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ORIGINAL ARTICLE

Traditional biomass energy consumption and the potential introduction of firewood efficient stoves: insights from western Tanzania

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Abstract Having access to firewood and charcoal for cooking purposes is essential for the world's poor. In this paper, we outline the consumption patterns of firewood and charcoal energy recorded at a specific south-western Tanzanian village (Laela) based on a household survey carried out in late 2010 ($n = 160$). We identify varying consumption rates among four relative income classes (rich, above average, self-sufficiency, below self-sufficiency). We furthermore simulate the effects of different dissemination levels (10, 25, 50, 100 %) for a specific type of efficient wood stove over the years 2010, 2015 and 2030, with a predicted increase in future energy consumption rates that correspond with population growth. Our findings suggest that energy consumption will increase until 2030. We also foresee excellent energy-saving potentials in different diffusion and adaptation scenarios. The limitations of the study as well as its developmental potentials are also addressed with one focus on the possible effects on local forests. The factors utilised and the results obtained are discussed and compared with other values drawn from the current literature. Furthermore, the pro-poor development potential is examined by using the energy-saving capacity of different dissemination/adaptation scenarios. Additionally, hurdles and hypothetical setbacks that may occur during the process of efficient stove dissemination are described. In sum, our findings highlight the need for efficient stove diffusion programmes to carefully incorporate weaker income classes within rural communities.

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Introduction

Energy is central to poverty alleviation and a key requirement for socio-economic development (Bazilian et al. 2012). In this regard, traditional bioenergy accounts for more than 90 % of consumed energy in the rural areas of developing countries (Hartter and Boston 2007; Martin et al. 2009) such as Tanzania (Brew-Hammond 2010; Peter and Sander 2009; Sosovele 2010). Currently, 40 % of the global population requires biomass as a source of energy for cooking (Maes and Verbist 2012). It is estimated that 2 million tons of biomass are consumed for cooking around the world on a daily basis (World Health Organization 2006). Due to global population growth, the latter amount is projected to increase continuously until 2030 (Brew-Hammond and Kemausuor 2009). In addition, deforestation, including uncontrolled conversion of forests to agricultural land, is continuing at very high rates with Africa and South America being especially affected (FAO 2010). A lack of sufficient cooking energy supply has negative effects on the levels of nutrition (Brouwer et al. 1997; Hartter and Boston 2007; Johnsen 1999; Kees and Feldmann 2011; Tabuti et al. 2003) and the welfare at the household (HH) level (Arnold et al. 2003), since the food types that require simmering (e.g. beans) are less often cooked, or more generally, cooking times need to be reduced. Traditional biomass can subsequently be characterised as the core energy provider for at least two billion people (Howells et al. 2005; von Braun and Pachauri 2006).

The share of Tanzanians using traditional bioenergy has not changed considerably over the past few decades (Kaale 2012). It is estimated that currently 1 million tons of charcoal are consumed nationwide on an annual basis (Peter and Sander 2009), being equal to 6.1 million m^3 of fuelwood or 4.4 million tons of fuelwood (assumptions: 165 kg of charcoal per cubic metre of fuelwood; wood density of 725 kg per m^3 of fuelwood (Drigo 2005)). This is likely to create problems, since charcoal, the cooking fuel of the urban Tanzanian centres (Mwampamba 2007; van Beukering et al. 2007), has been associated with forest degradation and deforestation by several authors (Malimbwi and Zahabu 2008a; van Beukering et al. 2007). On the contrary, Malimbwi and Zahabu (2008b) estimate that 26 million m^3 of fuelwood, as the major energy carrier of the (rural) poor, is consumed annually for domestic purposes (cooking and lighting) in Tanzania alone [18.9 million tons/fuelwood based on values provided by Drigo (2005)]. The impacts of collecting the wood on the local forests are likewise controversially discussed (Arnold et al. 2006; Hiemstra-van der Horst and Hovorka 2009; Kammen and Lew 2005; Maes and Verbist 2012). Nevertheless, both energy carriers represent the same energy source, namely wood. In this context, the overall deforestation rate in Tanzania is high, but information varies greatly depending on the source, with figures ranging from 91,000 to 500,000 ha annually at the turn of the millennium (Abdallah and Monela 2007). The related extent of forest degradation is, according to Burgess et al. (2010), hard to estimate, since most of it has been presented in unpublished case studies, and therefore, "great effort is required to develop a robust understanding of the level of degradation in the woodland and forest resources in Tanzania". Firewood is mainly used for cooking purposes in Tanzania (Hines and Eckman 1993). "Three-stone fires" are traditionally used to consume firewood for cooking purposes. However, since the early 1970s improved cooking stoves, characterised by comparably lower fuel consumption rates, have been promoted and disseminated in developing countries (Manibog 1984). The term "improved cooking stove" refers to a variety of designs which have the common characteristic of improved insulation and controlled oxygen supply (MacCarty et al. 2010). In this context, decreased fuel consumption potentially results in less forest degradation as, theoretically, less fuel is needed for the same activities. An alternative is a change in preparation habits (Kees and Feldmann 2011). Kassenga (1997), for example, describes efficient stoves as the most effective measure for arresting land degradation as well as alleviating the acute energy problem in rural areas. Simon et al. (2012) perceives them as a valuable opportunity to simultaneously improve rural livelihoods and combat climate change. They have also been characterised as innovative low-cost renewable energy technologies suitable for the poor (Karekezi 2002). As reviewed by Kammen and Kirubi (2008), three million improved HH woodstoves were disseminated up until 2004 throughout sub-Saharan Africa, with Tanzania receiving 54,000. Felix and Gheewala (2011) have claimed that the poor distribution of efficient stoves in Tanzania can be attributed to insufficient biomass energy policies and a lack of governmental support. However, as outlined by Barnes et al. (1994), the success of efficient stove programs does depend not only on politically induced availability but also on the financial framework of the distribution programs, close interaction between the designers, producers and users of stoves, the scale of stove production, as well as the funding periods. On the other hand, utilization and adaptation on the ground do depend not only on availability but also on the systems of society and traditions as well as the respective cooking habits (El Tayeb et al. 2003) and the prices for stoves (Adkins et al. 2010).

