in Idifu and Ilolo village, February 2015 - March 2016.

2.3.4 Upgrading Strategy: Improved on-farm wood supply

In Ilolo two tree nurseries (Bwawani and Mazengo) were established in close collaboration with the villagers (Figure 4). The Mazengo group consists of 16 members and the Bwawani group of 15 members. The tree seedlings are raised in the tree nurseries in order to plant them in the village surrounding. The UPS "improved on-farm wood supply" targets to increase the domestic firewood production and supports the afforestation efforts in the CSS. The tree nurseries follow an annual schedule of raising trees and shrubs. When the rainy season begins, on average in December and January of each year the seedlings are planted in the field. The raising of the seedlings in the tree nurseries starts some month before the planting in the fields.

The first trees were raised in 2014 in the tree nurseries. While the tree nurseries are operated by villagers, education on tree plantation, equipment for planting, as well as tree seeds are provided by ICRAF Tanzania. In the secured surrounding of the tree nurseries the seedlings can grow without being exposed to grazing animals and other external threats. In the tree nurseries the plants can be protected against pest and vermin. After the trees reach a height of approx. 10 cm to 20 cm, they are planted in the fields. Within the Trans-SEC project *G. sepium, Albizia lebeck, Acacia nilotica, Senna siamea, Terminalia mentaly and Afzelia quanensis* are planted as boundary trees, woodlot plantations or intercropped with crops.

The UPS “improved on-farm wood supply” targets to reduce cooking related deforestation of miombo woodlands. In the CSS existing miombo forests are already degraded and villagers have to walk substantial distances to collect firewood (chapter 2.3.2). Fast-growing tree species which provide firewood within a short growing period are preferred in the afforestation process. The trees planted by Trans-SEC are multipurpose trees but are planted with focus on firewood production. Besides firewood production on-farm trees fulfill different purposes for farmers and are usable for timber, for firewood or charcoal production, for medical purposes, as fertilizers for crops and as fodder for animals (Ekhuya et al., 2015).

Figure 4: Tree nursery Bwawani group in Ilolo in October 2015.
Photo credit: Anthony Tairo (tree seedlings raised in plastic bags).

The most commonly planted tree species in the tree nurseries in Ilolo is *G. sepium*. *G. sepium* is a member of the sub-family Papilionoideae and lies within the tribe Robinieae (Lavin, 1987). *G. sepium* is a medium-sized leguminous shrub which originates from Central America. It is planted because of its multiple uses among others such as foliage, green manure and firewood. *G. sepium* is a thornless tree and, if not pruned, attains a height of 10-12 m. The tree is strongly branched out from the base with basal diameters reaching 50-70 cm. The total lifetime of the shrub is cited to be 15 years. Its rapid growth makes it an aggressive pioneer capable of colonizing secondary forests and fallow dominated grasslands often forming dense stands (Anoka et al. 1991). *G. sepium* plantations are attractive because they improve the soil fertility and produce additional products in the form of firewood (Grist et al., 1998). The shrub is one of the most widely cultivated multipurpose trees in the tropics and has been used outside of its native habitat. It is a species of wide-ranging soil and climatic adaptations. The shrub has positive effects on soil properties due to its ability to store nitrogen in the soil and is therefore a suitable plant to enhance crop yields when intercropped (Rico-Gray et al. 1991). It is used as a shade tree for annual and perennial crops. Furthermore, it is used as living fences in order to prevent soil erosion, as an ornamental tree and in traditional medicine. The green biomass of *G. sepium* provides fodder for animals. When intercropped the shrub *G. sepium* fertilizes the soil by storing nitrogen into the soil.

The wood is hard, durable and termite-resistant (Reyes et al., 2009). It is an important source for firewood due to its quick growth after pruning. The easy coppicing nature of *G. sepium* attributes to its acceptability as a source of firewood. Firewood from *G. sepium* is frequently pruned by cutting branches or by completely coppicing trees at low levels above ground. After a growth period of one year the wood diameter of *G. sepium* is still low which emphasizes that *G. sepium* is mostly collected for self-consumption (Simons and Stewart, 1994).

3 Methodology

In this chapter the methodology of the KPT and the assessment of biomass production are presented.

3.1 Case Study Sites

In August 1964 the two states Tanganyika and Zanzibar formed the United Republic of Tanzania. The United Republic of Tanzania is located in East Africa within the African great lakes region. Tanzania's population composes of several ethnic, linguistic, and religious groups. Tanzania is a presidential constitutional republic; its capital is Dodoma. The currency is Tanzanian Shilling; the official languages are Kiswahili and English while Kiswahili is commonly used in daily communication. Tanzania’s land surface comprises of 947,087 km². The Tanzanian population and housing census (PHC) of 2012 states that the Tanzanian population amounts up to 44,928,923 people. Approximately 70.4 % (31,629,000 people) of the population lives in rural and 29.6 % (13,298,000 people) in urban areas (PHC, 2012). In 2012 28.2 % of Tanzanian mainland population lived below the basic needs poverty line, which was defined at 36.800 TZS (approx. 16 EUR) per month. 84.1 % of Tanzanians who lived below the basic needs poverty line live in rural areas (NBS, 2014).

Idifu and Ilolo are located within the Chamwino district in the Dodoma region in the semi-arid plains in central Tanzania close to the Tanzanian capital Dodoma (6°26′27″S 35°59′5″E) around 1,000 m.a.s.l. (figure 5). The Chamwino district is one among six districts in the Dodoma region and has a population of 2,083,588 people (NBS, 2013). The total surface of the Dodoma region amounts up to 41,176 km^2 of which approx. 19.3 % is suitable for wood plantations (Allen, 1985). The Chamwino district comprises 330,543 people with an average household size of 4.6 people per household. The annual population growth rate is 2.7 % since 2002 (NBS, 2013).

The climate of the Dodoma district is defined as semi-arid and consists of an unimodal rainy season from early December to April where approximately 85 % of the rain falls. Within Dodoma region on average 500-600 mm of annual precipitation is registered. Mahoo et al. (2015) state a high variability in rainfall from 326 mm to 882 mm per annum. The rainfall in the district is unpredictable with regard to frequency, amount and distribution especially during the cropping season in December and January. The high variability in precipitation contributes to a high variability in yields and affects food security directly (Kahimba et al., 2015). During daytimes, an annual average temperature of 29° C was recorded throughout the year. During nights, the temperatures dropped to an annual average of 16° C.

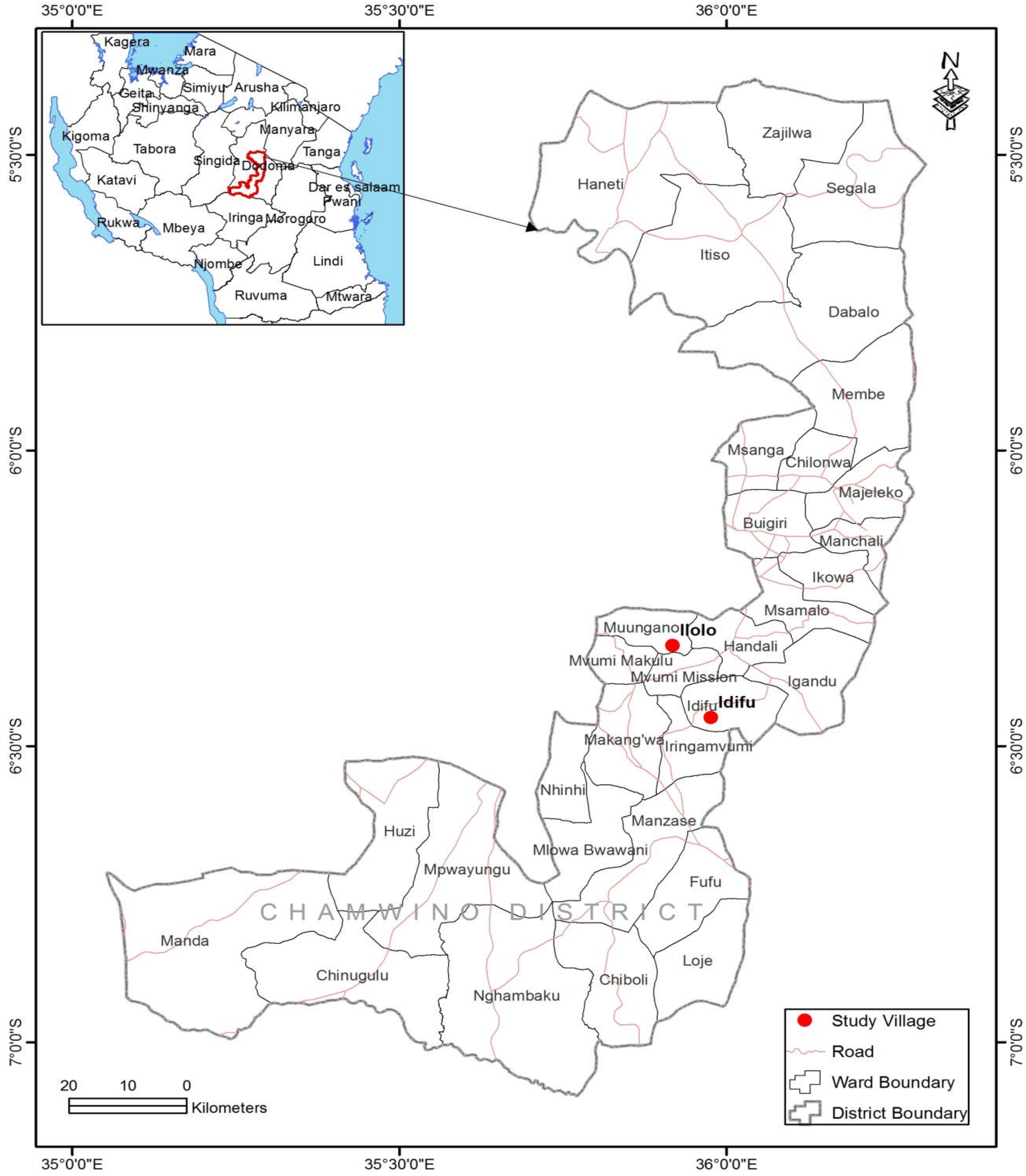

Figure 5: Map of Tanzania (top left corner) and Chamwino district, Dodoma region including the project villages Idifu and Ilolo (middle).
Source: Geographical Information System Unit, University of Dar es Salaam, 25.05.2016.

In Tanzania around 80 % of people rely on agriculture as the major source of income

(URT, 2001). Agricultural income is unpredictable due to unreliable rainfall, periodic famine, high grazing pressure and increased cultivation of marginal areas (Kangalawe and Lyimo, 2013).

The total ward area of Idifu amounts up to 15,485 ha. Idifu ward comprises 9,609 people (Kahimba et al., 2015). The Idifu village is estimated to have a population of 5,956 people living in 1,386 households. The village area covers about 6,000 ha out of which 2,000 ha are suitable for agriculture. The village is subdivided into 14 subvillages. Ilolo is located in Muungano ward which comprises 10,559 ha. The ward comprises 10,745 people. Based on local census data of the village office in Ilolo, the village comprises 4,125 people divided in 921 households. The village is subdivided into 12 subvillages.

3.2 Cooking stove performance assessment: Kitchen Performance Test

The information about the energy saving potentials of ICS with regard to firewood consumption is varying in the literature. The results of scholars have only limited applicability to the semi-arid region in Dodoma because different testing protocols were used. At the same time different site conditions influenced the results gathered during the stove testing.

After balancing out the merits and demerits of the different stove testing tools, a KPT was conducted in order to identify performance differences between ICS and 3 stone fire stoves. The field-based tests demonstrated how the ICS perform within a specific environment using local cooks, ingredients and fuels (VITA, 1985; Bailis, 2004). The results of this work added towards existing literature by measuring the performance of ICS while using a testing protocol with a two-pot design and one combustion chamber. In order to identify the firewood production potential from on-farm wood production in the semi-arid area of Dodoma the biomass growth of *G. sepium* shrubs was assessed, measuring the foliage and biomass production of different plots in the Dodoma region.

The design of the testing protocol and the questionnaire were adjusted to the ICS and site conditions (Appendices 1-5). The quantitative testing protocols were used to determine the firewood and time consumption of ICS and 3 stone fire stoves during predetermined cooking tasks. Semi structured questionnaire testing protocols were developed to determine how the ICS technology and the bioenergy situation in the village is perceived by ICS and 3 stone fire stove users.

In total two KPT were conducted in Idifu. The primary data collection was undertaken by 5 scholars. The two KPT were conducted in the same season with similar climatic conditions to avoid bias due to different weather conditions which might have affected the test outcome. In order to reduce adverse climatic conditions like intense wind, etc. the KPT was conducted inside the kitchen (Bailis et al., 2007).

In total 72 households were surveyed during the two KPT in January and February 2016. Every household which was part of the survey conducted two cooking tasks per day. The quantitative assessments were divided into three different cooking tasks. In January 2016 a fast cooking and a slow cooking dish was tested to grasp the ICS performance for different cooking tasks. In all the cases the cook who was normally responsible for cooking in the household was asked to perform the cooking task in order to get an authentic and real-world result. In order to secure the comparability of the results among the tested households, standardized testing procedures and testing utensils like pot size and type of firewood were used.

For the qualitative part every household answered one questionnaire which resulted in 72 samples. A further increase in sample size was not feasible due to financial and labor constraints.

3.2.1 Test setup: Comparison of Improved Cooking Stove and 3 stone fire stove performance

The first KPT in January 2016 was conducted from the 12.01.2016 until the 20.01.2016. The KPT captured the quantitative differences of ICS and 3 stone fire stove performance with regard to firewood consumption and cooking time. In total 40 households were surveyed. The test sample of 40 households consisted of 20 households which used the ICS technology and 20 households which used 3 stone fire stoves. Every household was assessed 2 times per day cooking lunch and dinner. In total 80 quantitative test samples (40 ICS, 40 3 stone fire) were conducted and used to compare the performance of ICS stoves and 3 stone fire stoves.

The KPT was designed as a cross-sectional study where the test groups were divided into groups using 3 stone fire and one using the ICS technology. The alternative would have been a paired-sample study where one group of households has to test both technologies sequentially (Hill et al., 2008). This option was not feasible because the 3 stone fire users did not own an ICS and were not trained in its handling. During the studies the households were selected randomly to avoid bias. On the 12.01.2016, the firewood and the cooking ingredients were prepared for the following tests. The participating households were informed about the goal of the KPT and asked about their willingness to participate in the cooking task. Every enumerator tested one household per day conducting two different cooking tasks.

The daily routine was standardized. At around 11 a. m. the households were visited, the testing procedure was explained and the cooks were instructed. The cooking site was inspected. Open questions concerning the KPT were answered. The firewood and the ingredients were weighted with a spring scale and afterwards handed over to the households. At the beginning and at the end of each cooking task the firewood was measured. The leftover charcoal was neglected because the households indicated that during a normal cooking task the charcoal remains in stove after cooking until it becomes ash. The total time consumption of the cooking task was recorded. During the KPT tests the firewood was provided by the testing team. Uniform firewood was chosen to avoid bias due to inconsistent moisture content and burning values of different types of firewood. During the KPT test in January 2016 the firewood used was a local wood species called mrama (Kiswahili). It was checked that only the firewood handed over and no “external” firewood was used during the cooking task. The moisture content of the firewood was measured to be 15 %. This was in line with other scholars who measured the moisture content of the provided firewood in Idifu (Rajabu, 2016). The cooks were instructed to use the stove similar to their daily cooking habits.

The amount of food cooked was predetermined by the testing team in order to control the amount of ingredients used. The amount of food cooked differed among the tested households in order to simulate different household sizes. Based on the average household size of 4.6 household members 3 different amounts of food were cooked in order to simulate 3 different household sizes. A normal distribution of household sizes was implied.

At lunch time the meal rice and vegetables was cooked. This type of food is defined as being fast to cook. It was cooked to see how ICS and 3 stone fire stoves perform during a relative short cooking task. At dinner, beans and rice were cooked. Beans are leguminous plants which require long cooking time until they soften; often 2 – 3 hours. The cooking task steered to identify the performance of ICS and 3 stone fire stoves during a long cooking task. The first group represented a small size family with 2-3 members. Group 1 cooked 500 grams (g) of rice and vegetables at lunch time. At dinner time 250 g of beans and 500 g of rice were cooked. This cooking task was conducted in 10 households.

The second group represented a middle size family with 4-5 members. Group 2 cooked 1000 g of rice and vegetables at lunch time. At dinner time 500 g of beans and 1000 g of rice were cooked. This cooking task was conducted in 20 households.

The third group represented a large size family of 6-7 members. Group 3 cooked 1500 g of rice and vegetables at lunch time. At dinner time 750 g of beans and 1500 g of rice were cooked. This cooking task was conducted in 10 households.

Due to different amounts of ingredients used during the cooking process, the firewood consumption per ingredient used (specific firewood consumption (SC), *Form. 3.6*), was calculated as a ratio of firewood consumed (f_c, *Form. 3.1*) per total amount of ingredients used (W_i, *Form. 3.4*). The figure W_i comprised out the weight of rice, water and oil used. In order to calculate the precise time consumption of the cooking task, the cooking time per unit of food cooked was measured (in this case time spent to cook 1000 g of ingredients, *Form. 3.10*). For facilitation purposes, there were no differences made between different volumetric mass densities of ingredients. Due to insufficient data quality, one case of ICS and one case of 3 stone fire had to be excluded from the analysis. The formulas used to calculate the performance indicators of the stoves were derived from Bailis (2004).

Total firewood consumed (g): $f_c = f_i - f_f$ *(Form. 3.1)*

Weight of firewood at start of the cooking task (g): f_i *(Form. 3.2)*

Weight of the firewood after finishing the cooking task (g):

f_f *(Form. 3.3)*

Total amount of ingredients used (g): $W_i = \sum_{u=1}^{n} i_u$ *(Form. 3.4)*

Type of ingredient used during cooking (g): i_u *(Form. 3.5)*

Specific firewood consumption (SC) ($\frac{grams\ of\ firewood}{gram\ of\ ingredient}$):

$SC = \frac{f_c}{W_i}$ *(Form. 3.6)*

Total cooking time (min): $\Delta t = t_f - t_i$ *(Form. 3.7)*

Time when cooking process begins (min): t_i *(Form. 3.8)*

Time when food is finished to cook (min): t_f *(Form. 3.9)*

Total time spent to cook 1000 g of ingredients (min):

$$t_{\text{time spent to cook 1000 g of ingredients}} = \frac{\Delta t}{\left(\frac{W_i}{1000}\right)} \qquad \textit{(Form.3.10)}$$

3.2.2 *Test setup: Comparison of "old" and "new" Improved Cooking Stove performance*

Since the implementation of the ICS in Idifu in February 2015 a design shift occurred induced by the villagers. Between the 26.02.2016 and the 01.03.2016, the KPT was conducted in order to determine whether the design shift entailed significant differences with regard to firewood and time consumption during cooking. The second quantitative KPT in February 2016 focused to get a clear picture of the ICS performance of the different types of ICS. The stoves were divided in "old" ICS and "new" ICS in order to monitor whether there are changes in cooking performance traceable. The category "old" ICS contains the initial ICS users and the early adopters. The "new" ICS users were those who adopted the technology after several months when experiences of the stove performance and design were already available among the villagers. The "old" ICS design was based on the rocket style principle with a higher combustion chamber compared to the "new" ICS. The "new" ICS were constructed with a lower total height suspending the rocket stove principle. Artisans who constructed the stoves cited that they expected a better cooking performance induced by the design shift. Reduced stove height as well as the increase of the diameter of the wood entry slot was seen as potentials to increase the total heat and the heat transfer between combustion chamber and the second pot.

