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Double jeopardy: The dichotomy of fuelwood use in rural South Africa

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HIGHLIGHTS

- ▸ Rural household demand for fuelwood is inelastic inspite of fuelwood scarcity.
- ▸ Electricity is incorporated into household energy mix but is rarely used exclusively.
- ▸ Opportunity-cost of wood collection is discounted by the lack of viable alternatives.
- ▸ Potential for land-use conflicts once communal woodland resources are depleted.

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ABSTRACT

Energy security is central to achieving sustainable development and reducing poverty worldwide. Over 70% of the population of Sub-Saharan Africa, mostly in the rural areas, depend on wood fuel, as firewood or charcoal, to meet their primary domestic energy requirements. This dependence is projected to increase with population growth in the intermediate future, regardless of the implementation of rural electrification programmes.. Fuelwood shortages occur at the localised village level and are a chronic landscape syndrome, becoming more severe over time, with increasing population pressures and competing land-uses. In the South African context, the provision of electricity to rural households at subsidised rates would be expected to provide a viable alternative to fuelwood under conditions of scarcity. This paper compares the fuelwood consumption strategies of households in a fuelwood-scarce environment against those in fuelwood-abundant environment in order to illustrate the inelastic nature of the demand for fuelwood in rural communities, even in the face of severely depleted wood stocks. We seek to understand the mechanisms that households implement to ensure household fuelwood/energy security and how these responses aggregate at the landscape level to shape landscape dynamics. This will aid better planning of intervention policies in the future.

1. Introduction

Household energy security is an essential aspect of poverty reduction amongst the vulnerable populations of less developed nations (Pachauri and Spreng, 2004, Starr, 1996). It is an essential building block in almost all socio-economic development activities (Zhang and Fu, 2011) and access to efficient affordable energy services is related to an improvement in human societal welfare (Davis, 1998; Leach and Mearns, 1988). The harsh reality is that a large proportion of the populations of less developed countries exist under conditions of energy poverty, lacking access to energy sources that are "adequate, safe and reliable for economic and human development" (Pereira et al., 2011). For these populations, residing mostly in rural, undeveloped areas, woodfuel either burnt directly as fuelwood or processed to charcoal is the primary source of domestic energy (Karekezi, 2002). In these rural communities household energy is secured at the opportunity cost to the household of time spent usually by females in fuelwood collection (Dovie et al., 2004).

Generally, fuelwood is collected from communal woodlands and agricultural fields around the homestead and/or village depending on the settlement pattern. Fuelwood collection is preferentially of dead and dry branches but as demand increases and begins to exceed the available deadwood resources, live woody stems and branches are cut for fuelwood, and over time this may bring about woodland degradation (Grainger, 1999). Concerns about this and the assumption that fuelwood harvesting would result in widespread deforestation, and therefore a gap between demand for fuelwood and the available supply, gave rise to what was referred to as the "Fuelwood Crisis" in the global energy planning arena in the 1970s (Eckholm, 1975; De Montalambert and Clement, 1983). Entire developing nations were projected to have insufficient woodland

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reserves to meet the needs of their populations as a result of this deforestation (Dewees, 1989). Subsequent and on-going research has shown that fuelwood deficits do not occur at the national level of accounting; rather, fuelwood crises are highly-localised, village-level phenomena (Dewees, 1989; von Maltitz and Scholes, 1995). The definition of a fuelwood crisis is the scarcity of fuelwood of sufficient quality (i.e., long-burning, smokeless, odourless), relative to the needs of the dependent communities (Arnold et al., 2006). This issue should remain within the focus of global concern because of the high dependence on fuelwood in the developing world, currently and well into the immediate future (Aron et al., 1991; Karekezi, 2002; Williams and Shackleton, 2002.