However, data about Tanzanian bioenergy consumption patterns differ widely and are scarcely available, if at all, especially for case study villages in very remote areas (Menéndez and Curt 2013; Wiskerke et al. 2010). Furthermore, a substantial amount of the available publications dates back to the twentieth century [sometimes even to the 1970s (Fleuret and Fleuret 1978)], even though changes in the physical environment and/or population might have occurred since [cf. overview by Menéndez and Curt (2013)]. For the Rukwa region, no respective data were available.

In response to this research gap, we conducted an in-depth HH survey in the settlement of Laela in western Tanzania in late 2010 ($n = 160$). The first objective of this paper is (1) to assess the traditional fuel consumption patterns of firewood and charcoal for a remote rural Tanzanian settlement with special focus on specific income classes (ICs), since we assumed different energy consumption levels in different groups, and (2) to depict a decrease in firewood consumption by examining different dissemination/utilisation scenarios whereby the effects of a simulated introduction of a specific efficient stove ("StoveTec"; assumed energy savings of 37.5 %) were calculated for the defined income groups. For this purpose, we simulated the diffusion and assumed replacement rates of 10, 25, 50 and 100 % of traditional three-stone fire replacement for StoveTec stoves in the reference year 2010. As third objective (3), we forecast these replacement levels for the years 2015 and 2030, assuming a respective increase in energy consumption with population growth. These target years were chosen to mirror the above-mean population growths in this region. In sum, we provide conservatively calculated energy insights into a very remote region which in 2000/2001 had the lowest rural per capita HH monthly income in mainland Tanzania (Urassa 2010) and forecast the utilization scenarios of efficient stoves by simulating different levels of dissemination as well as population growth levels and subsequently energy consumption. However, no further analysis with respect to reasons for adaptation or non-adaption as well as utilization and non-utilization of efficient stoves was conducted.