During the KPT in February 2016 32 ICS users were assessed. Each household was assessed two times which resulted in 64 samples. In total 36 test samples were collected from ICS users using the "new" ICS design and 28 test samples were collected from users of the "old" ICS design. The households which performed the second KPT were selected randomly among "new" and "old" ICS users. Uniform firewood was provided to avoid measurement differences due to different wood species. The firewood species used was Mtema (Kiswahili). The cooking process was similar to the one described in chapter 3.2.1. Before and after the cooking task the firewood and the ingredients were measured. Electronic scales instead of spring balances were used during the second KPT assessment. The electronic scales measured more precisely and allowed an assessment of the charcoal which was left over. By including the leftover charcoal into the firewood consumption calculation, the total firewood consumed on an oven-dried equivalent basis (0 % moisture content of the firewood) was calculated. The total time consumption of the cooking task was recorded.

During the second cooking task one type of meal was cooked for lunch and dinner. As a cooking task the food ugali (maize meal) and vegetables were chosen. Key informant interviews with the villagers in Idifu confirmed that this type of meal is the most popular meal in the villages.

In order to maintain the comparability of the results with other scholars the equivalent oven-dried firewood consumption of ICS (0 % moisture content of the firewood) was calculated:

Equivalent oven-dried firewood consumed (g): $f_d = (f_i - f_f)\; x\; (1 - (1.12\; x\; m)) - 1.5\; x\; c_c$ *(Form. 3.11)*

Wood moisture content (% - wet basis): m *(Form. 3.12)*

Weight of charcoal remaining (g): c_c *(Form. 3.13)*

Modified specific firewood consumption ($\frac{\text{grams of dry fireqood equivalent}}{\text{gram of ingredient}}$):

$$SC_{modified} = \frac{f_d}{W_i} \qquad \textit{(Form. 3.14)}$$

The modified specific firewood consumption was calculated ($SC_{modified}$, *Form. 3.14*) as a ratio of equivalent oven-dried firewood consumed (f_d, *Form. 3.11*) per ingredients used (W_i, *Form. 3.4*). Due to improved measuring devices all ingredients used were measured including the amount of ugali, water, vegetables, tomatoes, onions and oil. The difference between the SC and $SC_{modified}$ is that specific firewood consumption was calculated on a 15 % moisture content basis of firewood while the modified specific firewood consumption was calculated on a 0 % firewood moisture content basis.

During the comparison between “old” and “new” ICS three groups were formed and provided with different amounts of ingredients in order to simulate different household sizes.

The distribution of food was as following:

Group 1 (small size households with 2-3 members): 500 g of ugali and vegetables were cooked at lunch and dinner time (in total 19 times).

Group 2 (middle size households with 4-5 members): 1,000 g of ugali and vegetables were cooked at lunch and dinner time (in total 30 times).

Group 3 (large size households with 6-7 members): 1,500 g of ugali and vegetables were cooked at lunch and dinner time (in total 15 times).

The equipment used for the KPT in January and February 2016 is displayed in table 3:

Table 3: Equipment used during the quantitative and qualitative Kitchen Performance Test in January and February 2016

Item	Specification
Spring scale [a)]	Accuracy up to 0.5 kg resolution
Electronic Scale [b)]	Accuracy 0.001 kg resolution
Firewood [a)]	Tree species: Mrama (Kiswahili)
Firewood [b)]	Tree species: Mtema (Kiswahili)
Ingredients meal 1 [a)] **(rice / vegetables)**	Ingredients used during the cooking task (rice, water, vegetables, oil)
Ingredients meal 2 [a)] **(beans / rice)**	Ingredients used during the cooking task (beans, water, vegetables, onions, oil)
Ingredients meal 3 [b)] **(ugali/ vegetables)**	Ingredients used during the cooking task (ugali, water, vegetables, tomatoes, onions, oil)
Cooking pots [a) b)]	Uniform material to maintain equivalent testing
Thermometer [a)]	Used to determine the outside and water temperature
KPT protocol sheets [a)]	2 x Quantitative and 2 x qualitative KPT protocol sheets per household
KPT protocol sheets [b)]	2 x Combined Quantitative and qualitative KPT protocol sheets per household

[a)] Equipment used during the KPT in January 2016
[b)] Equipment used during the KPT in February 2016

3.2.3 Test setup: Cooking stove performance measured by an external expert team

On behalf of Trans-SEC a Tanzanian expert in the fields of renewable energy and power systems conducted a CCT with professional equipment before the KPT was conducted in January and February 2016 in Idifu. The expert team led by Dr. Rajabu conducted a CCT at Idifu on the 9th of January 2016 in order to identify the modified specific firewood consumption and time consumption for cooking.

The CCT of the expert team aimed to assess the cooking performance of the ICS compared to the commonly used 3 stone fire stoves. The test was conducted under strictly regulated and real-world conditions. A paired-sample study was conducted, where the cook of one preselected household performed a cooking task on a 3 stone fire stove and afterwards on an ICS. In total 6 cooking runs were conducted in Idifu (3 x ICS and 3 x 3 stone fire).

The CCT testing protocol differed from the one which was developed for the KPT by testing only the first pot. The second pot was not considered in the measurements. The food selected for the cooking task was rice.

In order to secure the comparability of the results among the tested households, standardized testing procedures and testing utensils like pot size and type of firewood were used. The firewood collected for each location was drawn from one source and type of tree. Although standardized testing measures were applied there were still factors like climate conditions which could not be controlled. To minimize errors caused by different environmental conditions (wind and ambient temperature) the CCT was conducted inside the kitchen to maintain similar environmental conditions among the testing sites.

The specific firewood consumption modified was calculated based on the dry equivalent firewood consumption and the total weight of the ingredients after finishing the cooking process. The wood moisture content was measured to be 15 %. The specific firewood consumption and the total cooking time were the principal indicators of stove performance for the CCT.

The cooking procedures were discussed and communicated before starting the cooking process. The firewood and ingredients were measured and prepared before the fire was lit. During the cooking process the pots used were covered. After the cooking process the remaining firewood and charcoal was collected and weighted. The following ingredients were used (table 4):

Table 4: Ingredients used during the Controlled Cooking Test of the expert team

Ingredients used	
Dry rice	1000 g
Water	1800 g
Salt	10 – 15 g
Oil	60 – 100 g

Source: Rajabu, 2016.

3.2.4 *Experiences of Improved Cooking Stoves and 3 stone fire stoves: A qualitative approach*

The first qualitative assessment was done during the Household Survey of Trans-SEC (baseline survey) in 2014 (chapter 2.3.2). The Household Survey was a general survey which did not only include ICS users but all households participating in Trans-SEC. The survey was done before the UPS were introduced.

Additional information on ICS and 3 stone fire stove users were conducted in January and February 2016 in form of the KPT, approx. 18 months after the Household Budget survey. In total 52 households which use ICS and 20 households which use 3 stone fire stoves were assessed after the introduction of ICS. The first assessment was in January 2016 (11 months after ICS introduction) and the second assessment was done in February 2016 (12 months after ICS introduction) (VITA, 1985; Baldwin, 1986).

The qualitative part of the KPT aimed to understand the driving factors for households to adopt the ICS technology as well as to maintain a long term use of the technology. A semi-structured interview was developed in order to receive information not only on the cooking time and firewood consumption but also on further socioeconomic factors such as stove acceptance and dissemination. A questionnaire was developed to gather personal experiences and impressions from the stove users.

In January 2016, in total 20 households which use ICS as well 20 households which use 3 stone fire stoves for cooking were questioned. The questionnaire of the 3 stone fire users focused on identifying the reasons why 3 stone fire users did not switch from the traditional cooking method to the ICS technology. The households provided indications on what might be the hindering factors for ICS dissemination in the villages.

During the KPT ICS users were asked about the benefits and challenges of the new ICS technology. The interviews steered to identify habitual changes which were induced by the usage of ICS. The questions pointed out multiple aspects of ICS dissemination like the monetary aspects and the willingness to pay. Health aspects which focused on the differences between 3 stone fire stoves and ICS were elaborated. The firewood collection patterns, walking time and frequency of collecting firewood of the two stove groups were compared.

In February 2016, the second qualitative survey in February 2016 included the assessment of 32 additional households which use ICS. The second qualitative survey contained a smaller range of questions focusing on identifying the frequency of cooking with ICS and the firewood collection pattern of the households.

3.3 Biomass production potentials from on-farm wood supply

3.3.1 Foliage and woody biomass assessment in Kongwa district

In October 2014, Trans-SEC established two tree nurseries in Ilolo (Mazengo group and Bwawani group) in order to enhance on-farm wood production. The tree nurseries are technically and financially supported by ICRAF Tanzania. Tree seedlings are raised in the tree nurseries. After the seedlings reached a height of 10 to 20 cm they are planted in the field.

Primary data had to be collected on growth rates of planted trees in order to estimate the biomass growth of trees. The trees planted in the tree nurseries in Ilolo were too young to deduct reliable data regarding biomass growth rates. Due to a very dry period in 2015 the tree seedlings growth was not sufficient to allow a data assessment of biomass growth in Ilolo.

Via ICRAF, there was a possibility to access sites of the project “Africa RISING,” a project on sustainable agricultural intensification which has a tree planting component that started in early 2014. In February 2016 three villages of the “Africa RISING” project were assessed. The data on biomass growth was conducted for plants with a growth period of 23 months respectively 25 months. The villages are located in Kongwa district, Dodoma with a distance of 100 km as the crow flies apart from the project sites Idifu and Ilolo. In Kongwa district and the CSS the climatic and topographic conditions are assumed to be similar. The same tree species as in Ilolo were planted in Kongwa district. Therefore, the results of biomass growth are approx. transferrable between the two locations.

Special emphasize was laid on identifying the biomass production potential of *G. sepium*, as it was identified being a fast growing shrub suitable for firewood production. Due to its nature being a fast growing species and its properties of being cut at least once a year, *G. sepium* was identified having the greatest potential to increase the annual on-farm wood supply.

Three different cropping patterns with different spacing of *G. sepium* were assessed in the villages Laikala, Molet and Mlali (figure 6). The data collected was extrapolated to estimate possible biomass gains from on-farm wood production.

In Laikala, Kongwa district the shrubs of *G. sepium* were planted in an intercropping system with spacing of 3 m by 3 m. The intercropping system consisted of the shrub species *G. sepium* which was intercropped with *Cajanus Cajan* (pigeon peas) and maize. At the 13th and 15th of February 2016, the two plots with *G. sepium* were assessed. The shrubs were planted in March 2014 and were assessed in February 2016 after a growth time of 23 months. The biomass growth of the shrubs was assessed by measuring the RCD around 20 cm above ground. Additionally the height of the shrub was measured. After the measurement of RCD and tree height the shrubs were pruned. The foliage and woody biomass of the shrub *G. sepium* were separated and then weighted.
At plot 1, in total 143 plantings were assessed. 93 plantings contained one or multiple stems of *G. sepium* plants. 50 stems were dead or still too small for measuring which indicated that they were planted at least one season later. An area of approx. 1,287 m² (143 x 9 m²) was assessed. The area of dead trees of 450 m² (50 x 9 m²) was subtracted. An area of living trees of 837 m² was assessed. A survival ratio of 65.0 % was calculated for the first plot (plantings alive / total number of trees in %).
At plot 2, in total 77 plantings with single or multiple stems of *G. sepium* were assessed. 16 plantings were dead or still too small for data assessment. An area of 693 m² (77 x 9 m²) was assessed. Subtracting the area of dead trees 144 m² (16 x 9 m²) an area of living trees of 549 m² was assessed. A survival ratio of 79.2 % (plantings alive / total number of trees in %) was found on the plot.

At the 12th of February 2016 shelterbelt plantations in Molet, Kongwa district in Dodoma were measured. The shelterbelt consisted of two species, *G. sepium* and *Grevillea Robusta* which a spacing of 1 m by 1 m. In January 2014 three shelterbelts were planted. The shelterbelt serves as a wind shield to protect the plants from strong winds. Every shelterbelt consisted of two rows of *G. sepium* with a length of approx. 80 meter. The two rows of *G. sepium* were divided by one row of the tree species *Grevillea robusta*. During the assessment of the shelterbelt, the shrubs of *G. sepium* and G*revillea robusta* were not pruned but the RCD as well as the tree height were assessed. On average an area of approx. 695 m² (695 x 1 m²) with regard to RCD and stem height of the plants was assessed. The woody and foliage biomass production potentials were approximated by deducting the foliage biomass and the woody biomass production from Laikala (plot 1).

A third data collection on biomass growth was done in Mlali. The trees were grown as a woodlot and consisted of three species *G. robusta, M. azadaraets, S. siamea* with a spacing of 1.5 m by 1 m. The trees were planted in January 2014 and assessed in February 2016. The total growth period of 25 months was too short to prune the trees; only the RCD and the stem height were assessed.

Figure 6: Measurement of foliage and woody biomass production in Laikala (left), root collar diameter (RCD) and stem height measurement in Molet in Kongwa district (right).
Photo credit: Anthony Tairo, February 2016.

3.3.2 Calculation of the annual firewood demand and supply

The data collected regarding firewood consumption of the ICS and firewood production of *G. sepium* is deducted on an annual basis. Based on the measurements in Idifu the annual firewood consumption for the meals ugali and vegetables, rice and vegetables as well as beans and rice was calculated. The results of the KPT were compared with the data gathered during the assessment of biomass growth of *G. sepium* in Kongwa district. The calculation of the biomass production potential was considered a best case scenario where losses due to external influences were neglected. In total the biomass production potential was calculated for three different spacing at an annual basis (3 m by 3 m; 1 m by 1 m; 0.5 m by 0.5 m). It is expected to increase yields in foliage and biomass yields when *G. sepium* is planted with a dense spacing. Higher biomass yields are induced by a larger number of plants per area.

Based on the total ward area and different cropping patterns, the total area needed to cover the village firewood demand for cooking purposes was calculated. When ICS are used direct time savings are primarily caused by reduced cooking time and reduced frequency of collecting firewood.

3.4 Statistical analysis

The primary data collected during the quantitative and qualitative data assessment was analyzed using different statistical tests. For the qualitative analysis the responses were clustered and displayed without further statistical transformation. For the quantitative part different statistical tests were applied to analyze the collected primary data. The software program SPSS 15.0 for Windows, Version 15.9.1 (22 Nov. 2006) was used for the statistical analysis of the data. All SPSS printouts which are not displayed in the main part of the thesis are attached in the appendix.

In this thesis the cooking performance among the different stove technologies was compared using a t-test (or equivalent). A two-sample t-test was used to determine whether the means of two samples differ significantly. The comparison of the means of the samples shows whether the differences between sample means are statistically significant at a certain error probability. Two hypotheses were stated for every t-test. The positive hypothesis (H_0) states that there are not significant differences in means between two samples. The alternative hypothesis (H_1) states that at a certain level of significance (in this thesis 0.05 or 0.01) the means differ between the two samples.

In order to conduct a t-test three preconditions were tested:

1. The test samples are statistically independent which means that the data collected is not correlated. This condition is fulfilled by all the data which is analyzed in this thesis.
2. The test samples are normal distributed. For a sample size below 50 samples, the Shapiro-Wilk test was used to test for a normal distribution of the samples. The Kolmogorov-Smirnov test was used for samples sizes above 50 samples.
3. When the second condition is fulfilled the test samples are tested for equality of variances (homoscedasticity). The Levene’s test for equality of variances was used in this work.

In case that the normality assumption (precondition 2) did not hold, a non-parametric alternative to the t-test was used. In this thesis the Mann-Whitney U test was used, as it has a higher explanatory power than the t-test when samples are not normal distributed (Wooldridge, 2015).

The tool analyses of variance (ANOVA) was used to determine whether significant differences in means of specific firewood consumption and time spent to cook 1000 g of ingredients exist among three different amounts of foods cooked (Miller Jr., 1997). ANOVA generalizes the t-test to more than two groups. Therefore, the assumption of normal distribution of samples and the condition equality of variances have to be tested as well. The post hoc test of Bonferroni was used to determine between which groups significant differences in means exist (Hochberg, 1988).

The Spearman's rank correlation coefficient (Spearman's rho), is a nonparametric measure of rank correlation. A bivariat rank correlation analyses of Spearmans rho was used to determine correlations between RCD and stem height as well as foliage and woody biomass production. The correlation coefficient of Spearmans rho varies between $-1 < \rho < 1$. A ρ value of 0 indicates that there is no correlation between the variables. The values -1 and 1 indicate a perfect negative or a perfect positive correlation between the variables analyzed (Gibbons and Chakraborti, 2011).

The correlation analyses is used to determine whether for plot 1 and plot 2 in Laikala a correlation between RCD and stem height as well as foliage and woody biomass production exist. The results of the correlation analyses are used to calculate the biomass production potential for Molet where only data on the RCD and stem height is available.

4 Results

In this chapter, the results of the KPT with regard to firewood and time consumption between ICS and 3 stone fire stoves are displayed. Due to a design shift further testing's were conducted in order to identify performance differences from "old" and "new" ICS. The outcome was compared with the results of a professional testing team from the University of Dar es Salaam which was led by Dr. Rajabu. The biomass yields from different plots were displayed indicating biomass production potentials for trees and shrubs (especially *G. sepium*) grown in semi-arid areas in the Dodoma region.

4.1 Firewood consumption patterns and sustained use of Improved Cooking Stoves

In table 5 the absolute firewood and time consumption per meal and cooking device are displayed in order to get a general overview on the firewood and time consumption patterns of different types of food.