Materials and methods

Laela village

The village of Laela is situated in the western Tanzanian Rukwa region close to the Zambian border (latitude: −8.572949; longitude: 32.045885). The mean maximum in the warmest month is 27 °C, and the mean minimum in the coolest month is 12.7 °C, while the mean annual temperature in Southern Rukwa is 21 °C (Brown and Abell 2013). The unimodal precipitation level ranges from 800 to 1,300 mm/year (The World Bank 2007), and the rainy season lasts from October/November to April/May, while the dry season lasts from June to September (Government of Tanzania 2007). Laelas' population is estimated at 5,460 inhabitants living in 1260 HH in five sub-villages (Hoffmann et al. 2014). The main staple food in the region is maize meal [locally known as "Insima" (Tröger 2004)], commonly consumed with beans (Government of Tanzania 2007). Efficient stoves are known in the village, but their overall impact was negligible at the time of the survey. Food is therefore prepared in cooking pots, placed on the traditional three-stone fireplace. Laela is situated in the geological sub-region of the Ufipa plateau (Szilas et al. 2007) which is, according to Urassa (2010), classified as an almost deforested plateau with open grassland vegetation. Accordingly, the few local forested areas left are mainly situated at the hillsides in the north-east of the village. These are increasingly being degraded through wood theft that has recently occurred in the few private forest compartments, as mentioned in a focus group interview (FGI). Additionally, the incremental use of corn cobs as fuel for cooking indicates fuelwood shortages and deforestation and/or forest degradation. The FGI also revealed that charcoal production, brick production, firewood collection and human-induced forest fires are further reasons for deforestation (in order of relevance). Fires are reported to be lit by hunters seeking to chase prey out of the forests. In accordance with Tanzanian bylaws, there is an environmental committee in the village that is responsible for fighting wood theft. However, this committee is not very active, and its resources are very restricted. Societal support for this committee is non-existent, indicating low acceptance and/or low understanding of forest management practices. The regional Miombo forests (Campbell et al. 1996) are generally described as "the most widespread fire-adapted, closed-canopy woodlands in southern and central Africa" (Shackleton 2011). Although several sub-types exist, one common characteristic is the "occurrence on nutrient-poor soils and the dominance of three woody-plant genera (Brachystegia, Julbernardia and Isoberlinia) with an undergrowth of grass and herbs" (Shackleton 2011). In general terms, wood plants in the undisturbed Miombo forests represent up to 98 % of the aboveground woody biomass (Frost 1996).

Methodology

Sampling and income classes

The data presented in this paper is derived from an in-depth HH survey carried out in Laela in late 2010 ($n = 160$) representing a sample size of 12.7 % of the total estimated HHs in the village ($N = 1{,}260$) (Hoffmann et al. 2014). The stratified sampling process is based on the definition of four relative ICs derived from an initial FGI with village representatives, which is described in Hoffmann et al. (2014). This approach was chosen to adequately display different social groups within the village, since this allows the calculation of differentiated consumption patterns according to the respective economic statuses. HH survey data were analysed using SPSS (version 15). We classified and analysed the following ICs: IC1 ("rich"), IC2 ("above average"), IC3 ("self-sufficiency") and IC4 ("below self-sufficiency"), generally corresponding with the classification of Nathaniels and Mwijage (2000) in southern Tanzania. Statistically significant differences between the ICs ($p < 0.05$) were determined by using the t test. Statistically viable sampling could be proven for key variables such as total value of assets per HH member (HHmem) and total savings per HHmem for the differentiation between IC1 and the other ICs (IC2–IC4) (Table 1). Missing answers per respective question resulted in lowered n (complete n per IC are outlined in Table 2). As for both variables, the differences between IC2 and IC4 were clearly visible, and as this classification was suggested by the villagers, we decided to nevertheless base further calculations on the sampled four ICs.

Assessment of traditional fuel consumption patterns

During the data collection in late 2010, HH energy consumption was estimated by interviewees mostly in terms of locally used units, namely bags and buckets for charcoal and headloads for firewood. Those units were recalculated to Standard International (SI) references (kg and subsequently MJ). The applied factors were extracted from a literature review (which will be discussed in the following sections) to result in 28 kg for a bag of charcoal (30.8 MJ/kg), 5.6 kg for a bucket of charcoal (30.8 MJ/kg) and 15 kg for a headload of firewood (18 MJ/kg) as very conservative assumptions. However, these energy consumption values were only derived from HH which reported to use the specific energy (Table 2, row I). Therefore, these values had to be adjusted to be expressive for the whole IC (Table 2, row II).

To display total energy consumption of Laela, the sums of these firewood and charcoal-specific energy consumption rates (IC1–IC4) were multiplied with the respective means of HHmem as determined through the survey [IC1: 7.7 (SD 3.0); IC2: 6.9 (SD 2.1); IC3: 6.1 (SD 2.5); IC4: 5.7 (SD 1.7)] and the total HHs per IC in Laela as determined from village lists (IC1: 160; IC2: 258; IC3: 387; IC4: 455).

As the percentage of ICs in the sample and the percentage of ICs in the village differed, we need to apply a weighting method to calculate the mean-energy consumption for the entire village based on IC-specific weighting factors (IC1: 0.63; IC2: 1.82; IC3: 1.86; IC4: 4.56). Respective mean-energy consumption for the average inhabitant of Laela is 19.0 MJ per capita/day (firewood and charcoal combined). The mean HH size in the village is 6.2 members. Additionally, those results were upscaled from daily to annual consumption levels (365) to simplify comparability with other publications.

Table 1 IC- and HHmem-specific means and SD for key economic variables

	n	Mean▲	SD
Total value of assets per HHmem [in Tanzanian Shilling (TSh.)]			
IC1	30	459.450[a]	1,157.396
IC2	27	93.000[b]	134.979
IC3	59	28.720[b]	33.134
IC4	32	7.240[b]	11.960
Total savings per HHmem (in TSh.)			
IC1	29	326.566[a]	829.903
IC2	25	63.610[b]	123.951
IC3	62	12.963[b]	21.336
IC4	33	2.001[b]	2.908

▲ Within this row, different superscript letters denote significant differences ($p < 0.05$) between different values

Incorporation of dissemination/utilization scenarios

Starting from this annual baseline of IC-specific total energy consumption for firewood and charcoal for the survey year 2010 in Laela, we simulated the potential energy-saving effects brought about by substituting the traditional three-stone fire method with a "StoveTec" wood stove and skirt—the model selected to calculate the effects of introducing efficient stoves for the consumption of firewood. Although the importance of charcoal in Laela is undisputable, examining the introduction of charcoal-efficient stoves or efficient kiln technology lies beyond the scope of this paper. The "StoveTec" stove is defined by MacCarthy et al. (2010) as "a lightweight engineered rocket stove mass-produced in China". However, based on

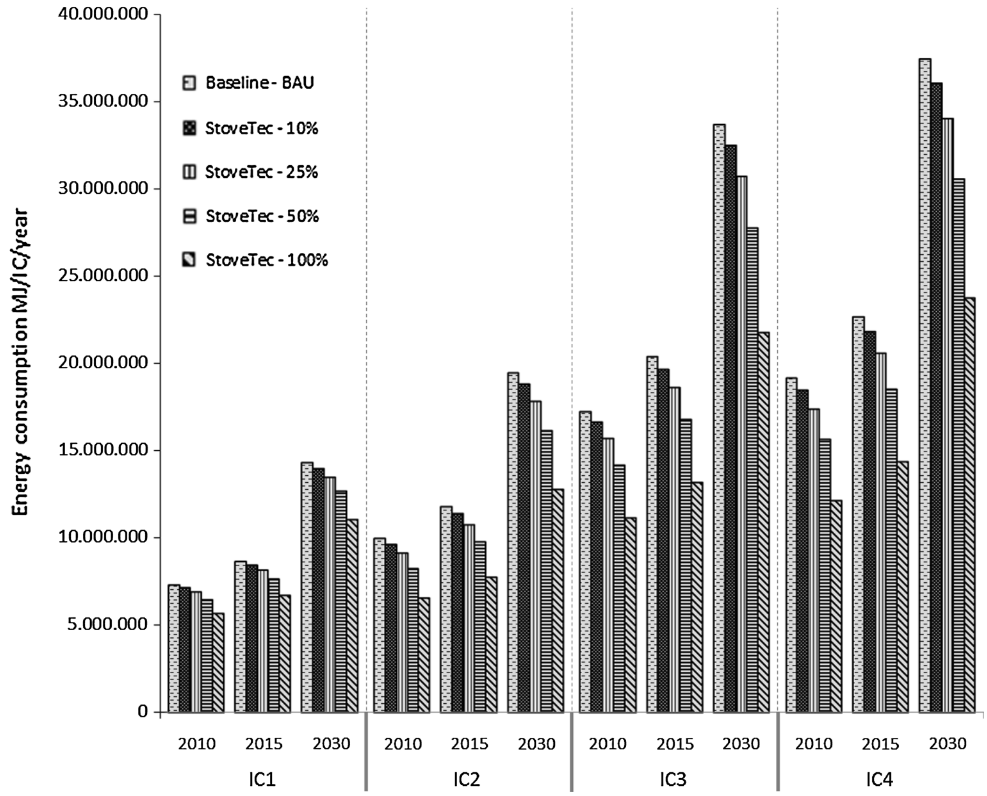
Table 2 Calculation pathway of IC- and HHmem-specific mean daily cooking energy consumption in MJ in Laela 2010

Row	Sample n	I HHs using a specific energy source (total number/percentage of sample n) (%)	II▲ Mean* daily energy consumption of energy source per HHmem users in MJ	III Mean daily energy consumption per IC and HHmem in MJ
Firewood				
IC1	32	17/53	18.6[a] (13.1)	9.9
IC2	29	23/79	17.8[a] (8.1)	14.1
IC3	64	58/91	20.8[b] (12.3)	18.9
IC4	36	36/100	19.9[b] (9.2)	19.8
Weighted mean				17.8
Charcoal				
IC1	32	24/75	8.5[a] (7.8)	6.4
IC2	29	8/28	4.7[b] (4.8)	1.2
IC3	64	15/23	4.7[b] (3.7)	1.1
IC4	36	4/11	4.3[b] (6.3)	0.5
Weighted mean				1.2