Table 5: Results of the stove tests regarding the absolute firewood and time consumption for different cooking tasks

Results of the comparison of 3 stone fire stoves and Improved Cooking Stoves (N= 76)				
	Firewood consumption		**Time consumption**	
	ICS (g)	**3 stone fire stove (g)**	**ICS (min)**	**3 stone fire stove (min)**
Meal: Rice and vegetables	1,375 (SD 792)	2,187 (SD 879)	60.3 (SD 13.6)	82.4 (SD 28.3)
Meal: Beans and rice	3,576 (SD 696)	4,241 (SD 1,540)	138.8 (SD 23.1)	179.7 (SD 43.3)
Results of the comparison of "old" (N = 28) vs. "new" Improved Cooking Stoves (N= 36)				
	Firewood consumption		**Time consumption**	
	"old" ICS (g)	**"new" ICS (g)**	**"old" ICS (min)**	**"new" ICS (min)**
Meal: Ugali and vegetables	1,204 (SD 378)	1,170 (SD 246)	32.4 (SD 10.1)	28.7 (SD 8.2)
Results of the expert team on 3 stone fire stoves and Improved Cooking Stoves (N = 6)				
	Firewood consumption		**Time consumption**	
	ICS (g)	**3 stone fire stove (g)**	**ICS (min)**	**3 stone fire stove (min)**
Meal: Rice	-	-	40 (SD 1)	37 (SD 1)

4.1.1 Cooking performance of Improved Cooking Stoves and 3 stone fire stoves

In the following chapters specific values for firewood consumption (firewood usage per unit of ingredients) and time utilization (time spent per unit) are displayed.

4.1.1.1 Fast cooking dish

The first KPT aimed to identify differences in the performance of ICS and 3 stone fire stoves with regard to firewood and time consumption. The cooking task "rice and vegetables" steered to identify performance related figures with regard to specific firewood consumption and time spent to cook 1000 g of ingredients. The meal rice and vegetables was chosen to simulate a cooking task with a fast cooking type of food (SPSS printout: Appendix 6.1).

The following results were measured for the **specific firewood consumption** of both stoves (SC, *Form 3.6*):

For ICS: $SC = 0.4637 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.225 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

For 3 stone fire: $SC = 0.6946 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.263 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

ICS consume 33.3 % less firewood per unit of food compared to 3 stone fire stoves. To test whether these results show significant differences in specific firewood consumption a Mann-Whitney U-test was conducted. At a level of significance of 0.05 ICS have lower specific firewood consumption than 3 stone fire stoves ($p < 0.006$).

The following results were measured for **the time spent to cook 1000 g of ingredients** (*Form 3.10*):

For ICS: $t_{\text{time spent to cook 1000 g of ingredients}} = 21.70$ min (SD 8.14 min).

For 3 stone fire: $t_{\text{time spent to cook 1000 g of ingredients}} = 27.58$ min (12.12 min).

ICS save around 21.3 % cooking time compared to 3 stone fire stoves. A t-test was conducted to determine whether the time spent to cook 1000 g of ingredients used differ significantly between the two cooking types. At a level of significance of 0.05 ($p = 0.088$) the time to cook 1000 g of ingredients does not differ significantly between the stove types.

In addition - for an understanding directed to the technical potential of ICS - the **best 50 % of performers with regard to specific firewood consumption** and the **fastest 50 %**

of performers with regard to the time spent to cook 1000 g of ingredients of both stove types were analyzed. The following values on specific firewood consumption were found:

For ICS: $SC = 0.4058 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$

For 3 stone fire: $SC = 0.5678 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$

It was found that the specific firewood consumption of the best 50 % performers was 29.05 % reduced when ICS compared is to 3 stone fire stoves.

The total time spent to cook 1000 g of ingredients for the two stove technologies was as following:

For ICS: $t_{\text{time spent to cook 1000 g of ingredients}} = 19.05$ min

For 3 stone fire: $t_{\text{time spent to cook 1000 g of ingredients}} = 25.55$ min

The results showed that the fastest 50 % performers of ICS with regard to the time spent to cook 1000 g of ingredients save around 24.5 % of time compared to the users of 3 stone fire stoves.

The performance related figures of specific firewood consumption and time needed to cook 1000 g of ingredients between ICS and 3 stone fire as well as the results of the best 50 % performers are summarized below (table 6):

Table 6: Improved Cooking Stove vs. 3 stone fire stove: Kitchen Performance Test results on specific firewood consumption and time needed to cook a meal (dish: Rice and vegetables)

KPT test results - Rice and vegetables						
	All households (N = 38)			**Best 50 % of each group (N = 19)**		
	ICS	3 stone fire	ICS compared to 3 stone fire in %	ICS	3 stone fire	ICS compared to 3 stone fire in %
SC (grams of firewood/ gram of ingredient)	0,464	0,695	**- 33.3***	0.406	0.568	**- 29.5**
Time spent to cook 1000 g of ingredients (min)	21.7	27.58	**- 21.3**	19.05	25.55	**- 24.5**

* Differences at a level of significance of 0.05.

The analyses of all households indicate that a significant reduction in specific firewood consumption of 33.3 % of ICS compared to 3 stone fire stoves is possible. The time saving analysis indicate that users of ICS spent 21.3 % less time for cooking compared to users of 3 stone fire stoves. When looked at the 50 % fastest households with regard to time spent to cook 1000 g of ingredients it can be stated that ICS contain even higher time saving potentials compared to the total group. This indicated that the advantages of ICS could be better achieved by those who are familiar with the stove handling and its usage.

4.1.1.2 Slow cooking food

The stove performance between the two technologies was assessed for a slow cooking food “beans and rice” (SPSS printout: Appendix 6.2). Due to different amounts of ingredients used during the cooking process the **specific firewood consumption** was calculated (*Form. 3.6*):

For ICS: SC = 0.5891 $\frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD 0.2400 $\frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

For 3 stone fire: SC = 0.6629 $\frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD 0.2087 $\frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

The specific firewood consumption is reduced by 11.1 % when ICS were compared to 3 stone fire stoves. A Mann-Whitney U-test was conducted to test significant differences in firewood consumption among the two stove types. At a level of significance of 0.05 (p = 0.112) the means in specific firewood consumption do not differ between ICS and 3 stone fire stoves.

A standardized measure was introduced to measure the **time spent to cook 1000 g of ingredients** (*Form. 3.10*).

For ICS: $t_{\text{time spent to cook 1000 g of ingredients}}$= 22.71 min (SD 7.79 min)

For 3 stone fire: $t_{\text{time spent to cook 1000 g of ingredients}}$= 30.75 min (SD 14.19 min)

A reduction of time spent to cook 1000 g of ingredients of 26.1 % between ICS and 3 stone fire was measured. A Mann-Whitney U-test was conducted to show whether significant differences of time spent to cook 1000 g of ingredients exist between the two stove types. At a level of significance of 0.05 ICS spent less time to cook 1000 g of ingredients compared to 3 stone fire stoves (p = 0.032).

The **best 50 % of performers with regard to specific firewood consumption** and **the fastest 50 % of performers with regard to time spent to cook 1000 g of ingredients** of both stove types were analyzed.

For ICS: $SC = 0.5573 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$

For 3 stone fire: $SC = 0.6831 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$

The analysis showed a reduction potential of 18.4 % in specific firewood consumption between the ICS and 3 stone fire technology. The advantages of ICS with regard to specific firewood consumption could be achieved better from users who use the ICS in an efficient way. Regarding all households specific firewood consumption savings of only 11.1 % could be realized.

The time spent to cook 1000 g of ingredients the following results was measured:

For ICS: $t_{\text{time spent to cook 1000 g of ingredients}}$= 22.85 min

For 3 stone fire: $t_{\text{time spent to cook 1000 g of ingredients}}$= 28.39 min

A time reduction of approx. 20.5 % was measured, when cooked with ICS compared to the use 3 stone fire stoves. Therefore, no reduction in time spent to cook 1000 g of ingredients can be expected compared to the total sample quantity.

The performance related figures of specific firewood consumption and time spent to cook 1000 g of ingredients between ICS and 3 stone fire as well as the results of the best 50 % performers are summarized below (Table 7):

Table 7: Improved Cooking Stove vs. 3 stone fire stove: Kitchen Performance Test results on specific firewood consumption and time needed to cook 1000 g of food (dish: Beans and rice)

KPT test results - Beans and rice						
	All households (N = 38)			Best 50 % of each group (N = 19)		
	ICS	3 stone fire	ICS compared to 3 stone fire in %	ICS	3 stone fire	ICS compared to 3 stone fire in %
SC (grams of firewood/ gram of ingredient)	0.589	0.663	**- 11.1**	0.557	0.683	**- 18.4**
Time spent to cook 1000 g of food (min)	22.71	30.75	**- 26.1***	22.85	28.39	**- 20.5**

* Differences at a level of significance of 0.01

4.1.2 Cooking performance of “old” and “new” Improved Cooking Stoves

Differences between the “new” and “old” type of ICS were found within the stove dimensions (stove height, length, width), the diameter of the wood entry slot and the reduced height between the bottom of the combustion chamber and the bottom of the first pot. All other design parameters of the stoves are expected to be similar which indicated that these design shifts might be the reasons for a deviating ICS performance (table 8).

Table 8: "New" vs. "old" Improved Cooking Stoves: Kitchen Performance Test results on differences in stove design

Type of ICS			**Stove height in cm**	**Stove length in cm**	**Stove width in cm**	**Diameter of the wood entry slot in cm**	**Distance between the bottom of the combustion chamber and the bottom of the first pot in cm**
new	N	Valid	36	36	36	36	36
		Missing	0	0	0	0	0
	Mean		**30.50**	**98.56**	**48.78**	**14.23**	**19.27**
	Median		30.00	99.50	49.00	15.00	18.0
	Standard Deviation		2.32	11.33	5.20	2.43	3.91
old	N	Valid	28	26	28	28	28
		Missing	0	2	0	0	0
	Mean		**43.29**	**115.3**	**56.89**	**12.92**	**26.17**
	Median		42.00	120.0	56.50	14.50	27.00
	Standard Deviation		8.01	23.04	4.581	2.59	5.75

A Mann-Whitney U-test was conducted to determine whether the changes in the stove design are significant or not (SPSS printout: Appendix 6.3). At a level of significance of 0.05 ($p < 0.05$), the old ICS are significantly higher in size (43.3 cm) compared to the new ICS design (30.5 cm). Corresponding to that the distance between the bottom of the combustion chamber and the bottom of the first pot are significantly reduced between the “old” ICS (26.2 cm) and the “new” ICS (19.3 cm). The stove dimensions stove length and stove width were significantly larger when the “new” ICS are compared to the “old” ICS. In addition, the diameter of the wood entry slot was significantly higher with “new” ICS (14.2 cm) compared to “old” ICS (12.9 cm).

The **modified specific firewood consumption** ($SC_{\text{modified},}$ *Form. 3.14*) was measured:

For “new” ICS: $SC_{\text{modified}} = 0.2096 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.0839 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

For “old“ ICS: $SC_{\text{modified}} = 0.2064 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.1044 \frac{\text{grams of firewood}}{\text{gram of ingredi ent}}$)

Based on the data collected, “new” ICS spent 1.6 % more firewood compared to “old” ICS. A t-test for independent samples was conducted to compare the means of modified specific firewood consumption. At a level of significance of 0.05 ($p = 0.892$) the means in specific firewood consumption do not differ between the two stove types.

The two stove types were compared by analyzing the **time spent to cook 1000 g of ingredients** (*Form. 3.10*).

For “new” ICS: $t_{\text{time spent to cook 1000 g of ingredients}} = 9.41$ min (SD 2.78 min)

For “old” ICS: $t_{\text{time spent to cook 1000 g of ingredients}} = 10.14$ min (SD 3.69 min)

“New” ICS use 7.2 % less time to cook 1000 g of ingredients compared to “old” ICS. A t-test was conducted to identify whether significant changes with regard to time spent to cook 1000 g of ingredients exist. At a level of significance of 0.05 ($p = 0.373$) there are no significant differences in means of time used to cook 1000 g ingredients among “new” and “old” ICS.

The results of the best **50 % of performers with regard to specific firewood consumption** and **the fastest 50 % of performers with regard to time spent to cook 1000 g of ingredients** are summarized.

For the modified specific firewood consumption, the firewood consumption patterns are as following:

For “new” ICS: $SC_{\text{modified}} = 0.208 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$

For “old” ICS: $SC_{\text{modified}} = 0.195 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$

This showed that that “new” ICS needed 7.0 % more firewood than “old” ICS.

With regard to the time spent to cook 1000 g of ingredients the following time consumption was measured:

For “new” ICS: $t_{\text{time spent to cook 1000 g of ingredients}} = 9.45$ min

For “old” ICS: $t_{\text{time spent to cook 1000 g of ingredients}} = 9.70$ min

This indicated that “new” ICS use 2.6 % less time to cook the same amount of food than “old” ICS.

When looked at the best 50 % performers with regard to specific firewood consumption and the fastest 50 % performers with regard to the time spent to cook 1000 g of ingredients means differ more compared to the analyses of the total sample. Following the trend of the best 50 % performers of both stove technologies, the results indicate that there is a tradeoff between firewood consumption and time needed to cook 1000 g of ingredients.

The figures modified specific firewood consumption and time needed to cook 1000 g of ingredients between ICS and 3 stone fire stoves as well as the results of the best 50 % performers are summarized below (table 9):

Table 9: “New” and “old” Improved Cooking Stoves: Kitchen Performance Test results on specific firewood consumption and time needed to cook a meal (dish: Ugali and vegetables)

KPT test results - Ugali and Vegetables						
	All households (N = 64)			**Best 50 % of each group (N = 32)**		
	“new” ICS	“old” ICS	“new” ICS compared to “old” ICS in %	“new” ICS	“old” ICS	“new” ICS compared to “old” ICS in %
$SC_{modified}$ (grams of firewood/ gram of ingredient)	0.2096	0.2064	**1.6**	0.2082	0.1946	**7.0**
Time spent to cook 1000 g of ingredients (min)	9.41	10.14	**- 7.2**	9.45	9.70	**-2.6**

When the KPT test was conducted, different amounts of food were cooked simulating the food demand of small, medium and large size households. In total 64 test samples were assessed.

The **ANOVA among** the **three groups** showed that the specific firewood consumption and the time spent to cook 1000 g of ingredients differ at a level of significance of 0.01 ($SC_{modified}$ p = 0.004 and time to cook 1000 g of food p = 0.004).

The following modified specific firewood consumption per group was measured:

Small size group: $SC_{modified} = 0.2452 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.1047 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

Middle size group: $SC_{modified} = 0.2162 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.0739\frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

Large size group: $SC_{modified} = 0.1417 \frac{\text{grams of firewood}}{\text{gram of ingredient}}$ (SD $0.0783\frac{\text{grams of firewood}}{\text{gram of ingredient}}$)

The following was measured for the time spent to cook 1000 g of ingredients:

Small size group: $t_{\text{time spent to cook 1000 g of ingredients}}$= 11.28 min (SD 2.98 min)

Middle size group: $t_{\text{time spent to cook 1000 g of ingredients}}$= 9.76 min (SD 2.87 min)

Large size groups: $t_{\text{time spent to cook 1000 g of ingredients}}$ = 7.69 min (SD 3.18 min)

The results exemplified that ICS work more efficient when larger amounts of food are prepared. The modified specific firewood consumption was reduced by 42.2 % if large the size group is compared to small size group. The large size group spent 31.8 % less time to cook 1000 g of ingredients than the small size group.

The post hoc test of Bonferroni was conducted to determine significant differences between the three groups. At a level of significance of 0.01 the means of modified specific firewood consumption ($p = 0.003$) and time spent to cook 1000 g of ingredients ($p =0.003$) differ with regard to the small size group and the large size group.

4.1.3 Cooking performance of Improved Cooking Stoves and 3 stone fire stoves assessed by an independent testing team

An independent testing team conducted a CCT on the firewood consumption of ICS and 3 stone fire stoves. The assessment of Dr. Rajabu provided results on differences of the ICS and 3 stone fire stove performance with regard to firewood and time consumption. The testing procedures were stated in chapter 3.2.3.

The summarized results for ICS and 3 stone fire stoves and the comparison on modified specific firewood consumption and cooking time are shown in table 10. At a level of significance of 0.05, the study showed a reduction of 33 % on modified specific firewood consumption for ICS compared to 3 stone fire The total cooking time of ICS exceeded the total cooking time of 3 stone fire stoves by 8 %.

Table 10: Results of the Controlled Cooking Test of the expert team from Idifu (dish: Rice and vegetables)

	CCT Chamwino - Test results					
STOVE TYPE		**Test 1**	**Test 2**	**Test 3**	**Mean**	**SD**
3 stone fire	$SC_{modified}$ (grams of fire-wood/ gram of ingredient)	0.164	0.172	0.128	0.154	0.024
	t_c: Total cooking time (min)	37	37	36	37	1
Improved Cooking Stove		**Test 1**	**Test 2**	**Test 3**	**Mean**	**SD**
	$SC_{modified}$ (grams of fire-wood/ gram of ingredient)	0.118	0.097	0.095	0.103	0.013
	Δt: Total cooking time (min)	41	39	39	40	1
3 stone fire and Improved Cooking Stoves			**Difference of Improved Cooking Stoves compared to 3 stone fire**			
	$SC_{modified}$ (in %)		- 33 *			
	Δt: Total cooking time (in %)		8 *			

Source: After Rajabu, 2016.
* Differences at a level of significance of 0.05.

4.1.4 Qualitative analysis of Improved Cooking Stoves and 3 stone fire stoves

4.1.4.1 Merits and demerits of the stove technologies

The results of the qualitative analysis of ICS and 3 stone fire users attempted to understand the behavioral changes and utilization patterns of the two stove users. The detailed test setup is displayed in chapter 3.2.4.

20 households which use ICS at a daily basis were asked. 18 out of 20 households claimed that they were using the ICS technologies throughout the year. Only 2 households stated that they could not use the ICS during strong winds and heavy rains. Alternative types of ICS were not demanded by the villagers. 19 out of 20 ICS users said they would not need a portable version of an ICS. Only 1 household gave to protocol that a portable version of an ICS would be needed. 12 households wished no changes in the existing ICS design.

The perceived changes with regard to health issues are substantial. The indoor air pollution during cooking is highly reduced with ICS. 20 households claimed that respiratory diseases and infections of the mucous membrane were not existent when ICS instead of

3 stone fire stoves were used. With regard to the cooking habits, all 20 households stated that there were no restrictions on meals cooked. The ICS design did not exclude meals from being cooked and did not influence the diet of the users negatively. 18 out of 20 households claimed to cook faster with ICS compared to 3 stone fire stoves. 17 out of 20 households stated that the total time of firewood collection was reduced. 3 households saw no changes in firewood collection patterns. The time savings were used for other activities such as farm work or housework. All 20 households collect their firewood from public places. 5 out of 20 households purchased partly or all of their firewood from vendors. In the perception of the ICS users in Idifu, the population growth and human habitat enlargement were seen as major sources for deforestation (14 households). 3 households blamed uncontrolled charcoal making to be the major reason for the ongoing deforestation while one household blamed the poor legal system which was seen to be insufficient to protect existing forests. Two households did not see any changes in the forest endowment in the village area. Regarding the firewood availability in the future 19 households claimed that they expected lower firewood availability in the future. 1 household expected no changes in the forest endowment in the village surrounding. When asked about how to react against further deforestation 10 households claimed that afforestation around the villages is needed and should be enforced legally. 3 households stated that energy efficient cooking technologies like ICS should be used. 6 did not know what to do. 1 household claimed that further education on the importance of forests would be needed. When asked about their perception on what would happen if every household in the village would use an ICS, 14 households claimed that the problem of firewood availability would be solved or at least highly reduced. 6 households did not answer this question.

25 % of the households asked during the KPT wished changes in the ICS design. ICS users cite that a persistent problem of the ICS was the insufficient the heat transfer from the combustion chamber towards the second pot. Due to insufficient heat transfer the food cooked at pothole two has to be shifted to pothole one in order to be fully cooked. This reduces the benefits of the ICS to cook simultaneously at two pots. The ICS are constructed by local artisans; design changes can be implemented by the constructors themselves. One of the major changes requested was a reduced height to improve the heat transfer between the first and the second pot. A reduced height implies the renunciation of the rocket stove principle.

The construction of an air-bypass in order to increase the air availability inside the combustion chamber might be suitable to increase the heat transfer from pot one to pot two. Furthermore, the design change could facilitate the lighting process of firewood and increase the total heat during combustion due to increased air inflow. The air-bypass can be closed when a reduced air inflow is wished (figure 7).

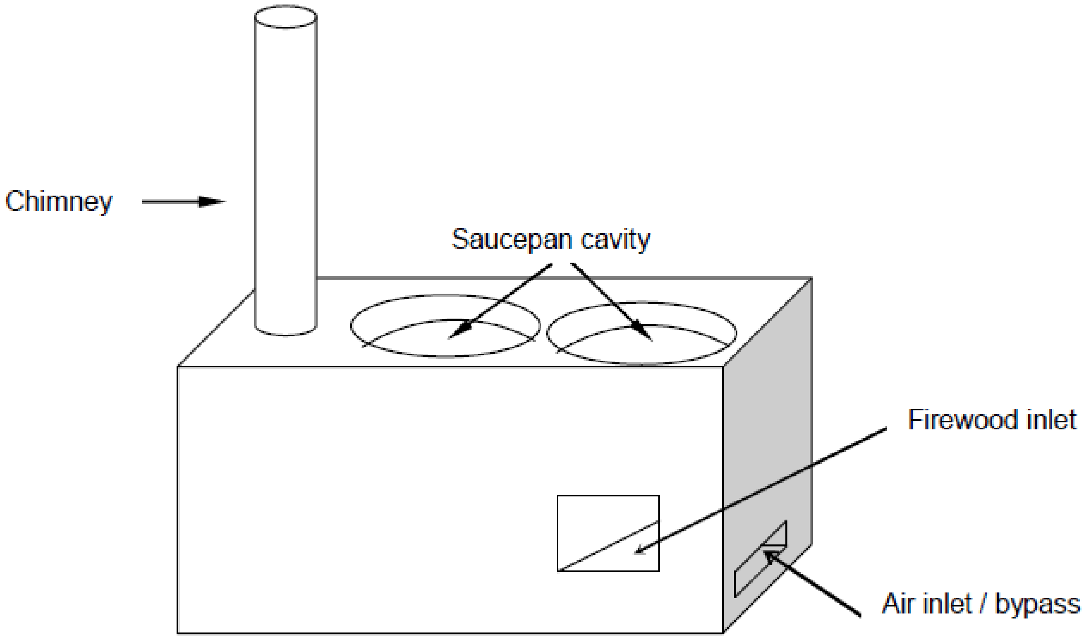

Figure 7: Archetype of an Improved Cooking Stove with air-bypass.
Source: Simonis et al., accessed 01.04.2016.

During the qualitative questionnaire 20 3 stone fire stove users were asked about the reasons not to adopt the ICS technology. 6 out of 20 households mentioned that they were not aware of the advantages and the overall handling of ICS. 5 households claimed that in their homes were not spacious enough to construct an ICS. 4 households mentioned a lack of financial means or input materials (e.g. bricks) as hindering factors to adopt the new stove technology. Only one household answered that they did not want to change the cooking technology because of the long lasting application of 3 stone fire stoves in the village.

When asked about health related issues resulting from the usage of 3 stone fire stoves. 17 households mentioned problems related to the usage of 3 stone fire stoves such as respiratory diseases and mucous membrane infections. 3 households mentioned no negative health effects from using 3 stone fire stoves. All 20 households expected that future firewood availability would diminish. Already 5 out of 20 households stated to buy firewood on a regular basis. 16 out of 20 households cited that reasons for deforestation were human made. Population growth, enlargement of agricultural areas, increased need for building materials and charcoal production were cited to be the driving factors of deforestation among others. 12 households claimed that the villagers should engage in afforestation programs in order to increase the supply of domestic firewood and reduce the rate of deforestation. 14 households stated that ICS technologies, which reduce the demand of firewood, should be applied to reduce the cutting down rate of trees. 3 households claimed that legal regulation and the establishment of by-laws are required connected with penalties to reduce deforestation. 2 villagers wished a switch to other forms of energy sources such as electric energy to avoid deforestation.

4.1.4.2 Firewood collection patterns

As shown ICS use less firewood compared to 3 stone fire stoves. Ceteris paribus, this should result in a lower frequency of collecting firewood for ICS users. During the qualitative test the participating households were asked about their firewood collection patterns. The results were used to crosscheck whether the frequency of collecting firewood differs significantly between ICS and 3 stone fire stove users and whether the firewood saving due to ICS is directly reflected in the reduction of firewood consumption.

In total 71 samples were collected within 51 households using ICS and 20 households using 3 stone fire stoves. 6 households using ICS, respectively 5 households using 3 stone fire stoves were excluded from the calculation because firewood was bought and not collected. For ICS (N = 45) a mean frequency of collecting firewood of 2.56 times per week (SD 1.61 times per week) was measured. 3 stone fire households (N = 15) collected firewood on average of 3.73 times per week (SD 1.68 times per week). The frequency of collecting firewood per household and week was divided by the number of household members including children and those members who do not collect firewood.

On average a household member had to collect firewood 0.537 times a week (SD 0.380 times a week) in a household which uses an ICS for cooking. On average a household member had to collect firewood 0.71 times per week (SD 0.371 times per week) in a household which uses a 3 stone fire stove for cooking. This results in a reduction of collecting firewood of 31.4 % of ICS households compared to 3 stone fire stove users (SPSS printout: Appendix 6.4).

A Mann-Whitney U-test was conducted to test if the means of frequency of collecting firewood differ significantly between “old” and “new” ICS users. At a level of significance of 0.05, the frequency of collecting firewood per household member per week is lower for ICS households compared to 3 stone fire users.

Based on the firewood collection patterns cited by the villagers, the annual amount of firewood collected per household was calculated. The calculation was based on the assumption that on average a household member can carry 20 kg (30 kg) of firewood on the head.

For **ICS (20 kg)** this results in an annual firewood collection per household of 2,691 kg (SD 1,691 kg) (Frequency of firewood collection per week x 52 weeks x 20 kg)

For **3 stone fire stove (20 kg)** this results in an annual firewood collection per household of 3,883 kg (SD 1,745 kg) (Frequency of firewood collection per week x 52 weeks x 20 kg)

For **ICS (30 kg)** this results in an annual firewood collection per household of 3,995 kg (SD 2,507 kg) (Frequency of firewood collection per week x 52 weeks x 30 kg)

For **3 stone fire stove (30 kg)** this results in an annual firewood collection per household of 5,824 kg (SD 2,618 kg) (Frequency of firewood collection per week x 52 weeks x 30 kg)

Calculations carried out in the framework of this thesis showed that walking distances to collect firewood are substantial in Idifu and Ilolo (chapter 2.3.2). The KPT conducted in 63 randomly chosen households in Idifu indicated that the time needed to collect firewood (go and return) mounts up to 354 min (SD 98.7 min). The results of the Household Survey in mid-2014 indicated that the villagers in Idifu spent on average 286.82 min to collect firewood (go and return). The villagers indicated that the walking distances in order to collect firewood had increased compared to 5 years ago. Comparing the data on time spent to collect firewood of the Household Survey in mid-2014 and the data collected in January and February 2016, the time spent to collect firewood had increased again by approx. 70 minutes.

4.1.4.3 Willingness to pay for Improved Cooking Stoves

Approx. 13 months after the ICS implementation, the dissemination of ICS in Ilolo and

Idifu is still at a moderate level (March 2016: 165 ICS). Reasons are manifold; some scholars argue that the pricing of ICS is one reason of a low dissemination of ICS being too high. The purchasing agreements in Idifu and Ilolo include a burden sharing concept. The ICS are constructed using sand, clay or anthill soil, rice husks or dried sand, bricks, water and the construction can be facilitated by banana stems to design the interior of the stove (in Trans-SEC plastic tubes are used). It was agreed that the household which buys an ICS provides the input materials (bricks, clay soil, loam, sand and insulation materials, e.g. rice husks, grass, groundnut husks) for constructing the ICS (table 11). Only the constructors and their working time are paid. In Idifu and Ilolo 2,000 TSH (around 0.90 EUR) had to be paid to the artisans for the construction of an ICS. The low price was seen as a pro-poor approach to make the new ICS technology affordable (SPSS printout: Appendix 6.5). The stove itself has the advantage that it can be built with local input materials, so that a dependency on external material supply is not given. The costs for bricks, water, soil and isolation material - if bought - are considered with the cited market prices. Other costs like transport or advertising costs were neglected in this consideration.

Table 11: Costs to construct an Improved Cooking Stove at market prices

Input materials	Amount and unit	Price per unit in TSH	Total TSH
Labour costs	2 – 3 constructors		2,000,-
Bricks	22 pieces	100,-/ piece	2,200,-
Water	6 buckets of 20 liter	500,-/ container	3,000,-
Soil (4 x clay, 2 x loam, 2 x sand)	8 buckets of 20 liter	500,-/ bucket	4,000,-
Insulation material: Rice husks, grass, groundnut husks	1 bucket	1,000,-/ bucket	1,000,-
Total			12,200,-

During the qualitative questionnaire the villagers were asked about their willingness to pay for an ICS. The analysis of the test samples were corrected by three ICS outliers and two 3 stone fire user due to high deviations from the average willingness to pay. In total 49 answers from households using ICS concerning the willingness to pay were analyzed. On average the willingness to pay was 8,081 TZS (SD 4,872 TZS) at ICS households. 18 households which use 3 stone fire stoves claimed to have a willingness to pay of 4,833 TZS (SD 4,409 TZS).

The willingness to pay for an ICS is 36.1 % lower among 3 stone fire stove users compared to ICS users. The means of the willingness to pay between ICS and 3 stone fire users differ at level of significance of 0.05 (Mann-Whitney U test). ICS users are willing to pay more for the ICS than 3 stone fire users.

4.2 Firewood production potential: On-farm wood production

4.2.1 Biomass growth assessment: Laikala, Molet, Mlali

The data analysis on biomass growth was done in Kongwa district. Three sites were analyzed in detail to determine the growth potentials of the tree species *G. sepium* and among others.

In Laikala two plots with an intercropping **scheme of 3 m by 3 m** were assessed in order to forecast the **biomass growth for *G. sepium*** in the semi-arid region of Dodoma (table 12 + 13). The biomass production potential cited for Laikala is based on a tree growth period of 23 months.

Plot 1:

On the first plot the average RCD was 25.01 mm (SD 6.15 mm) and the average tree height was 161.07 cm (SD 39.75 cm). A total of 202.6 kg of foliage biomass was produced. The branches which were usable as firewood amounted up to 72.6 kg. Deducted to one hectare the productivity for *G. sepium* for foliage biomass amounted up to 2420.5 kg per ha ((1 ha / area of living trees) x foliage biomass plot 1) and for woody biomass to 868 kg per ha ((1 ha / area of living trees) x woody biomass plot 1).

Plot 2:

The average RCD was 32.40 mm (SD 7.81 mm) and the average tree height was 213.57 cm (SD 48.54 cm). A total of 198.9 kg of foliage biomass was produced. The woody biomass which was usable as firewood amounted up to 138.1 kg. Deducted to one hectare, the productivity of *G. sepium* for foliage amounted up to 3622.7 kg per ha ((1 ha / area of living trees) x foliage biomass plot 2) and to 2515.9 kg per ha of woody biomass ((1 ha / area of living trees) x woody biomass plot 2).

Table 12: Foliage and woody biomass production in Laikala (Plot 1) with a spacing of 3 m by 3 m, Kongwa district

		Root Collar Diameter (mm)	Height (cm)	Foliage biomass (g)	Woody biomass (g)
N	Valid	162	162	93	90
	Missing	50	50	118	121
Mean		**25.01**	**161.07**	2178.49	807.20
Median		24.15	160.00	1888.00	555.00
Standard Deviation		**6.15**	**39.75**	1424.382	704.81
Variance		37.80	1580.47	2028865.34	496758.45
Minimum		10.90	60.00	99.00	20.00
Maximum		43.00	270.00	6666.00	3721.00
Sum		4052.10	26093.0	**202600.00** [a)]	**72648.00** [a)]

[a)] Yields are based on a wet moisture content of the wood of 30 % (firewood at wet-basis).

Table 13: Foliage and woody biomass production in Laikala (Plot 2) with a spacing of 3 m by 3 m, Kongwa district

		Root collar diameter (mm)	Stem height (cm)	Foliage biomass (g)	Woody biomass (g)
N	Valid	112	112	63	61
	Missing	16	16	65	67
Mean		**32.40**	**213.57**	**3156.93**	**2264.33**
Median		32.35	210.00	3008.00	2138.00
Standard Deviation		**7.81**	**48.54**	1521.84	1282.55
Variance		60.99	2356.211	2316004.80	1644937.75
Minimum		15.00	110.00	50.00	330.00
Maximum		56.60	380.00	6678.00	5532.00
Sum		3629.20	23920.00	**198887.00** [a)]	**138124.00** [a)]

[a)] Yields are based on a wet moisture content of the wood of 30 % (firewood at wet-basis).

Plot 1 produced 33.2 % less foliage biomass and 65.5 % less woody biomass per hectare compared to plot 2.

A t-test was conducted to determine whether there are significant differences with regard to foliage and woody biomass production per hectare between the two plots in Laikala (Appendix 6.6).

At a level of significance of 0.05, the Mann-Whitney U test for non-parametric distributions showed that the means of foliage biomass and woody biomass at plot 1 and two differ (p = 0.00). The amount of foliage and woody biomass produced at plot 2 is significantly higher than at plot 1.

In **Molet village**, the ***G. sepium*** **growth was assessed on a spacing of 1 m by 1 m**. The climatic and geographic endowment of *G. sepium* at the first plot in Laikala was assumed similar to the one in Molet. The shrubs of *G. sepium* in Molet were grown for 25 months. The mean RCD was 24.4 cm (SD 6.9 cm) and the tree height was 156.8 cm (SD 42.2 cm) for the shrubs of *G. sepium* assessed in Molet.

A correlation analysis from Laikala (plot 1 and plot 2) of the RCD and stem height and foliage and woody biomass production showed a correlation among these parameters (table 14). The correlation between the RCD and the tree height as well as woody biomass and foliage biomass are highly significant.

At plot 1 in Laikala there a positive correlation between RCD and woody biomass production (0.54 = medium correlation) as well as foliage biomass production (0.407 = medium correlation) was found. There is also a positive correlation between stem height and woody biomass production (0.631 = strong correlation) as well as foliage biomass production (0.416 = medium correlation).

For plot 2 in Laikala a positive correlation between RCD and woody biomass production as well as for foliage biomass (0.55 = medium correlation production (0.343 = weak correlation) was found. There is also a positive correlation between height and woody biomass production (0.401 = medium correlation) as well as foliage biomass production (0.359 = low correlation).

Table 14: Correlation analysis between root collar diameter (RCD) and tree height as well as foliage and woody biomass production in Laikala (Plot 1 + 2) using Spearman's rank correlation coefficient

Plot _No				**RCD in mm**	**Stem height in cm**	**Woody biomass in g**	**Foliage Biomass in g**
1	Spear man's rho	RCD in mm	Correlation Coefficient	1.00	.679(**)	.540(**)	.407(**)
			N	162	162	90	93
		Stem height in cm	Correlation Coefficient	.679(**)	1.000	.631(**)	.416(**)
2	Spear man's rho	RCD in mm	Correlation Coefficient	1.000	.455(**)	.550(**)	.343(**)
			N	112	112	61	61
		Stem height in cm	Correlation Coefficient	.455(**)	1.000	.401(**)	.359(**)

** Differences at a level of significance of 0.01.

Because of the correlation between the RCD and the stem height as well as foliage and woody biomass the biomass yield of the shrubs of *G. sepium* at Molet was measured to be similar to plot 1 due to a similar average RCD and an average tree height (table 15). Based on the findings concerning biomass production in Laikala (plot 1 and 2), the total foliage and woody biomass production potential for different spacings was calculated. A multiplication of the yields measured and gathered for the cropping pattern of 3 m by 3 m by 9 approximated the biomass yields for a 1 m by 1 m cropping pattern. Assuming a denser cropping pattern of 0.5 m by 0.5 m, the figures of the foliage biomass and woody biomass were multiplied by 36 compared to the initial scenario with a spacing of 3 m by 3 m.

Table 15: Biomass production potential of *Gliricidia sepium* with different spacings in the Dodoma region

Biomass production potential – *Gliricidia sepium* (different spacing)			
	Laikala (Plot 1) [a]	Laikala (Plot 2) [a]	Molet (Shelterbelt) [b]
RCD in mm	25.0	32.4	24.4
Stem height in cm	161.1	213.6	156.8
Biomass production potential – *Gliricidia sepium* (3 m by 3 m)			
Foliage biomass in kg per ha	2,420	3,623	2,420
Woody biomass in kg per ha	868	2,516	868
Biomass production potential – *Gliricidia sepium* (1 m by 1 m)			
Foliage Biomass in kg per ha	21,785	32,604	21,785
Woody Biomass in kg per ha	7,812	22,643	7,812
Biomass production potential – *Gliricidia sepium* (0.5 m by 0.5 m)			
Foliage Biomass in kg per ha	87,139	130,418	87,139
Woody Biomass in kg per ha	31,246	90,573	31,246

[a] Tree growth period of 23 months. Figures are based on own measurements. Yields are based on a wet moisture content of the wood of 30 % (firewood at wet-basis).

[b] Tree growth period of 25 months. Due to similar growth patterns the foliage and biomass yields are approximated based on the measured growth patterns of Laikala plot 1. Yields are based on a wet moisture content of the wood of 30 % (firewood at wet-basis).