* Mean values with standard deviation in parenthesis

▲ Within this row, different superscript letters denote significant differences ($p < 0.05$) between different values

Fig. 1 Total annual energy consumption in Laela in different diffusion scenarios per IC in MJ



the saving potentials recorded by Adkins et al. (2010), a firewood fuel saving of 37.5 % was calculated by averaging the recorded savings for maize (41 %) and beans (34 %), both major staple crops in Laela. Villagers judged this model to be superior to others during field trials carried out in central Tanzania using similar dietary patterns (maize and beans) as observed in Laela (Adkins et al. 2010). To display differing levels of dissemination/adaptation success, we calculated additional scenarios for respective substitution percentages (10, 25, 50, 100), mirroring the possible saving ranges (depicted in Fig. 1).

Projections of the saving potentials for 2015 and 2030

We projected a respective saving potential for the years 2015 and 2030 by factoring in a population growth of 3.42 % annually in all the applied scenarios. This factor was derived from the Government of Tanzania's (2006) studies carried out in the Rukwa region. The applied saving factor of 37.5 % (see above) was used only in relation to firewood-specific consumption data. Charcoal was assumed to stay constant in that it only increased in line with population growth. For comparison, the baseline consumption was also forecasted by assuming a "business as usual" (BAU) scenario for the respective years, with energy consumption increase being congruent with population growth.

Results

Assessment of traditional fuel consumption patterns

According to our calculations, the mean annual energy consumption per capita in Laela (as calculated by multiplying the means from Table 2, row III by 365) was 6,930 MJ in 2010 for firewood and charcoal combined (Table 3). There is, however, a clear divergence between the different ICs defined for the village of Laela concerning the respective consumption patterns (Table 3).

In 2010, firewood consumption per HHmem increased as economic status decreased, while charcoal consumption evolved conversely. Especially, remarkable is the sharp drop of charcoal consumption between IC1 and the other ICs (−80 % between IC1 and IC2)—a mean IC4 HHmem consumes only 7.5 % of the charcoal consumed by a mean IC1 HHmem. In contrast, the increase of firewood consumption was comparatively stable for the increase between IC1 and IC2 (+43 %) and from IC2 to IC3 (+33 %). The respective increase from IC3 to IC4, however, is only marginal (+5 %). Nevertheless, the respective firewood consumption of an IC4 HHmem was double that of the consumption rates of an IC1 HHmem (Table 3). The general trend towards higher energy consumption at lower levels of economic status is visible, but

Table 3 Annual mean-energy consumption per HHmem and IC for firewood and charcoal in MJ in 2010

	Firewood	Charcoal	Combined
IC1	3,610	2,334	5,945
IC2	5,161	475	5,636
IC3	6,884	405	7,289
IC4	7,256	175	7,431
Weighted mean	6,489	439	6,927

IC2 represents an outlier in this regard, where the energy consumption decreases slightly.

Incorporation of dissemination/utilization scenarios

As firewood is by far the most important energy source of HHs below or in self-sufficiency status (IC3 and IC4) in 2010, these groups consequently also gain most when examining the simulated introduction of efficient stoves. In Fig. 1, the respective baseline scenarios, the first columns in 2010 per IC and the outlined dissemination/utilisation assumptions are displayed for the year of data collection ("2010").

Projections of the saving potentials for 2015 and 2030

Projections of the baseline scenarios without the introduction of efficient stoves were incorporated in addition to these assumptions associated with the time of the survey ("2010"), (BAU; the first column in 2015 and 2030). Similarly, the effects of a simulated introduction of the efficient stoves for the different diffusion scenarios ("StoveTec") are outlined for 2015 and 2030 in terms of the amount of MJ consumed by HHs in Laela and differentiated in ICs (Fig. 1).