In **Mlali** which is a neighboring village of Laikala and Molet similar site conditions can be assumed. Three tree species were grown in a **woodlot formation (1 m by 1.5 m)**. The **tree species** grown were ***S. siamea, G. robusta* and *M. azadaraets***. The RCD and the stem height were assessed (SPSS Printout: Appendix 6.7). Preliminary results show that G*revillea robusta* is the fasted growing species with regard to a RCD of 38.04 cm (SD 11.89 cm) and stem height of 223.31 cm (SD 58.61 cm) among the three species assessed. The trees were not pruned during the assessment because of the growth period of trees of 25 months. Therefore, the data was not used for the deduction of biomass yields.

4.2.2 Focus group discussion: Challenges of firewood production

The challenges of the UPS "on-farm tree production" are manifold. Two focus group discussions among the two nursery groups in Ilolo showed the challenges of the UPS "on-farm wood production" as perceived by the villagers. Especially at tree nursery level and after the planting of the trees in the field challenges occur.

At the nursery level it was reported that some tree species did not germinate properly which led to a tree loss at the tree nursery level. Another issue reported were termites destroying the seeds and small seedlings. Although ICRAF reacted with the distribution of termite poison, the problem was still reported being existent. ICRAF supported the tree nurseries by covering water bills. Equipment of the tree nurseries was stolen and slowed down the planting process.

After planting the trees in the field, major hindering factors to reach a higher dissemination of tree seedlings were seen in the extreme heat of 2015 with a long dry period without rain which resulted in the dead of tree seedlings. Some trees were planted near water channels. Heavy rainfalls in Dodoma led to an extensive water runoff. Seedlings planted close to the water channels were washed away. In the period from June to September of 2015 it was reported that livestock in the area destroyed tree seedlings in the field.

Up to now, record keeping on seeds planted in the tree nurseries as well as trees distributed to the fields with corresponding survival rates was lacking. Group activities in the tree nurseries were performed by few individuals. The groups aimed to formulate a group constitution and register the group at governmental level which would entail financial and legal benefits.

4.3 Synopsis of firewood demand and supply in the Case Study Sites

Based on the results of the KPT and the biomass growth assessment different scenarios were developed in order to determine the firewood demand and supply for the CSS on an annual basis (Hoffmann et al., 2015). The scenario analysis takes the different cropping schemes of wood plantations into account.

4.3.1 Annual firewood consumption and production for cooking purposes

Ugali and vegetables is the most frequent cooked meal in Idifu. This type of meal is cooked very fast and with low firewood input compared to all meals assessed during the KPT. The households used ICS on average 2.34 times per day.

The annual **firewood consumption of oven-dried firewood** (**0 % moisture content**) *including* leftover charcoal for **the meal ugali and vegetables** was calculated:

The measurements showed that on average f_d = 632.6 g (*Form. 3.11*) of dry equivalent firewood per meal were used for cooking ugali and vegetables for an average size of 4.6 household members. The energy content of the leftover charcoal was considered as "leftover energy" which is reused during the next cooking task. If ugali and vegetables are cooked every day, a household can reach a dry equivalent firewood consumption of **540 kg per household and year** (632.6 g x 2.34 times per day x 365 days (*Form 3.11*)). Accordingly one household member consumes 117 kg of dry-equivalent firewood per year.

One household member consumes **140 g of firewood per meal** (oven dried-equivalent firewood). The calculated value is a hypothetical value and not reachable in a real world situation.

The annual **firewood consumption of air-dried firewood** (**15 % moisture content**) *excluding* charcoal consumption for **the meal ugali and vegetables** was calculated:

Based on this conditions a firewood consumption of **1,012 kg per household and year** (*Form. 3.1*) was calculated. Accordingly one household member consumes 220 kg of firewood (air-dried) per year. Based on the calculation one household member consumes **260 g of air-dried firewood per meal**. This figure can be seen as the lowest reachable boundary of firewood consumption per household and year in case the annual diet consists only of ugali and vegetables.

At an **oven-dried basis** one household member consumes **221 g of firewood per meal**.

The annual **firewood consumption of air-dried firewood** (**15 % moisture content**) *excluding* charcoal consumption **for the different meals** was calculated:

It is derived that 3 different types (or equivalent) of meals are cooked throughout the year. Key informant interviews suggest that around 80 % of all meals cooked consist of ugali and vegetables. Around 15 % of all meals cooked consist of rice and vegetables. Beans and rice are cooked around 5 % of all cooking tasks per annum.

When ICS stoves are used, on average 1,185 g (SD 307 g) of firewood were used to cook ugali and vegetables (N = 63). 1,376 g of firewood (SD 792 g) were used to cook rice and vegetables (N = 19). 3,576 g of firewood (SD 696 g) were used to cook the meal beans and rice (N = 19).

The firewood consumption is **1,139 kg per household and year** (810 kg (ugali and vegetables) + 176 kg (rice and vegetables) + 153 kg (beans and vegetables)).

A firewood consumption of 248 kg per household member and year when ICS are used was derived (1,139 kg per household and year / 4.6 household members). Following this assumption a firewood consumption **(air-dried) of 290 g per household member and meal** was calculated.

At an **oven-dried basis** one household member consumes **246 g of firewood per meal**.

The Idifu village comprises 1,386 households and Ilolo 921 households. Based on a dissemination of ICS of 100 %, the firewood demand for cooking purposes for Idifu is **1,578,219 kg per year** (1,139 kg per household and year x 1,386 households) **(air-dried basis).** The findings on firewood consumption patterns in Idifu are applied to Ilolo. For Ilolo village the demand of firewood for cooking purposes is **1,048,730 kg per year** (1,139 kg per household and year x 921 households) **(air-dried basis).** The above cited firewood demand equals an oven dry firewood consumption (**oven-dried basis**) of **1,341,486 kg per year for Idifu** and **891,420 kg per year for Ilolo**.

The annual **demand of firewood of 968 kg per household** and year was calculated for a moisture content of **0 % (oven-dried basis)**. Based on the calculated annual consumption patterns of firewood for cooking purposes and the firewood production potential of *G. sepium* an estimation of the amount of trees needed to cover this demand was drawn.

The average of woody biomass production of the two plots in Laikala (plot 1 and plot 2) are assumed. For a growth period of 23 months and 25 month of *G. sepium* a woody biomass production of 1,766 kg per ha was calculated (wet firewood moisture content of 30 % is assumed). A linear correlation between biomass production and the age of the plants was assumed.

On a 12 months basis the woody biomass production potential of plot 1 was 0.39 kg per plant. For plot 2 a production potential of 1.13 kg per plant was measured. An average of woody biomass production of **0.761 kg per plant and year** was calculated (**moisture content of firewood of 30%).** This equals a woody biomass production potential of **0.533 kg per plant per year.** Based on different cropping patterns the annual firewood production of *G. sepium* for a growth period of 12 months and the number of trees needed to cover the firewood demand for cooking purposes was calculated (table 16):

Table 16: Woody biomass production of *Gliricidia sepium* based on the growth pattern of Laikala (plot 1 and 2) with different spacing

Woody biomass production of *Gliricidia sepium* per year			
	Woody biomass (wet-basis) (kg per ha) [a)]	**Woody biomass (oven-dried basis) (kg per ha) [b)]**	**Equivalent number of trees needed per ha**
3 m by 3 m	883	618	1,160
1 m by 1 m	7,944	5.561	10,439
0.5 m by 0.5 m	31,779	22,245	41,759

[a)] Derived from a growing period of 23 months including two uni-modal rainy seasons (assumed wood moisture content of 30 %) (firewood at wet-basis).
[b)] Derived from a growing period of 23 months including two uni-modal rainy seasons (assumed wood moisture content of 0 %) (firewood at oven-dried basis).

Based on the measurements of the ICS performance and firewood production potential the total area needed to cover the firewood demand for cooking purposes was calculated at village and household level. The calculation is based on a moisture content of firewood at an oven-dried basis (0 % moisture content) (table 17). The total ward area of Idifu amounts up to 15,485 ha. Ilolo is located in Muungano ward which comprises 10,559 hectare.

With a spacing of *G. sepium* of **3 m by 3 m** a total of **2,170 ha in Idifu** (firewood demand per village (oven-dried basis) / woody biomass production per hectare (spacing 3m by 3m, oven-dried basis)) and **1,442 ha in Ilolo** are needed to cover the firewood demand for cooking purposes. Expressed as a ratio of the total ward area, in Idifu 14.02 % and in Ilolo 13.66 % of the ward area needs to be afforested.

With a spacing of *G. sepium* of **1 m by 1 m** a total of **241 ha in Idifu** and **160 ha in Ilolo** are needed to cover the firewood demand for cooking purposes. Expressed as a ratio of the total ward area, in Idifu 1.56 % and in Ilolo 1.52 % of the ward area needs to be afforested.

With a spacing of *G. sepium* of **0.5 m by 0.5 m** a total of **60 ha in Idifu** and **40 ha in Ilolo** are needed to cover the firewood demand for cooking purposes. Expressed as a ratio of the total ward area, in Idifu 0.39 % and in Ilolo 0.38 % of the ward area needs to be afforested.

Table 17: Forest area of *Gliricidia sepium* needed on village level (Idifu and Ilolo) and per household in order to cover the firewood demand for cooking purposes (different cropping patterns)

***Gliricidia sepium* plantations needed to cover the firewood demand for cooking purposes for Idifu**		
	***Gliricidia sepium* plantations in ha**	***Gliricidia sepium* plantations in % of total ward area**
3 m by 3 m	2,170	14.02
1 m by 1 m	241	1.56
0.5 m by 0.5 m	60	0.39
***Gliricidia sepium* plantations needed to cover the firewood demand for cooking purposes for Ilolo**		
	***Gliricidia sepium* plantations in ha**	***Gliricidia sepium* plantations in % of total ward area**
3 m by 3 m	1.442	13.66
1 m by 1 m	160	1.52
0.5 m by 0.5 m	40	0.38
Area of *Gliricidia sepium* plantations needed per household in m^2		
3 m by 3 m	15,659	
1 m by 1 m	1,740	
0.5 m by 0.5 m	435	

ICS users will need the following area demand of wood plantations at household level:

A cropping pattern of **3 m by 3 m** of *G. sepium* results in an area demand of approx. **15,659 m^2 per household** (G. sepium demand in hectare per village and cropping pattern x 10000 m^2) / number of households) to cover the annual firewood demand by on-farm plantations. A cropping pattern of **1 m by 1 m** of *G. sepium* results in an area demand of approx. **1,740 m^2 per household** to cover the annual firewood demand by on-farm plantations. A cropping pattern of **0.5 m by 0.5 m** of *G. sepium* results in an area demand of approx. **435 m² per household** to cover the annual firewood demand by on-farm plantations.

In order to cover the annual firewood demand of *G. sepium* plants per household, approx. **1,816 plants per household** need to be planted. ((Firewood demand per household and year in kg (oven-dried basis) / firewood production per plant and year in kg (oven-dried basis) = 968 kg per household and year / 0.533 kg per plant and year).

Based on the amount of people living in **Idifu a total of 2,516,976 plant**s (1,386 households x 1,816 plants) and in **Ilolo 1,672,536 plants** (921 households x 1,816 plants) are needed to cover the annual firewood demand of the village.

4.3.2 Time saving potentials of Improved Cooking Stoves

Based on the stove technology used in the households the annual time spent to collect firewood can be calculated.

For ICS (N = 45) a mean frequency of collecting firewood of 2.56 times per week (SD 1.61 times per week) was calculated. 3 stone fire stove households (N = 15) collect firewood on average 3.73 times per week (SD 1.68 times per week). A walking distance of 354 min was measured.

This results in a time spent to collect firewood per annum for a 3 stone fire stove household of 1,144 hours. A household, which uses ICS, spends 785 hours to collect firewood on an annual basis. On average one household can **save 359 hours (15 days) of walking time** on an annual basis when ICS instead of 3 stone fire stoves are used.

During the cooking process with an ICS additional time savings result. For ICS the total cooking time for ugali and vegetables was measured to be 30.32 min (SD 9.35 min). The total cooking time for rice and vegetables was measured to be 60.32 min (SD 13.61 min). The total cooking time for beans and rice was measured to be 138.78 min (SD 23.11 min). Based on interviews with the villagers in Idifu a standard diet consists of 80 % ugali and vegetables, 15 % of rice and vegetables and 5 % of beans and rice. Based on the responses from the cooks, the ICS is used 2.34 times per day.

This results in an annual time spent to cook with ICS of 573 hours (0.8 x 2.34 x 30.32 min x 365 days + 0.15 x 2.34 x 60.32 min x 365 days + 0.05 x 2.34 x 138.78 x 365 days.)

When the meal rice and vegetables was cooked, a time reduction of 21 % in time spent to cook 1000 g of ingredients was reported for ICS compared to 3 stone fire stoves. For the meal beans and rice a reduction of 26 % in time spent to cook 1000 g of ingredients was measured. Based on the results a reduction in total cooking time of 25 % was assumed when ICS instead of 3 stone fire stoves are used. This results in an annual time spent to cook with 3 stone fire stoves of 716 hours. **143 hours (approx. 6 days)** can be **saved from cooking on an annual basis with ICS** instead of 3 stone fire stoves.

In total around **502 hours per household and year** (around 27 %) (359 hours per household + 143 hours per household) can be saved on an annual basis when ICS are used instead of 3 stone fire stoves (table 18). This calculation suggests that all firewood collected is used as firewood. This assumption will be discussed in the next chapter.

Table 18: Annual time savings induced by Improved Cooking Stoves per household

	ICS	3 stone fire	Difference
Time spent to collect firewood in hours	785	1,144	359
Time spent for cooking in hours	573	716	143
Total consumption in hours	1,358	1,860	502

5 Discussion

5.1 Improved Cooking Stoves: A tool to improve livelihoods

The research done in this work shows a direct link between ICS and reduced deforestation. The results of the thesis provide answers to the research questions as stated in the introduction. The KPT provides reliable and robust data on ICS performance. The standardized testing procedure allows a transfer of the results towards other regions with similar geological and climate conditions (De Lepeleire et al., 1981).
The results gathered during the field test have to be assessed carefully. Measurements taken during the KPT are subject to high variance compared to laboratory-based tests due to the manifold potential sources of errors. FAO (1983) showed a variation of fuelwood consumption per capita of around 40 % of field-based tests (KPT) while the variation of the results from the laboratory tests (WBT) is around 10 %.

The Trans-SEC approach followed a random selection of UPS members among the villagers in the CSS. Therefore, the UPS groups comprised besides high also low motivated members. The results gathered show a high standard deviation which influenced the prognosis value of the data. A larger variance means a less precise estimator, and this translates into larger confidence intervals and less accurate hypotheses tests (Wooldridge, 2015). In order to minimize the inaccuracies induced by “bad” performing stove users, the best 50 % performers of each stove technology were looked at in-depth in order to eliminate the bias from slow or inefficient outliers. A higher data sample might reduce the standard deviation and contribute towards a higher significance of results.

The quantitative part of the KPT showed the following:

During the cooking task “*rice and vegetables”*, a significant reduction of firewood consumption of 33.3 % was measured when ICS were compared to 3 stone fire stoves. With regard to time consumption ICS saved approx. 21.3 % of cooking time compared to 3 stone fire stoves (results were marginally significant). The two-pot ICS design induced performance improvements compared to 3 stone fire stoves with regard to firewood consumption and total cooking time. Efficiency gains of ICS are related to a simultaneous cooking on two pots compared to 3 stone fire stoves where pots are cooked consecutively.

Regarding the slow cooking food (*beans and rice*) which requires a long simmering time an 11.6 % reduction of firewood consumption between ICS and 3 stone fire was measured. Due to the fact that beans are swelling during the cooking process, the total amount of beans could not be accommodated in one pot and therefore had to be cooked consecutively. This can be seen as a major advantage of 3 stone fire stoves which can accommodate different pot sizes. The limits of ICS became apparent because ICS stoves are constructed for a predefined pot size. Other pot sizes do not fit inside the defined potholes. Nevertheless, some households were found which used a gear rim of a bicycle in order to reduce the pothole size which allows the adjustment of different pot sizes.

A significant reduction of 26.15 % in time spent to cook 1000 g of ingredients of ICS was observed in comparison to 3 stone fire stoves. This might be explained by the better insulation and thermal efficiency of ICS compared to 3 stone fire stoves and the performance of the second ICS pot.

It was important to test the ICS and 3 stone fire stoves by cooking a dish with a long simmering time to get a clear picture on ICS performance during a long cooking task. Nevertheless, with regard to future testing, the amounts of beans should be revised and adjusted to the pot size.

The results of the KPT were flanked by the results of the expert team of Dr Rajabu (chapter 4.1.3). The results of Dr. Rajabu provided a good indication on the performance capacity of ICS under perfectly controlled environment setting. The expert team cooked rice without measuring the second pot. The results showed a reduction in specific firewood consumption of 33 % between ICS and 3 stone fire stoves which is in line with the measured results of the KPT during the meal *rice and vegetables*. With regard to the time consumption the results deviate. While the expert team indicated that cooking with ICS is 8 % slower compared to 3 stone fire stoves, the KPT test results showed that cooking with ICS is 21.3 % faster compared to 3 stone fire stoves. The deviations in cooking time can be explained by the different cooking protocols used. While the expert team measured the firewood consumption and cooking time for pot one, the KPT measured the performance of both pots. It is vital to develop a standardized testing protocol to maintain the comparability of the test results among different scholars. The results and the explanatory power of the results of the expert team were limited due to a small sample size (6 samples).

Since the introduction of ICS in Idifu, the stove did undergo a design shift. Reduced stove height and an increased wood entry slot were the most demonstrative ones. Nevertheless, the assessment of “old” and “new” ICS did not show significant differences in specific firewood consumption and time needed to cook 1000 g of ingredients. Based on the results it can be emphasized that “new” ICS perform a cooking task slightly faster than “old” ICS at the expense of marginally increased firewood consumption. The results lead to the suggestion that an accelerated combustion of firewood might directly affect the total firewood consumption negatively. There seems to be a tradeoff between cooking time and firewood consumption. Nevertheless, a design shift has the potential to alter the performance of ICS stoves which emphasized the need for further ICS tests after the design shift.

The modified specific firewood consumption and time to cook 1000 g of ingredients of large households were reduced in comparison to small households (with regard to the amount of food cooked). The modified specific firewood consumption is reduced by 42.2 % between the large size group in comparison to the small size group of ICS users. The time spent to cook 1000 g of ingredients showed that large size groups spent 31.8 % less time than small size groups. The findings suggest that benefits of ICS are increased when food is prepared for a larger group of people. The larger the amount of food cooked, the smaller is the firewood and time consumption per ingredient used.

The benefits of ICS with regard to firewood and time savings at a single or two-person household are reduced. As a recommendation it can be concluded that small households should cook larger amounts of food in order to save firewood and cooking time.

The annual firewood demand measured per village was based on the data of the national population census of 4.6 household members. The test samples gathered during the KPT showed that the average ICS household size was 5.3 household members and 5.5 household members for 3 stone fire stoves. A higher average of household members might increase the total firewood demand per household but at the same time less firewood per capita is used due to the above cited correlation between family size and reduced firewood and time consumption.