The energy consumption substantially increases over time for all ICs. The positive effects of StoveTec introduction are therefore clearly visible. However, the respective introduction scenarios reduce the required cooking energy required, with highest saving potential particularly evident among IC3 and IC4. For IC4, for example, the saving potential doubles from a total of 7 million MJ/year in 2010 to 13.7 million MJ/year in 2030 when the baseline scenario/BAU and 100 % substitution are compared. Although also doubled due to a lower firewood-consumption rate and a lower number of HHs in IC1, the absolute energy-saving potential is relatively low with 1.7 million MJ/year in 2010 compared to 3.3 million MJ/year in 2030. If 18 MJ/kg heating value for firewood is assumed, the respective differences represent the equivalent annual saving potential of 372 t of dry wood for IC4 to 88 t of dry wood for IC1.

The saving potentials for the specific ICs are substantial. Therefore, the combined saving possibilities for all ICs for a given scenario are also remarkable. When a scenario is applied with a lesser distribution/adaptation rate, e.g. 25 %, the combined energy savings in 2010 for all ICs was 4.6 million MJ/year (250 t of wood). In the 2015 scenario, the respective figure reaches 5.4 million MJ/year (300 t of wood) to peak with savings of 8.9 million MJ/year (500 t of wood) in 2030.

In addition to this, it becomes evident that when economically weaker ICs are focused on, the dissemination/adaptation rates need to be much lower when compared to stronger ICs if the same overall savings effects are to be reached. The total energy-saving potential is 3.4 million MJ, for example, if a moderate diffusion/adaptation scenario of 25 % is assumed in 2030 for IC4. If, however, a respective 100 % scenario is applied for IC1, 3.3 million MJ could be saved, although a 100 % dissemination rate requires a greater effort to be reached. Even if a 100 % dissemination/adaptation scenario is applied for IC1 in 2010, less than half of the overall energy could be saved when contrasted to a 50 % adoption scenario for IC4 in the same basis year.

Discussion

Our results show that different socio-economic classes in the village of Laela use different biomass sources in differing quantities to satisfy their cooking energy needs. Furthermore, we could determine that these groups would profit from the introduction of efficient firewood using stoves to various degrees. Additionally, based on their numerical superiority and on their stronger reliance on firewood-energy supply, economically weaker classes would profit more, since the overall energy-saving potential is higher.

As outlined in the methodology, we applied a number of factors drawn from the literature to reach our first objective, which was to calculate energy consumption in the village of Laela. We used explicitly conservative values, although a literature review resulted in a multitude of values for each factor applied, most of them higher than those applied in this study. However, our aim was to carefully describe the status quo, and the possible energy consumption development in Laela, and also to avoid overestimation. The weight of a charcoal bag in literature varies, for example, from 23 to 70 kg (Abdallah and Monela 2007; Johnsen 1999; Kaale 2012; Kimaryo and Ngereza 1988, 1989; Luoga et al. 2000; Malimbwi and Zahabu 2008c; Menéndez and Curt 2013; Mwampamba 2007; Openshaw 1983; Peter and Sander 2009; Sunseri 2005; Wiskerke et al. 2010), while weights of firewood headloads are cited to weigh between 15 and 26 kg (Bwalya 2006; Johnson and Bryden 2012; Malimbwi and Zahabu 2008b; Openshaw 1983; Wiskerke et al. 2010). Furthermore, there is evidence that although the "bag" unit is applied in a variety of studies within the charcoal value chain, a uniform size is yet to be agreed upon, (TaTEDO 2004). The factor for the charcoal-specific "bucket" unit (5.6 kg) was derived from Butz (2013), who reports a ratio of 1:5 between bucket and bag. The range of heating values was comparably small, lying between 28 and 31.8 MJ/kg for charcoal (Maes and Verbist 2012; Malimbwi and Zahabu 2008c; Menéndez and Curt 2013; Openshaw 1983) and 16–22 for firewood (Maes and Verbist 2012; Malimbwi and Zahabu 2008c; Openshaw 1983; Wiskerke et al. 2010).

For the purposes of keeping our values on the conservative side (as described above), we decided to apply a 28 kg weight for a charcoal "bag", as this is also the official weight for the unit in Tanzania (Peter and Sander 2009). The 15 kg weight for a headload was also chosen based on findings from Bwalya (2006) that an average travelling distance for collecting firewood was 5.2 km, which corresponds very closely with the travelling distances outlined by IEA (2006) for the Rukwa region (5.0 km) and the fact that firewood headload weight is greatly dependant on travelling distance. We also assumed a rather stable inter-annual energy consumption level as reported by local experts and in accordance with the findings of Brouwer et al. (1996). This literature-based approach is one possible pathway to derive respective factors. However, we are in coherence with the studies of Mwampamba (2007) and Wiskerke et al. (2010), who, respectively, base their weight assumptions of charcoal bags (30 kg) and firewood headload weight (16 kg) on the available literature.

The calculated total mean-energy consumption per HHmem and year of approximately 7,000 MJ in Laela differs from other sources. Menéndez and Curt (2013), for example, report a total of 4,487 MJ annual energy consumption including firewood (87 %), charcoal (9 %) and, to a lesser extent kerosene (4 %), in a Tanzanian case study. Variations such as these are reasonable. Johnson and Bryden (2012) outline that the domestic wood consumption in sub-Saharan Africa varies by a factor of 15. In Kenya, the given figures range from 300 to 1,200 kg/HHmem/year (energy assumption 18 MJ/kg firewood = 5,400–21,600 MJ/HHmem/year) for example. Brouwer et al. (1997) on the other hand report between 8.1 and 9.9 kg/HHmem/week (energy assumption 18 MJ/kg firewood = 7,581–9,266 MJ/HHmem/year) in central Malawi. Tabuti et al. (2003) report 14 MJ/HHmem/day (5,110 MJ/HHmem/year) from Uganda. In general terms, consumption levels highly depend on the availability of wood. Ishengoma (1987) reports a respective variation of factor three for Tanzania between villages with and without access to forests. However, information on biomass availability and use is scarce and, when available, has wide margins of error. The data are also location specific (Mwandosya and Luhanga 1993). Munslow et al. (1988) describe this phenomenon as "mosaics of varying levels of stress".

Our results show substantial energy savings if StoveTec stoves are to be applied. Consequently, they are also likely to reflect positive effects on the local wood resources, since biomass energy savings can be assumed to decrease local deforestation and/or forest degradation—a benefit that shall be discussed below. However, as detailed local forestry data were not available, we refrained from doing this analysis, since respective literature-based variables are explicitly site specific. The reason for this is that deforestation/forest degradation is always the result of specific human impacts as well as soil, landscape, landscape position and (micro-) climatic influences (Shackleton 2011). As a result, the forest-stock densities outlined in the literature for Miombo forests vary between 13.8 and 140 t/ha (Chidumayo 1991; Luoga et al. 2000; Malimbwi et al. 1994; Malimbwi and Zahabu 2008c; Mwampamba 2007; Shackleton 2011). Isango (2007) summarises the wide span of stand-structure variables as outlined in the literature concerning the Miombo forests in Tanzania, e.g. regarding the density of individuals per hectare (74–1,041), diameter at breast height (DBH) (4.5–65 cm) and canopy cover (20–75 %). In this context, species composition plays a major role, since respective biomass stock, supply and regrowth rates vary considerably (Chidumayo 2013; Kimaro et al. 2011; Shackleton 2011). Finally, if forest area consumption is to be calculated, potential seasonal fluctuations in supply that occur because of dry and wet season variations should be considered.

The respective effects of firewood collection and charcoal production on deforestation and forest degradation are a moot topic. Simon et al. (2012) argues that fuelwood shortages can also be attributed to changes in land rights, forest conservation policies and land-clearing processes. Tabuti et al. (2003) in their case study outline that the majority of collected firewood is composed of dead branches and trees from bushland and/or fallow. Mwampamba (2007) supports this finding, although he highlights the negative impact of charcoal production on deforestation. Gmünder et al. (2014), however, summarise that charcoal production leads to temporal deforestation only, while Zulu and Richardson (2013) called the view of charcoal as being a major cause of deforestation and environmental degradation a "misperception". However, Mugo and Ong (2006) have reported the extensive end-use energy losses during the carbonisation process to be 60–70 %; Kammen and

Lew (2005) outlined the woodfuel equivalent of charcoal to be 4–6 times larger due to this inefficient conversion process. This discussed split in the fuelwood debate has been addressed in detail by Hiemstra-van der Horst and Hovorka (2009), Kammen and Lew (2005), Arnold et al. (2006) and Maes and Verbist (2012) among others. Nevertheless, as outlined above, the village representatives in Laela referred to charcoal and firewood collection as being two of the major contributors to deforestation during a FGI.

Another major factor affecting energy consumption patterns in local Miombo forests is the efficiency of the charcoal earth kilns traditionally used in Laela. The respective range given in the literature varies between 5 and 30 %, with realistic estimations being most likely between 10 and 15 % for untrained producers operating with lowest technology (CAMCO 2014; Felix and Gheewala 2011; Malimbwi and Zahabu 2008c; Menéndez and Curt 2013; Mwampamba 2007; Peter and Sander 2009; Tabuti et al. 2003). These vast differences result from the different uniformity of input material (e.g. size of logs, tree species used), the uniformity of oxygen supply and subsequently the equal burning processes as well as the insulation and finally the professionalism of the charcoal burner. In summary, kiln efficiencies are highly variable, which, according to Wood and Baldwin (1985), “may reflect a normal variation in charcoal making”.