The qualitative part of the KPT showed the following:

The qualitative assessment of 72 households indicated that the frequency of collecting firewood is reduced by 31.4 % when ICS were used compared to traditional 3 stone fire stoves. The results showed that deforestation is reduced by the usage of ICS technologies. Nevertheless, it is difficult to quantify the exact reduction of deforestation induced by ICS. The findings of the KPT indicated that around 42 % of the annual firewood consumption of a household which uses ICS (1,139 kg per year consumed for cooking / 2,691 kg per year collected) can be explained by cooking purposes (air-dried basis). The findings showed that the annual firewood reduction potential might be based on the amount of firewood used for cooking purposes (1,139 kg per household and year) and not based on the total amount of firewood collected (2,691 kg per household and year).

Scherr (2004) cites that around 50 % of the firewood collected is used as firewood in sub-Sahara Africa. Makundi (2001) and Van der Plas (1995) argue that in Tanzania 70 % - 85 % of the deforestation is connected to firewood or charcoal production.

This could not be confirmed by the data gathered. The findings of the KPT suggest that even less than 50 % of firewood collected might be used as firewood. The results of the KPT pointed out that deforestation caused by cooking purposes is below 40 %.

The scope of thesis was limited to identify the contribution of cooking related energy demand towards deforestation. Nevertheless, further driving factors of firewood consumption need to be examined in order to identify further reduction potentials of firewood consumption. More research is needed to identify in which ways the additional firewood is used. This is particularly important to detect further areas of firewood reduction potentials.

Most villagers in Ilolo and Idifu collected firewood from miombo woodlands which surround the villages. The firewood collected is carried on top of the head because passable streets to the forests are not available for vehicles. The weight of firewood carried by one person varies between age and gender of the collector. Women and children are mainly responsible for collecting firewood. In Dodoma, women carry on average 20-30 kg headloads of firewood (Skutch, 1983). The importance of a reduction of the frequency of collecting firewood is obvious with regard to the measured walking distances in Idifu. On average around 6 hours are spent per firewood collection in Idifu. Therefore, the implementation of ICS relieves the most vulnerable population of the village.

Findings of the KPT on the annual firewood collection are based on the estimation of the weight of a headload of firewood carried. In case of ICS, the annual firewood collected ranges between a lower limit of 2,691 kg (20 kg per headload) and an upper limit of 3,995 kg (30 kg per headload) (air-dried basis). 3 stone fire stoves firewood collection ranges between a lower limit of 3,883 kg (20 kg per headload) and an upper limit of 5,824 kg (30 kg per headload) (air-dried basis). More research needs to be done in order to determine a standardized measure for a headload weight in order to determine the total firewood collection per household, since official monitoring authorities on deforestation are not in place in Tanzania.

Skutch (1983) cited that a household in sub-Sahara Africa consumes 3400 kg of firewood per household and year, including all demands for firewood. Fuel demands remain constant per capita but grow with population increase. An average firewood consumption of 3,882 kg per household and year (20 kg headload) was assessed for 3 stone fire users (average household size of 5.5 people based on the data assessment). The findings of the KPT on the annual firewood collection are corresponding with the literature and state that the results gathered are realistic.

Wiskerke et al. (2010) exemplified in a Tanzanian case study that investments in ICS technologies significantly lowers the costs of cooking. This affects directly households which buy their firewood but also indirectly for those who spend substantial time for collecting firewood from remote areas. A reduced frequency to collect firewood and a reduced cooking time of ICS compared to 3 stone fire stoves is directly connected to increased time availability. Additional time can be spent on activities which support rural livelihoods. The results of the thesis showed that time savings of around 500 hours per year and household could be saved when ICS instead of 3 stone fire stoves would be used. These time savings might be valued more in the villages if “measurable” opportunity costs of time would exist. In this context, an analysis of opportunity costs for the population in the CSS would be required in order to quantify the time savings financially.

Present challenges are related to inadequate awareness of the potential benefits of efficient use and utilization of ICS and wood conservation practices, technology and appliances as well as non-existence of legislation and regulatory framework for energy efficiency and conservation.

While substantial time is spent on introducing new stove programs, there is still a lack of understanding on how ICS technologies are adopted and used sustainably. Systematic knowledge regarding adoption reasons of the new technology seems to be more vital than the initialization of new stove programs (Hessen et al., 2001, Rehfuess et al., 2014). Analyses of the households provide indications on what might be the driving factors for a sustained dissemination of ICS. The results of the qualitative KPT showed that ICS were usable throughout the year; also within the rainy season. All dishes could be cooked which indicates that ICS do not compromise the diet of the villagers. All ICS users claimed that indoor smoke burden was not perceived as an issue due to the integrated chimney of the ICS.

3 stone fire users indicated that the ICS stoves were not affordable. This statement could not be confirmed by the responses of the KPT to the willingness to pay. The answers of ICS and 3 stone fire users suggested that they were expecting a reduction of forest endowment in the village and its surrounding for the future. The findings of the KPT in January 2016 and the baseline survey in mid-2014 support that perception. ICS users cited that the new ICS technology is a feasible tool to reduce the pressure on remaining forest resources. Almost 65 % claimed that deforestation could be reduced by increasing on-farm wood supply if energy efficient cooking gears such as ICS would be used. Still 30 % did not know any means to combat deforestation. Local initiatives to improve the forest situation are not yet in place in the CSS. Based on the findings of the qualitative KPT there is still a lack of understanding concerning the importance of trees for the local ecosystem and the connection of ICS and deforestation in the village.

Especially households which use 3 stone fire stoves were not aware of the benefits of ICS. Further training in order to increase the local awareness and the understanding of the importance of forest protection and ICS utilization might be suitable. Training and education on the UPS are possible ways to increase the usage of ICS and increase the efforts of villagers to plant more trees on own plots.

Despite the multiple benefits linked to ICS, many households of developing countries have failed to adopt them until the end of the 20th century (Barnes et al., 1994). There is no example in Tanzania to date of a successful adoption and diffusion of an energy-efficient stove program. Findings in Idifu point out that although benefits of ICS compared to 3 stone fire stoves are known, the adoption rate of ICS remains low.

Technology adoption decisions are complex. Adoption decisions might be different at household and community level. While in the first place income and education seem to be the driving factors for adopting a new technology, long-term use can be traced back to cultural reasons (Troncoso et al, 2007). A high dissemination rate is vital and long-term usage of the new technology and a crucial indicator to determine the programs' success (Sinton et al., 2004).

Scholars emphasize the key role of governments in implementing ICS technologies. National governments might induce further ICS dissemination by introducing subventions. Experiences from China support the idea that broad dissemination of ICS is based on strong governmental inception. The Chinese cook stove program can be cited as an example of a successful governmental driven dissemination process of the ICS technology (Smith et al., 1993).

The success factors and challenges of Trans-SEC ICS might be as follows: One of the major strengths of the ICS project is the development of a local knowledge base on how to construct an ICS. A sheer subsidization of ICS producers to accelerate the dissemination of ICS cannot be successful. High subsidization of ICS counteracts the idea of developing a business model which is based on the stove construction itself. Subsidized products might create false incentives for the villagers to use and construct ICS because its utilization is connected to financial benefits. Daily allowances might be the only incentive for unmotivated group members to take part in group meetings (Barnes et al., 1993). Furthermore, low motivated UPS members might discourage ambitious members to engage further within an UPS. Trans-SEC focused on knowledge dissemination without major subsidization of the ICS technology. The introduction of a business model allows artisans of ICS to continue with ICS construction after the phase-out of Trans-SEC (Kees and Feldmann, 2011). By focusing on local artisans during the ICS construction process, the ownership of the stove program might be increased (Omar Makame, 2007).

Some villagers complained that the lighting of firewood is challenging and directly connected to improper usage of wet firewood. Training on proper usage of the ICS was undertaken to react on complaints from the villagers about the complicated way to light the ICS stove especially when the firewood was not well dried. In December 2015, the ICS users in all CSS were instructed on how to collect and store firewood in order to reduce the moisture content of the firewood and the smoke congestion during the lighting process of the ICS. The training provided further understanding on firewood processing in the villages, facilitated the usage of ICS and increased crucial knowledge about storing firewood throughout the rain periods. Further trainings on ICS handling as well as firewood preparation are needed to increase the understanding of ICS utilization. The construction of an air-bypass which accelerates the lighting of firewood might be a suitable solution to solve the issue connected to the difficult ignition of ICS.

Local ownership of stove programs is vital to further disseminate ICS. Based on the tested and verified performance improvements of ICS the results can be used for marketing purposes in the villages. The results of the KPT provide a solid basis for the development of a quality label which indicates the major advantages of ICS. Successful marketing of the ICS stoves might accelerate the dissemination of ICS and convince more households to switch from 3 stone fire stoves to ICS. A sustainable marketing concept needs to be developed to benefit the constructors of the stove in an adequate manner.

The finance sharing agreement of Trans-SEC stipulated to share the payment for an ICS among the artisans and the whole ICS member group. Construction and dissemination of ICS contributes to income generation and employment of artisans and technicians. A higher income for artisans seems to be feasible due to an increase in the stove price. Based on the findings on the willingness to pay for ICS, a higher price for the ICS is justifiable.

The knowledge on how to construct an ICS is concentrated on few people. During the focus group discussions in Idifu and Ilolo it became clear that although all initial ICS group members are able to construct an ICS, only few people in the CSS were actively constructing ICS. This bears the risk that the knowledge on constructing a stove could get lost in case these key persons stop constructing ICS. It is recommended to draw special emphasis on knowledge sharing systems in order to increase the knowledge base of villagers on how to construct an ICS.

Projects which intend to change the cooking habits of the rural population in Tanzania face a tradition of 3 stone fire stoves of hundreds of years. Adaptation of a new cooking technology cannot only be achieved by communicating improvements induced by ICS without considering the social and cultural aspects of the villages (Muneer, 2003).

5.2 Increased on-farm wood supply: A tool to increase the firewood production

The analysis of RCD, tree height and the biomass production potential in Kongwa district, provided a good indication to determine the area of *G. sepium* shrubs needed to cover the firewood demand for cooking purposes. The data on foliage and woody biomass production was based on a growth period of 23 months and 25 months. The annual woody biomass production was calculated based on a growth period of the trees of 12 months. The data on biomass yields collected was based on one assessment per plot. Findings on the firewood production potential of *G. sepium* showed that an area of 15,659 m² per household are needed to cover the firewood demand by on-farm tree production (spacing 3 m by 3 m). Assuming a cropping pattern of 1 m by 1 m and 0.5 m by 0.5 m, one household needs to plant 1,740 m^2 respectively 435 m^2 to cover the firewood demand by on-farm trees. These areas are equivalent to 1,816 plants of *G. sepium* needed by one household (assuming ICS usage).

Nevertheless, the calculated figures depend on annual precipitation, silvicultural treatment of the trees, soil properties, grazing animals, pest and vermin among others. These are the main factors which explain the high variability of the results on biomass growth. The biomass yields of *G. sepium* assessed differed significantly among similar sites. Further research is needed to determine the growth patterns of *G. sepium*. For the villagers who are engaged in afforestation it is important to understand the driving and hindering factors of *G. sepium* growth. Measurements that are more frequent and a higher sample size of the trees assessed might increase the accuracy of the results gathered on biomass production potentials.

A linear correlation between RCD and tree height as well as foliage and woody biomass production was assumed. This assumption is subject to discussion as results show that woody biomass yields do not grow linear with regard to RCD and tree height growth (chapter 4.2.1). Based on the assessment of tree plantations it is suggested that pruning of the trees should not be done at a growth period of 12 months because the woody biomass production at that point might still be low. More research is needed on growing patterns of *G. sepium* in order to determine the optimal point of pruning.

The yields of woody biomass obtained from *G. sepium* plantations differ among the literature. The accumulation of woody biomass depends very much on climate and soils, management, planting density and growing cycle. Salazar (1986) reports dry wood yields of up to 6.3 t per ha and year from *G. sepium* shrubs in Costa Rica. In the Philippines, where *G. sepium* was grown in woodlots, woody biomass yields of up to 23-40 m^3 per ha and year have been obtained (Wiersum and Dirdjosoemarto, 1987). Because knowledge on moisture content and spacing of the trees are not available, the literature results are only limited comparable to the biomass data gathered during the assessment in Kongwa district.

The biomass production potential calculated in this thesis can be seen as a best-case scenario without external factors like droughts, floods, vermin and lack of management skills hampering the dissemination and growth of the shrubs. Own measurements on tree growth showed a firewood yield of around 31.8 t per ha and year for a woodlot plantation with a spacing of 0.5 m by 0.5 m. For wider spacings of 3 m by 3 m to 1 m by 1 m, a range of 0.9 to 7.9 t per ha and year were produced on a wet-basis (30 % moisture content).

Studies of Karim und Savill (1991) on alley cropping systems of *G. sepium* showed that the survival rate and tree height are not affected by the spacing between or within rows. The studies claimed that total biomass production per unit area was higher when the spacing between the alleys of *G. sepium* plants was smaller. Lower individual tree productivity is compensated by higher plant density. Only small changes in biomass production per plant were cited for narrow spacings of plants ranging from 4 to 50 cm (Atta-Krah, 1987). This findings indicate that a very dense cropping pattern of *G. sepium* of 0.5 m by 0.5 m might not compromise the biomass production. Nevertheless, the projections of a production potential of 31.8 t per ha and year are very ambitious. Further research is needed to examine how root competition regarding water and nutrients affects the growth of *G. sepium* with a spacing of 0.5 m by 0.5 m and below.

The hectare amount needed to cover the firewood demand for cooking purposes is based on different assumptions. Different calorific values (CV) between *G. sepium* and the firewood used during the KPT as well as differences in wood moisture content between air-dried firewood used during the KPT and fresh cut *G. sepium* might influence the calculated forest area. Firewood with a high density burns slowly because heat is released more slowly and for a longer period. The specific gravity of *G. sepium* is cited to be 0.49 g per cm³ with a calorific value of 22.1 MJ per kg (Fuwape and Akindele, 1997). Other scholars report of an average specific gravity of 0.50 - 0.60 g per cm³ with a heating value of 19.8 MJ per kg for *G. sepium* at an air-dried basis (Withington et al. 1987).

The firewood used during the KPT in January and February 2016 had a different CV compared to *G. sepium*. In the CSS and the surrounding areas mango trees (Mangifera indica) were most abundant. The CV of the wood served as a representative species of a CSS. Mango trees have a CV of 4200 kcal per kg at an air-dry basis (approx. 17.58 MJ per kg) (ICRAF, Mangifera indica, assessed at 20.06.2016). This indicated that the CV of *G. sepium* was higher than the CV of the representative wood sample of the village. This suggested that a smaller area of *G. sepium* plantations might be needed to cover the energy demand for cooking purposes in the CSS. Nevertheless, wood with small diameter has a lower specific gravity compared to firewood with larger diameter. Therefore, the hectare savings induced by a higher CV of *G. sepium* compared to firewood from other trees have to be treated carefully.

Wood with low moisture content is preferred as firewood because of its high energy content. Findings from Nigeria on *G. sepium* plantations state a moisture content of 31 % of fresh cut *G. sepium*. The region receives two times more rainfall than Dodoma region on an annual basis (Fuwape and Akindele, 1997). In the CSS, the shrubs of *G. sepium* are harvested at the end of the dry period. Therefore, the moisture content of the shrubs might be slightly reduced compared to the values found in Nigeria but still above 15 %.

The results of the KPT in January and February 2016 indicated that the firewood availability in the village Idifu might have decreased since 2014 which resulted in longer walking distances. If the UPS "improved on-farm wood supply" can contribute towards firewood production, the walking time to collect firewood might decrease due to the fact that the planted trees or shrubs are located in the nearer surroundings of the villages. As a result firewood does not have to be collected from public sites which are located far from the homesteads.

Besides the firewood production potential additional benefits can be achieved from intercropping *G. sepium* with crops. Some scholars warn that the roots of *G. sepium* may directly increase the competition between shrub and crop for water which not only discriminates crop yields but also reduces biomass production (Duguma et al., 1988). Other scholars cite different findings. Studies on *G. sepium* in West Africa found that the root length density of the shrubs were too low to compete with crops for soil resources. This property makes *G. sepium* suitable for combined planting with crops which possess root systems of low own competitive ability, and for climates with a high risk of drought during the cropping season. The roots of *G. sepium* are cited to have a positive effect on nutrient leaching (Schroth and Zech, 1995). *G. sepium* was cited to produce excessive amounts of foliage biomass which can be used as soil fertilizer or fodder. Findings from Guatemala cite that G. sepium showed an outstanding result for leaf production (Simons and Dunsdon, 1982). Depending on the site conditions, annual leaf dry matter production of *G. sepium* ranges from about 2 t per ha and year to 20 t per ha and year (Wong and Sharudin, 1986; Sriskandarajah, 1987).

The assessment of the trees *S. siamea, G. robusta* and *M. azadaraets* indicated that trees can potentially contribute to firewood production but need a much longer growth period than *G. sepium* in order to produce firewood. For these trees being used as firewood a proper management without pruning of the trees is needed with regard to firewood production in the future. Therefore, it is necessary that villagers do not prune the trees before they reach a sufficient height. It is questionable whether villagers will not cut the trees planted if the trees are no longer under surveillance of Trans-SEC.

The measurements of different tree species assessed showed the potentials of different tree species to on-farm tree production. Due to its properties being a fast growing species, *G. sepium* is a suitable shrub to increase on-farm wood supply and might be even more suitable than trees which need substantial growth periods before they can be used as firewood. Due to its fast growing nature and the possibility to be pruned frequently, it is convenient to plant the trees in the village surrounding. The usage of on-farm wood benefits directly the villagers via reduced frequency of collecting firewood. Additionally on-farm tree production reduces the demand from miombo forests and therefore has the potential to lower deforestation.

As shown there are several laws and programs in Tanzania to protect forest resources. In rural Tanzania law enforcement is often weak and not present. Property rights are either not established or not enforced which affect the planting of trees negatively (Sander et al. 2013). Therefore combined legal efforts on village, district, regional and national level are needed to reduce deforestation in the country and support afforestation processes. Data concerning forest endowment in Tanzania exist aggregated on a national level. Detailed information on deforestation and afforestation on regional or district level is not available. This hinders a precise analysis of deforestation in the project villages. Changes in the forest endowment can only be assessed by qualitative assessments like key informant interviews. Monitoring schemes have to be developed to increase the data availability on soil properties and precipitation in order to determine suitable site conditions for tree plantings.

Furthermore, land tenure and property rights need to be strengthened. One factor which limits the planting of trees are prospective insecurities on appropriating future benefits of trees (seeds, fruits, timer among others). When land is owned long term investments (such as tree planting) are made without hesitation because future benefits can be claimed.

Capacity building measures are necessary to enhance the tree production capacity of the tree nurseries in order to cover the total cooking related firewood demand within the next couple of years. Tree nurseries can be seen as a bottleneck which limits the tree production. More people in the villages need to be engaged in tree planting. Besides the raising of seeds of *G. sepium* at the tree nurseries, the shrub can be replanted by cutting branches and plant them directly into the soil (Gunathilake et al., 2005). This is a feasible procedure for planting more *G. sepium* shrubs without getting seedlings from the tree nurseries.

Regarding the tree nurseries in Ilolo the following can be stated: Besides the UPS "increased on-farm wood supply" local initiatives to plant trees were not existent although deforestation is perceived as a problem and most villagers said that more trees should be planted. It will be important that the tree nurseries work financially independent to ensure that the functionality of the tree nurseries is secured without input from Trans-SEC. It is vital that the production capacity of tree nurseries is increased in order to cover the demand of firewood for cooking purposes by on-farm trees. Focus group discussions within both tree nurseries in Ilolo showed further challenges of the UPS "improved on-farm wood supply." The Trans-SEC project will end in 2018. Therefore, the UPS members of the two tree nurseries were asked on how they expect to increase the self-sufficiency of the still donor depending project. Existing challenges are water costs at tree nursery level, vandalism, material unavailability and seed unavailability. The villagers proposed to react on seed unavailability by reproducing trees by taking seeds from existing trees, which is not possible for young trees which do not produce tree seeds. Therefore, seeds or seedlings might have to be bought by the villagers.

In order to understand the suitability of *G. sepium* plantations as source of firewood it is required that test trials are conducted in the CSS measuring the firewood of freshly cut *G. sepium* after the pruning. All ICS users should start test trials of *G. sepium* plantings on their homestead surroundings based on the plantation recommendations made in chapter 4.3.1. Nevertheless, it has to be taken into account that the wards consist of several villages with different land use practices like livestock keeping and farming among other. Different land use systems might affect the afforestation process.

The firewood produced from *G. sepium* can be seen as a complement to ICS. It is vital that ICS technologies are supplemented by increased on-farm tree plantings. Due to its relative narrow wood entry slot, ICS technologies can accommodate firewood with a maximal diameter of approx. 10 cm. The firewood of *G. sepium* can be used directly within the

ICS without resizing the wood. *G. sepium* shrubs with an age of approx. two years do not exceed a RCD of 3 cm to 4 cm. Further cooking tests with ICS need to be done to see how *G. sepium* plants are suitable for cooking purposes in line with ICS.

6 Conclusion

Measurements in Idifu showed that there is a direct link between the utilization of ICS and the reduction of firewood and time consumption. When ICS are used less firewood and time is spent for cooking purposes compared to traditional 3 stone fire stoves.

ICS reduce the amount of firewood spent for cooking significantly by 33.3 % compared to 3 stone fire stoves for a fast cooking dish (*rice and vegetables*). With regard to time consumption ICS save 21.3 % of cooking time compared to 3 stone fire stoves. Regarding the slow cooking food (*beans and rice*) which requires a long simmering time an 11.6 % reduction of firewood consumption in comparison with ICS and 3 stone fire was measured. By looking at the time to cook a meal, significant time saving of 26.15 % of ICS compared to 3 stone fire stoves was detected. It is of main interest that these results are addressed by the fact that the ICS are constructed by trained trainers and adjusted during the implementation and dissemination process.

Accordingly, a design shift between “old” and “new” ICS could be observed since the introduction of ICS in the CSS. Performance measurements showed no significant differences in the stove performance between “old” and “new” ICS, which suggested that the adjusted ICS design did not lead to a decrease in cooking performance. Analyses showed that a decrease in cooking time can be achieved at the expense of firewood used repealing any positive or negative effect of the change.

Based on the findings of this work, the benefits of ICS compared to 3 stone fire stoves such as reduced firewood and time consumption as well as reduced smoke burden and increased security during cooking are the prevailing ones.

The reduced firewood consumption of ICS was directly reflected by the amount of firewood collected. The qualitative results showed that ICS induce a lower frequency of collecting firewood compared to 3 stone fire stoves and contribute towards a reduction of deforestation of up to 30 %.

It can be concluded that the usage of ICS saves time at two levels. The frequency of collecting firewood is reduced and the usage of ICS is saving cooking time compared to 3 stone fire stoves. In total 502 hours (approx. 27 % of total time spent to cook and to collect firewood) per household and year can directly be saved when ICS instead of 3 stone fire stoves are used. Direct beneficiaries are women and children who are mainly responsible for cooking and firewood collection.

One year after the introduction of the ICS technology a low ICS dissemination of 7.4 %

in Idifu and 6.7 % in Ilolo among all village households was observed. The awareness of the problem of deforestation and inefficient cooking devices was spread to a large extend in the villages; still there is a lack of self-sufficient problem solving. On national level there is no governmental program which supports the dissemination of ICS. If the dissemination of ICS technologies in Tanzania remains limited to international research or donor institutions, a renunciation of 3 stone fire stoves remains unrealistic.

The measured firewood consumption patterns combined with on-farm tree production with three different cropping patterns (3 m by 3 m, 1 m by 1 m, 0.5 m by 0.5 m) pointed out that in Idifu between 2,170 ha and 60 ha and in Ilolo between 1,442 ha and 40 ha have to be planted with *G. sepium* shrubs to cover the cooking related firewood demand. An average household of 4.6 household members need to plant between 15,659 ha and 435 ha in order to cover the annual firewood demand by own firewood. The results of the thesis showed that 1,816 plants per household of *G. sepium* are required to cover the annual firewood demand for cooking purposes. The woody biomass production potential of *G. sepium* ranges from 31.8 t per ha and year to 0.9 t per ha and year (wet basis, firewood moisture content of 30 %).

Although the two UPS achieved preliminary success it is important that further efforts are undertaken in order to increase the outreach of the UPS. This requires a close monitoring of the ICS dissemination in Idifu and Ilolo as well as the tree nursery activities in Ilolo. ICS users should engage in tree planting activities in order to confirm the findings of this thesis on woody biomass growth.

Combined efforts of all stakeholders in Trans-SEC are required to secure the sustained implementation of both UPS in the villages. The knowledge created on the construction, usage and adjustment of ICS and tree nursery management must not remain limited to the CSS. The dissemination of the UPS might be the beginning of a transition towards cleaner and more efficient cooking solutions in the CSS and the Dodoma region. The UPS have to be spread among other villages in order to increase its outreach for improved livelihoods.

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Appendix

Appendix 1: KPT Quantitative Data Assessment January 2016 - Improved Cooking Stove Protocol

Kitchen Performance Test: Quantitative Data Collection

Cooking device tested: Improved Cooking Stove

Testing date: 12.01.2016 – 16.01.2016

Data collection site: Idifu

Subvillage:

Minutes of the testing procedure:

Date of Measurement:

Name of the enumerator:

Tree species used as Firewood (Name):

Moisture Content of the Firewood (% - wet basis):

Preparations BEFORE the start of the cooking process

Comments:

1. Welcome and request of taking part in the cooking procedure. Quick introduction of the tools used (Scale, temperature measure device, etc.)
2. Testing site is inspected. Influencing factors like other firewood is removed from the testing site.
3. General Data

   Household ID and Name of Head of Household:

   Name of Cook (the one who cooks normally):

   Age of the cook:

   Gender of the cook:

   Number of Household members:
4. Measure size of pot 1 in cm. Diameter: Height:
5. Outside Temperature is measured in C° :
6. Environmental conditions are stated (sun/ clouds/ rain /wind speed?):

7. Member of another UPS (if yes, which):
8. Measured pile of Firewood is handed over to the cook, and should be ONLY used during the cooking procedure (in gram):
9. Amount and state of ingredients for the cooking test are measured:

Pot 1		Pot 2	
Ingredients	Amount (gram)	Ingredients	Amount (gram)

10. Measure the temperature of the water in the first pot before ignition of the fire if applicable (in C°):
11. Measure the temperature of the water in the second pot before ignition of the fire if applicable
    (in C°):

Beginning of the cooking process

Comments:

12. If everything is prepared the cooking of the meal can start:
    State starting time here:
13. Time from ignition until water is boiling in the first pot
    (State time here): ………………………
14. Time when the first pot is finished cooking:…………………………………….
15. State time when the second pot is put on the fire:
    …………………………………………..
16. Time is stopped when second pot is finished:
    (State time here): …………………………………………………………………
17. Total amount of cooking time (in minutes):
    …………………………………………………….

AFTER the cooking is finished

18. All the remaining firewood and charcoal is collected and measured after finishing cooking
    (in gram):

Comments:

……………………………………………………………………………………………

……………………………………………………………………………………………

Appendix 2: KPT Qualitative Data Assessment January 2016- Improved Cooking Stove Protocol

Kitchen Performance Test: Qualitative Data Collection

Cooking device tested: Improved Cooking Stove

Testing date: 12.01.2016 – 16.01.2016

Data collection site: Idifu

Subvillage:

General Data

1. Testing Date:
2. Household ID and Name of Head of Household:
3. Name of Cook (the one who cooks normally):
4. Age of the cook:
5. Gender of the cook:
6. Number of Household members:

Market potential / Further dissemination of the technology

7. How many times do you cook per day (with fire source):
8. What time of the day do you use ICS? (Yes/ NO):

Morning…………….. Lunch………………….. Dinner……………….. Others…………….

9. Do you use the ICS throughout the year? (Yes/ No):

If no, when do you not use ICS:

10. Are the annual rain periods (vuli /Dezember and Masika / March to Mai) influence ICS?

If yes how?

11. Could a mobile / portable version of ICS be a substitution of 3SF? If yes (Why and when)
12. What do you miss while using ICS compared to 3 stone fire?
13. What changes would you wish regarding ICS?

Economical aspects of dissemination of ICS

14. How much firewood do you purchase per month (in TSH)?
15. How much money did you spent per month on firewood before using ICS?
16. Think about ICS which does fit all your expectations. How much are you willingness to pay for that ICS? (in TSH)
17. What do you think are the reasons for people in your village not adopting the new ICS technology?

Health condition of ICS user

18. Does the utilization of ICS have any influence on the health condition of your family?

If yes, how?:

Changes in Behavioral pattern

19. Using ICS. Did your habits change regarding the meals you cook? If yes, which meals?
20. Using ICS. Do your daily habits change with regard to time utilization?
21. After using ICS. Did your behavior regarding firewood collection change?

<table>
<tr><td colspan="3">22. What changes with regard to firewood collection pattern? Please exact answer</td></tr>
<tr><th>Concerning Firewood</th><th>Before using ICS</th><th>After using ICS</th></tr>
<tr><td>Who collects FW (number of people)</td><td></td><td></td></tr>
<tr><td>How often do collect Firewood per week?</td><td></td><td></td></tr>
<tr><td>Time to collect Firewood (go and return and collection itself) *in Minutes*</td><td></td><td></td></tr>
<tr><td>Type and size of Firewood</td><td></td><td></td></tr>
</table>

(Diameter and length)		
What do you do with the collected Firewood (Storing/ using/selling)		

Firewood preparation / Firewood storage for ICS

23. Please state the process of preparing Firewood for ICS:
24. Do you store it before usage? If yes where and how?
25. Comparing to the times when you used 3 stone fire, now using ICS what changed regarding firewood storage?

Firewood availability outlook

26. From where do you obtain your firewood?
27. Regarding the future, do you see any problems in the availability of firewood?

If yes, how do you cope with that issue?

28. If yes, what are in your opinion the reasons for the decrease of firewood availability in the village?
29. What will change concerning the firewood situation of the village if the members of the village would own and use an ICS?
30. What else should be done to improve the firewood situation in the village or reduce pressure on wood resources?

Appendix 3: KPT Quantitative Data Assessment January 2016 - 3 stone fire Protocol

Kitchen Performance Test: Quantitative Data Collection

Cooking device tested: 3 stone fire

Testing date: 17.01.2016 – 20.01.2016

Data collection site: Idifu

Subvillage:

Minutes of the testing procedure:

Date of Measurement:

Name of the enumerator:

Tree species used as Firewood (Name):

Moisture Content of the Firewood (% - wet basis):

Preparations BEFORE the start of the cooking process

Comments:

1. Welcome and request of taking part in the cooking procedure. Quick introduction of the tools used (Scale, temperature measure device, etc.)
2. Testing site is inspected. Influencing factors like other firewood is removed from the testing site.
3. General Data

   Household ID and Name of Head of Household:

   Name of Cook (the one who cooks normally):

   Age of the cook:

   Gender of the cook:

   Number of Household members:

4. Measure size of pot in cm. Diameter: Height:
5. Outside Temperature is measured in C° :
6. Environmental conditions are stated (sun/ clouds/ rain /wind speed?):
7. Member of another UPS (if yes, which):
8. Measured pile of Firewood is handed over to the cook, and should be ONLY used during the cooking procedure (in gram):
9. Amount and state of ingredients for the cooking test are measured:

Pot 1		Pot 2	
Ingredients	Amount (gram)	Ingredients	Amount (gram)

10. Measure the temperature of the water in the first pot before ignition of the fire if applicable (in C°):
11. Measure the temperature of the water in the second pot before ignition of the fire if applicable
    (in C°):

Beginning of the cooking process

Comments:

12. If everything is prepared the cooking of the meal can start:
    State starting time here:
13. Time from ignition until water is boiling in the first pot
    (State time here): …………………………
14. Time when the first pot is finished cooking:…………………………………….
15. State time when the second pot is put on the fire:
    ……………………………………………..
16. Time is stopped when second pot is finished:
    (State time here): ……………………………………………………………
17. Total amount of cooking time (in minutes):
    ……………………………………………………

AFTER the cooking is finished

18. All the remaining firewood and charcoal is collected and measured after finishing cooking
    (in gram):

Comments:

………………………………………………………………………………………

………………………………………………………………………………………

Appendix 4: KPT Qualitative Data Assessment January 2016 - 3 stone fire Protocol

Kitchen Performance Test: Qualitative Data Collection

Cooking device tested: 3 stone fire

Testing date: 17.01.2016 – 20.01.2016

Data collection site: Idifu

Subvillage:

General Data

1. Testing Date:
2. Household ID and Name of Head of Household:
3. Name of Cook (the one who cooks normally):
4. Age of the cook:
5. Gender of the cook:
6. Number of Household members:
7. Member of another ICS group:

Market potential / further dissemination of the technology

8. How many times do you cook per day (with fire source):
9. What time of the day do you use 3SF? (Yes/ NO):

   Morning…………….. Lunch………………….. Dinner……………….. Others…………….

Adoption of ICS technology

10. Think about ICS which does fit all your expectations. How much are you willingness to pay for that ICS? (in TSH)
11. What are your reasons not to adopt the new ICS technology?

Health condition of 3 stone fire users

12. Does the utilization of 3 stone fire have any influence on the health condition of your family?

    If yes, how?:

Firewood collection pattern

13. How much firewood do you purchase per month (in TSH)?
14. Who collects Firewood (number of people)?
15. How often do you collect FW per week?
16. How much time do you spend on collecting FW?

Firewood preparation / Firewood storage for 3 stone fire stove

17. What do you do with the collected Firewood (Storing, using, selling, etc.):
18. Where do you store your collected FW:
19. How long do you store your firewood before using:
20. Comparing to the past, do you now store more Firewood or less Firewood? Why?:

Firewood availability outlook

21. From where do you obtain your firewood?
22. Regarding the future, do you see any problems in the availability of firewood?

    If yes, how do you cope with that issue?

    If yes, what are in your opinion the reasons for the decrease of firewood availability in the village?
23. What will change concerning the firewood situation of the village if all the members of the village would own and use an ICS?
24. What else should be done to improve the firewood situation in the village or reduce pressure on wood resources?

Appendix 5: KPT Quantitative and Qualitative Data Assessment February 2016 – "old" and "new" Improved Cooking Stoves Protocol

Kitchen Performance Test: Quantitative and Qualitative Data Collection

Cooking device tested: New and old Improved Cooking Stoves

Testing date: 26.02.2016 – 01.03.2016

Data collection site: Idifu

Subvillage:

Minutes of the testing procedure:

Type of Improved Cook Stove (new / old):

Name of the Enumerator:

Date of Measurement:

Tree species used as Firewood (Name):

Moisture Content of the Firewood (% - wet basis):

---

1. Measurements of the stove (in cm):
   Height:

   Length:

   Width:
2. Type of connection channel between big and small pot (diagonal / horizontal)_
3. Diameter of the wood entry slot (in cm):
4. Distance between the bottom of the combustion chamber and the bottom of the 1st pot:
5. Distance between the bottom of the combustion chamber and the bottom of the 2nd pot:
6. Height and diameter of the 1st pot:
7. Height and diameter of the 2nd pot:
8. Diameter of the connection channel between pot 1 and 2 (in cm) :
9. Construction: Gaps between pot and wall – is there enough space for hot air to flow:
10. State other improvements compared to the old ICS design (if applicable):
    ……………………………………………………………………………………

    …………………………………………………………………………………….
11. Step: General Data
    Household ID and Name of Head of Household:

    Age of head of Household:

Name of Cook (the one who cooks normally):

Age of the cook:

Gender of the cook:

Number of Household members:

12. Step: Environmental conditions are stated (sun/ clouds/ rain /wind speed?):
13. Type of food to be cooked (slow or fast cooking)
14. Direction of chimney (horizontal or vertical)
15. Amount and state of ingredients for the cooking are measured (in Gram) the ingredients are measured before cooking:

1 Pot		2 Pot	
Ingredients	Amount (in gram)	Ingredients	Amount in (gram)

Beginning of the cooking process:

(Task: During cooking the pot should be always covered).

16. Stove area has to be cleaned and all other charcoal and FW has to be removed.
17. Preparation of firewood (resizing, time spent in minutes):
18. Firewood weight before starting (in Gram):

State in detail the steps 16 -18:

……………………………………………………………..

19. Time when fire in the stove is ignited:

20. Time when water is boiling in the first pot:

21. Water boiling in second pot? Yes >> time when: No >> please mark:

State in detail the steps 19-21 (pots are covered, when was the food put in the pot):………………………………………………………………………………… …………………………………………………………………………………………

22. Time when 1 Pot is finished:
23. Time when 2 Pot is finished:

24. Calculate total cooking time for 1 Pot (in minutes):
25. Calculate total cooking time for 2 Pot (in minutes):
26. During the cooking process, did you apply the firewood saving brick (yes/no)?
27. The remaining firewood AND the remaining charcoal are collected and measured (in gram):

Firewood at start (in gr)	Firewood remaining (in gr)	Charcoal remaining (gr)	Total Firewood used (gr)

Describe the cooking process (especially the order of preparation of ingredients and time when the ingredients were added).

Were the beans soaked before cooking (yes / no): If yes, how long:

Was the rice roasted before cooking (yes / no):

When was the maize meal (ugali) mixed with the water (in the beginning or after the water was boiling)?......................................