The assumed substitution levels of traditional three-stone fireplaces represent different development pathways. However, dissemination/utilization assumptions below 100 % should be focused on, since the domain of cooking is very traditional and full replacements are rather unlikely in the short term to mid-term due to the fact that technological and behavioural changes are hard to implement (Kees and Feldmann 2011). Munslow et al. (1988) additionally points out the additional benefits of traditional cooking practices as further reasons for non-adaptation, including light production and the repelling of insects. There is nevertheless evidence that owning a more efficient stove increases a woman’s prestige (World Health Organization 2006), which could in turn contribute towards a more widespread adoption. Hence, the total saving potential for a rural settlement is high, underlining the urgency of disseminating efficient stoves into rural settings. So far the hot spots of dissemination have occurred in urban areas. But it is necessary that the same process needs to be “aggressively pursued” in rural settings (Kammen and Kirubi 2008). However, Kammen and Lew (2005) as well as Johnson (2013) point out that successful technology transfer must be supported by appropriate training and education and cannot work in isolation. Efficient stove production is nevertheless easy technology and, according to Barry et al. (2011), consequently easy to adopt. In sum, the continent-wide positive economic benefit of introducing efficient stoves (Hutton et al. 2006) seems also to validate the potential subsidies required for efficient stoves. Those are, according to Adkins et al. (2010), need to increase adaptation rates, although Kammen and Kirubi (2008) report that rural people are already willing to pay for and adopt improved energy services. A general overview of financing models for energy projects has been provided by Bazilian et al. (2012). As technology improves, adaptation costs of charcoal, fuelwood and efficient stove production are likely to drop through to 2030. However, as no data were available, technological developments were not considered in our analysis.

The results differ if the outlined ICs are analysed individually and in detail. The vast majority of charcoal is consumed by IC1 (70 %; Table 2), since charcoal has distinct advantages over firewood (Kimaryo and Ngereza 1989) (Malimbwi and Zahabu 2008c). It is an energy source associated with additional costs and therefore hardly available for ICs other than IC1. On the other hand, firewood, as well as total energy consumption, increases when the economic strength of ICs decreases. The former is due to the unaffordability of charcoal outlined above. The latter is potential also because of the higher efficiency rates of charcoal stoves that are common for charcoal burning, while traditional firewood consumption via three-stone fires represent one of the least efficient conversion options from biomass to heat. Wiskerke et al. (2010) reports efficiency rates of 7–12 % for traditional fuelwood consumption and 11–19 % for charcoal consumption, respectively. MacCarty et al. (2010), on the other hand, found that under laboratory conditions traditional charcoal stoves were as efficient as three-stove fires without including the high-energy losses during the production process of the charcoal.

The IC-specific analysis also revealed that the major benefiters of the StoveTec introduction would be the lower ICs, especially IC3 and IC4. This is not only because of the reduced physical effort and time required to collect firewood, but it also implies potentially higher off-farm income, since more time is freed up for paid activities. Additionally, negative health effects that cooks may suffer due to indoor air pollution are likely to be reduced (MacCarty et al. 2010; World Health Organization 2006). As traditionally women and children are responsible for firewood collection and cooking, these vulnerable and marginalised groups would also benefit from efficient stove introduction efforts in this remote region. Additionally, children freed from these obligations might also be able to spend more time learning, and therefore increase their chances of a full education. In sum, these pro-poor development effects will greatly support lower ICs, particularly IC4 (Fig. 1).

Conclusion

In this paper, we assessed the energy consumption of a specific village in a very remote area of Tanzania where no respective data collection has been carried out to date. We were able to outline the quantitative correlation between the energy sources and energy consumption of the four socio-economic classes making up the population. Since the energy consumption of firewood and charcoal combined will, due to population growths, increase substantially until 2030, our scenarios suggest that considerable energy savings are possible if efficient wood stoves are diffused and used even to a limited extent. This effect becomes even more noticeable at lower income group levels. We therefore suggest that respective projects might be optimised by specifically aiming at income classes with low investment potential, in addition to enhancing efforts to promote stove diffusion programs in rural areas of Tanzania. Benefits of this approach would include improved human welfare as well as a reduction in total energy consumption. However, more research is needed on the ground to evaluate the effects on local forest resources, including the integration of more efficient charcoal production.

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