Qualitative Questions

1. What time of the day do you use ICS? (Yes/ NO)

Morning…………….. Lunch………………….. Dinner……………….. Others…………….

2. Which cooking devices do you use besides ICS (Which meal)?.................................

3. Think about an ICS which does fit all your expectations. How much are you willing to pay for that ICS? (in TSH) ……………................

4. How much firewood do you purchase per month (in TSH)?..

5. Who collects firewood in your family (No of persons)?......................................

6. How often do you go per week to collect FW?..

7. How much time do you spend on collecting FW (in Minutes)?....................................

Appendix 6: SPSS printouts

Appendix 6.1: Cooking task: Rice and Vegetables

Time spent to cook 1000 gram of ingredients
Firewood used in gram per ingredient used in gram
Total firewood used in gram
Total time of cooking in min
25, 50, 75 Percentiles of best performers

Descriptive Statistic

Type of stove			Time spent to cook 1000 g of ingredients	Firewood used per ingredient used	Total firewood used in gram	Total cooking time in minutes
ICS	N	Valid	19	19	19	19
		Missing	0	0	0	0
	Mean		21.6967	.4637	1375.68	60.32
	Standard Deviation		8.14283	.22515	792.352	13.614
	Percentiles	25	15.1875	.2955	878.00	50.00
		50	19.0476	.4058	1160.00	58.00
		75	27.6753	.6702	1710.00	72.00
3SF	N	Valid	19	19	19	19
		Missing	0	0	0	0
	Mean		27.5769	.6946	2187.52	82.42
	Standard Deviation		12.12516	.26329	878.967	28.275
	Percentiles	25	18.8462	.4842	1500.00	61.00
		50	25.5521	.5678	1838.00	79.00
		75	35.1213	.9707	2955.00	106.00

Shapiro-Wilk to test for normal distribution of samples: Firewood used in gram per ingredient used in gram

Test of Normality

	Code STOVE 1 = ICS; 2 = 3SF	Shapiro-Wilk		
		Statistic	df	Sig.
Firewood used in gram per ingredient in gram	ICS	.889	19	.031
	3SF	.898	19	.045

Mann-Whitney U-test for non parametric test samples (homoscedasticity): Firewood used in gram per ingredient used in gram

Test Statistics (b)

	Firewood used in gram per ingredient in gram
Mann-Whitney U	87.000
Wilcoxon W	277.000
Z	-2.730
Asymp. Sig. (2-tailed)	.006
Exact Sig. [2*(1-tailed Sig.)]	.006(a)

a Not corrected for ties.
b Grouping Variable: Code STOVE 1 = ICS
2 = 3SF

Shapiro-Wilk test to test for normal distribution of samples: Time used to cook 1000 g of ingredients

Tests of Normality

	Type of stove	Shapiro-Wilk		
		Statistic	df	Sig.
T1_Time_used_per_1000 g of ingredients	ICS	.916	19	.096
	3SF	.944	19	.314

T-test of independent test samples: Time used to cook 1000 g of ingredients including Levene's test for equality of variances

t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference
Time spend to cook 1000 g of ingredients	Equal variances assumed	3.344	.076	-1.755	36	.088	-5.88019
	Equal variances not assumed			-1.755	31.492	.089	-5.88019

Appendix 6.2: Cooking task: Beans and rice

Time spent to cook 1000 g of ingredients
Firewood used in gram per ingredient used in gram
Total firewood used in gram
Total time of cooking in min
25, 50, 75 Percentiles of best performers

Descriptive Statistic

Type of stove			Time spent to cook 1000 g of ingredients	Firewood used per ingredient used	Total firewood used in gram	Total cooking time in minutes
ICS	N	Valid	19	19	19	19
		Missing	0	0	0	0
	Mean		22.7102	.5891	3576.21	138.79
	Standard Deviation		7.79170	.24001	695.812	23.112
	Percentiles	25	16.4572	.4942	3003.00	121.00
		50	22.8449	.5573	3674.00	135.00
		75	26.9131	.6599	4000.00	160.00
3SF	N	Valid	19	19	19	19
		Missing	0	0	0	0
	Mean		30.7529	.6629	4241.47	179.74
	Standard Deviation		14.19326	.20873	1539.801	43.324
	Percentiles	25	21.8783	.4950	2878.00	154.00
		50	28.3929	.6831	4500.00	173.00
		75	34.8284	.7655	5300.00	215.00

Shapiro-Wilk test to test for normal distribution of samples: Firewood used in gram per ingredient used in gram

Test of normality

	Type of stove	Shapiro-Wilk		
		Statistic	df	Sig.
Firewood_used_per_ingredient	ICS	.762	19	.000
	3SF	.933	19	.195

* This is a lower bound of the true significance.

Mann-Whitney U-test for non parametric test samples (homoscedasticity): Firewood used in gram per ingredient used in gram

Ranks

	Code STOVE 1 = ICS 2 = 3SF	N	Mean Rank	Sum of Ranks
Firewood used in gram per ingredient cooked in gram	ICS	19	16.63	316.00
	3SF	19	22.37	425.00
	Total	38		

Test Statistics (b)

	Firewood used in gram per ingredient cooked in gram
Mann-Whitney U	126.000
Wilcoxon W	316.000
Z	-1.591
Asymp. Sig. (2-tailed)	.112
Exact Sig. [2*(1-tailed Sig.)]	.116(a)

a Not corrected for ties.

b Grouping Variable: Code STOVE 1 = ICS; 2 = 3SF

Shapiro-Wilk test to test for normal distribution of samples: Time used to cook 1000 g of ingredients

Tests of Normality

	Type of stove	Shapiro-Wilk		
		Statistic	df	Sig.
Time spend to cook 1000 g of ingredients	ICS	.912	19	.082
	3SF	.831	19	.003

Mann-Whitney U test for non parametric test samples (homoscedasticity): Time used to cook 1000 g of ingredients

Ranks

	Code STOVE 1 = ICS 2 = 3SF	N	Mean Rank	Sum of Ranks
Time spend to cook 1000 g of ingredients	ICS	19	15.63	297.00
	3SF	19	23.37	444.00
	Total	38		

Test Statistics (b)

	Time spend to cook 1000 g of ingredients
Mann-Whitney U	107.000
Wilcoxon W	297.000
Z	-2.146
Asymp. Sig. (2-tailed)	.032
Exact Sig. [2*(1-tailed Sig.)]	.032(a)

a Not corrected for ties.

b Grouping Variable: Code STOVE 1 = ICS; 2 = 3SF

Appendix 6.3: Comparison of “old” and “new” ICS stoves

Total firewood used in gram per stove type
Time spent to cook 1000 g of ingredients per stove type
Total time of cooking in min per stove type
Firewood used in gram per ingredient used in gram (equivalent dry matter) per stove type
25, 50, 75 Percentiles of best performers per stove type

Descriptives

Type of stove used			Total firewood used in gram	Time spent to cook 1000 g of ingredients	Total_Time_of_Cooking_Pot_1_2	Firewood used per ingredient used (equivalent dry matter)
old	N	Valid	27	28	28	26
		Missing	1	0	0	2
	Mean		1204.2222	10.1359	32.4286	.2064
	Standard Deviation		378.04938	3.69406	10.39383	.10443
	Percentiles	25	921.0000	7.3047	25.2500	.1191
		50	1038.0000	9.7014	29.5000	.1946
		75	1468.0000	12.9142	39.7500	.2707
new	N	Valid	36	36	36	36
		Missing	0	0	0	0
	Mean		1169.7778	9.4097	28.6944	.2096
	Standard Deviation		245.97632	2.78310	8.23518	.08393
	Percentiles	25	1017.5000	7.1733	21.2500	.1488
		50	1152.0000	9.4482	29.0000	.2082
		75	1334.0000	11.6833	33.7500	.2996

ICS performance of „new“ and “old” ICS combined

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Firewood used per ingredient used (equivalent dry matter)	62	.06	.45	.2083	.09227
Time spent to cook 1000 g of ingredients	64	4.38	17.74	9.7274	3.20677
Total firewood used in gram (wet basis)	63	614.00	2362.00	1184.5397	307.22251
Total_Time_of_Cooking_Pot_1_2	64	17.00	56.00	30.3281	9.35211
Firewood consumption (dry basis)	62	236.99	1596.18	632.5697	245.09918

Shapiro-Wilk test to test for normal distribution of samples: Different stove dimensions

Tests of Normality

			Type of ICS (new/old)	
			new	old
Sig.	Shapiro-Wilk	Stove height in cm	.000	.013
		Stove length in cm	.000	.000
		Stove width in cm	.323	.000
		Diameter of the wood entry slot (in cm)	.001	.000
		Distance between the bottom of the combustion chamber and the bottom of the 1 pot	.000	.047

Mann-Whitney U-test for non-parametric samples (homoscedasticity): Different stove dimensions

Ranks

	Stove-height in cm	Stove-length in cm	Stove-width in cm	Diameter of the wood entry slot in cm	Distance between the bottom of the combustion chamber and the bottom of the 1 pot
Mann-Whitney U	28.000	200.000	113.00	336.000	170.000
Wilcoxon W	694.000	866.000	779.00	742.000	836.000
Z	-6.582	-3.873	-5.315	-2.307	-4.551
Asymp. Sig. (2-tailed)	.000	.000	.000	.021	.000

a Grouping Variable: Type_stove_1old_2new

Shapiro-Wilk test to test for normal distribution of samples: Equivalent dry firewood consumption per ingredient used

Tests of Normality

	Type of stove	Shapiro-Wilk		
		Statistic	df	Sig.
Firewood used per ingredient used (equivalent dry matter)	old	.924	26	.056
	new	.942	36	.058

Levene’s test to test for equality of variances and t-test to test for equality of means: Equivalent dry firewood consumption per ingredient used

t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Equivalent dry firewood in gram per total ingredients used in gram	Equal variances assumed	.584	.448	-.137	60	.892
	Equal variances not assumed			-.132	46.53	.896

Shapiro-Wilk test for normal distribution of samples: Time spent to cook 1000 g of ingredients

Tests of Normality

		Shapiro-Wilk		
	Type_stove_1old_2new	Statistic	df	Sig.
Time spent to cook 1000 g of ingredients	old	.940	28	.107
	new	.981	36	.784

* This is a lower bound of the true significance.

Levene's test to test for equality of variances and t-test to test for equality of means: Time spent to cook 1000 g of ingredients

t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Time spent to cook 1000 g of ingredients	Equal variances assumed	2.239	.140	.897	62	.373
	Equal variances not assumed			.866	48.769	.390

ANOVA analysis between different groups of SC and time spent to cook 1000 g of food

Descriptive Statistic: Time spent to cook 1000 g of ingredients and Specific Firewood consumption

Descriptive Statistic

	Group size	N	Mean	Standard Deviation
Time spent to cook 1000 g of ingredients	small	19	11.2812	2.97956
	medium	30	9.7602	2.86504
	large	15	7.6938	3.18560
Specific firewood consumption	small	19	.2452	.10467
	medium	29	.2162	.07388
	large	14	.1417	.07826

Shapiro-Wilk test to test for normal distribution of sample: Different amount of ingredients (3 groups)

Tests of Normality

	Group size	Shapiro-Wilk		
		Statistic	df	Sig.
Time spent to cook 1000 g of ingredients	small	.947	19	.350
	medium	.946	29	.145
	large	.825	14	.010
Specific firewood consumption	small	.936	19	.224
	medium	.967	29	.481
	large	.850	14	.022

Levene‘s test to test for equality of variances (homoscedasticity): Different amount of ingredients (3 groups)

t-test

	Levene’s Statistic	df1	df2	Sig.
Time spent to cook 1000 g of ingredients	.116	2	61	.891
Specific firewood consumption	1.884	2	59	.161

ANOVA table

Descriptive statistic

		Sum of Squares	df	Mean Square	F	Sig.
Time spent to cook 1000 g of ingredients	Between Groups	107.933	2	53.966	6.097	.004
	Within Groups	539.918	61	8.851		
Specific firewood consumption	Between Groups	.090	2	.045	6.160	.004
	Within Groups	.430	59	.007		

Post hoc test: Bonferroni to test for significant differences between the groups

Post hoc test

Dependent Variable	(I) Groups_based_on_amount_of_food	(J) Groups_based_on_amount_of_food	Mean Difference (I-J)	Standard Error	Sig.
Time spent to cook 1000 g of ingredients	small	medium	1.52099	.87229	.259
		large	3.58733(*)	1.02758	.003
	medium	small	-1.52099	.87229	.259
		large	2.06634	.94080	.096
	large	small	-3.58733(*)	1.02758	.003
		medium	-2.06634	.94080	.096
Specific firewood consumption	small	medium	.02895	.02519	.765
		large	.10345(*)	.03006	.003
	medium	small	-.02895	.02519	.765
		large	.07450(*)	.02777	.028
	large	small	-.10345(*)	.03006	.003
		medium	-.07450(*)	.02777	.028

* Differences at a level of significance of 0.05.

Appendix 6.4: Frequency of firewood collection

Frequency of firewood collection per household member per week. ICS vs 3 stone fire

Descriptive statistic

ICS	N	Valid	45
		Missing	6
	Mean		**.5368**
	Standard Deviation		.37974
	Variance		.144
3 stone fire	N	Valid	15
		Missing	5
	Mean		**.7146**
	Standard Deviation		.37185
	Variance		.138

Shapiro-Wilk test to test for normal distribution of samples: Frequency of collecting firewood per household member per week

Tests of Normality

	Type_cooking_device	Shapiro-Wilk		
		Statistic	df	Sig.
Firewood collection per household member per week	ICS	.832	45	.000
	3 stone fire	.863	15	.026

Mann-Whitney U-test for non-parametric samples (homoscedasticity): Frequency of collecting firewood per household member per week

Ranks

	Type_cooking_device	N	Mean Rank	Sum of Ranks
Frequency of collecting firewood per household member per week	ICS	45	27.64	1244.00
	3 stone fire	15	39.07	586.00
	Total	60		

Test Statistics(a)

	Frequency of collecting firewood per household member per week
Mann-Whitney U	209.000
Wilcoxon W	1244.000
Z	-2.202
Asymp. Sig. (2-tailed)	.028

a Grouping Variable: Type_cooking_device

Descriptive Statistic: Amount of firewood collected per household per year

Descriptive statistic

Type_cooking_device			Amount of firewood collected per household per year
ICS	N	Valid	43
		Missing	6
	Mean		2690.6977
	Standard Deviation		1690.60344
	Minimum		520.00
	Maximum		8320.00
	Percentiles	25	1560.0000
		50	2080.0000
		75	4160.0000
3 stone fire	N	Valid	15
		Missing	3
	Mean		3882.6667
	Standard Deviation		1745.42449
	Minimum		520.00
	Maximum		6240.00
	Percentiles	25	3120.0000
		50	3640.0000
		75	6240.0000

Descriptive Statistic: Household members per stove technology (ICS and 3 stone fire stoves)

Descriptive Statistic

ICS	N	Valid	49
		Missing	0
	Mean		5.2857
	Standard Deviation		2.30036
	Minimum		1.00
	Maximum		11.00
3 stone fire	N	Valid	18
		Missing	0
	Mean		5.5000
	Standard Deviation		1.82305
	Minimum		2.00
	Maximum		9.00

Appendix 6.5: Willingness to pay for ICS

Descriptive Statistic: Willingness to pay for ICS in Idifu (N = 67), KPT test in January and February 2016

ICS	N	Valid	49
		Missing	0
	Mean		8081.6327
	Standard Deviation		4872.69918
	Minimum		.00
	Maximum		20000.00
3 stone fire	N	Valid	18
		Missing	0
	Mean		4833.3333
	Standard Deviation		4409.21495
	Minimum		.00
	Maximum		20000.00

Shapiro-Wilk test to test for normal distribution of test samples: Willingness to pay

Tests of Normality

	Type of stove	Shapiro-Wilk		
		Statistic	df	Sig.
Willingness_to_pay_for_ICS_in_TSH	ICS	.930	49	.006
	3 stone fire	.709	18	.000

Mann-Whitney U-test for non parametric test samples (homoscedasticity): Willingness to pay

Ranks

	Type_cooking_device	N	Mean Rank	Sum of Ranks
Willingness_to_pay_for_ICS_in_TSH	ICS	49	37.97	1860.50
	3 stone fire	18	23.19	417.50
	Total	67		

Test Statistics(a)

	Willingness_to_pay_for_ICS_in_TSH
Mann-Whitney U	246.500
Wilcoxon W	417.500
Z	-2.811
Asymp. Sig. (2-tailed)	.005

a Grouping Variable: Type_cooking_device

Appendix: 6.6: Biomass growth: Laikala (Intercropping)

Shapiro-Wilk test to test for normal distribution of samples: Tree samples Laikala (plot 1 and plot 2)

Tests of Normality

	Plot_No	Shapiro-Wilk		
		Statistic	df	Sig.
Foliage_Biomass_gram	1	.922	87	.000
	2	.960	56	.062
Woody_Biomass_gram	1	.855	87	.000
	2	.954	56	.031

Mann-Whitney U-test for non parametric test samples (homoscedasticity): Tree samples Laikala (plot 1 and plot 2)

Ranks

	Plot_No	N	Mean Rank	Sum of Ranks
Foliage_Biomass_gram	1	93	66.11	6148.00
	2	63	96.79	6098.00
	Total	156		
Woody_Biomass_gram	1	90	54.14	4872.50
	2	61	108.25	6603.50
	Total	151		

Test Statistics (a)

	Foliage_Biomass_gram	Woody_Biomass_gram
Mann-Whitney U	1777.000	777.500
Wilcoxon W	6148.000	4872.500
Z	-4.163	-7.461
Asymp. Sig. (2-tailed)	.000	.000

a Grouping Variable: Plot_No

Appendix: 6.7: Biomass growth: Mlali Woodlot

RCD and tree height of several tree species assessed. Data assessment in February 2016.

Tree_species		N	Minimum	Maximum	Mean	Standard Deviation
Grevillea robusta	Root_collar_Diameter_mm	107	14.10	90.90	38.0430	11.89600
	Tree height_cm	107	112.00	400.00	223.3084	58.61071
Senna siamea	Root_collar_Diameter_mm	75	18.50	56.30	33.2600	8.45030
	Tree height_cm	75	80.00	370.00	195.2800	45.14887
Melea azadareats	Root_collar_Diameter_mm	21	12.20	45.30	28.9476	10.70512
	Tree height_cm	21	100.00	280.00	189.0952	50.61413

Affirmation

I hereby declare that the present thesis has not been submitted as a part of any other examination procedure and has been independently written. All passages, including those from the internet, which were used directly or in modified form, especially those sources using text, graphs, charts or pictures, are indicated as such. I realize that an infringement of these principles which would amount to either an attempt of deception or deceit will lead to the institution of proceedings against myself.

Date Signature