Fuelwood scarcity in Sub-Saharan Africa is a chronic landscape condition (Brouwer et al., 1997). This means that it generally becomes worse over time through woodland loss, as a result of rural agricultural and settlement expansion (Petit et al., 2001) and increasing extractive pressure on the remaining wood stocks for multiple uses (Shackleton and Shackleton, 2000; Twine and Siphugu, 2002). Restricted access to fuelwood implies a loss of societal welfare and the gravity of the situation depends on the ability of households to cope with decreasing levels of fuelwood availability (Arnold et al., 2006). Underpinning the societal implications of these shortages is the own-price demand for fuelwood which is often expressed through the increased opportunity cost of fuelwood collection time (Baland et al., 2010; Cooke et al., 2002) and financial investment through purchasing wood as harvestable fuelwood stocks decrease by the household (Brouwer et al., 1997; Twine et al., 2003). However, rural demand is not very responsive to decreasing fuelwood availability (Arnold et al., 2006) and this has been attributed to a lack of economically viable energy alternatives (Cooke et al., 2002). It is therefore important to understand what factors sustain the demand for fuelwood in situations of scarcity, that is, how and if households adjust their fuelwood consumption strategies to ensure household energy security particularly in economically vulnerable, rural communities. For the purposes of this study, fuelwood consumption was considered to refer to how households access and use fuelwood. The aggregate household responses will determine the impact of the village on the socio-ecological landscape and this depends on a complex interplay of socio-economic conditions, such as local land-use rights, systems of governance (Kaschula et al., 2005) and available alternatives (Brouwer et al., 1997).

In South Africa, the post-Apartheid government implemented an accelerated electrification programme to address the historical developmental imbalances in today's rural areas – the former "homelands" of pre-democracy South Africa (Department of Minerals and Energy, 1998). These are economically and socially marginalised areas that were designated for forced resettlement of indigenous black people by the Apartheid government (Thornton, 2002). The electrification programme increased household access to electricity in the general populace from 36% in 1994 to 74% by 2007 (Department of Minerals and Energy, 2007). However, in the rural areas, the introduction of electricity had little bearing on the demand for fuelwood, as up to 95% of households with access to electricity still use fuelwood as the primary energy choice (Davis, 1998; Madubansi and Shackleton, 2006; Thom, 2000). The cost of electricity relative to the financial income of these households is a major factor preventing households from switching to exclusive use of electricity (Williams and Shackleton, 2002). Madubansi and Shackleton (2006) found that rural households tend to incorporate electricity into their domestic energy mix (primarily for lighting)even though a free basic allowance is granted to them by the national electricity provider, ESKOM, resulting in subsidised electricity tariffs (Davis, 1998; Thom, 2000). Even with decreasing fuelwood availability, households preferentially invest limited financial resources into buying fuelwood rather than electricity in order to meet their domestic energy needs (Davis, 1998; Thom, 2000). This is linked to various socio-economic factors such as the prohibitive costs of monthly tariffs (relative to household incomes) and the costs of purchasing and maintaining the appliances needed to use electricity efficiently (Williams and Shackleton, 2002).

In the context of predicted (Banks et al., 1996) and proven fuelwood shortages (Madubansi and Shackleton, 2007), there is little information as to the mechanisms that rural households and communities in South Africa are adopting to combat shortages. This is relevant in light of the wide-spread introduction of electricity as a domestic energy alternative provided to rural users at a subsidised cost. Determining if and how household fuelwood consumption behaviour changes relative to the availability of the resource in the presence of electricity is pivotal to understanding whether similar interventions could be successfully introduced in other rural communities. This study investigated the strategies that rural households engage in to meet their energy needs under conditions of fuelwood scarcity, where electricity has been made available as an alternative. Specifically, this study compared fuelwood use in two rural villages in the communal lands of the Bushbuckridge rural local municipality which falls in the buffer zone of the Kruger to Canyons Biosphere (K2C) in Mpumalanga Province, South Africa. Welverdiend represents a village under conditions of fuelwood scarcity, while Athol represents village with sufficient fuelwood resources, based on predictions made by a previous study focusing on these two villages (Banks et al., 1996). After comparing the household demographic and socio-economic characteristics of the two villages, this study investigated the strategies households used to ensure domestic energy security with respect to use patterns of fuelwood and identify differences related to fuelwood scarcity and access to electricity. The characteristics of fuelwood collection and the associated opportunity costs relative to the costs of electricity in each village were quantified and compared. This was done with the aim of assessing whether there is a discernable difference in fuelwood consumption characteristics with loss of fuelwood availability. This paper contributes to the dialogue around why the issue of fuelwood scarcity is still highly topical in rural Sub-Saharan African communities, despite over 30 years of discussion and debate around the relevance of the fuelwood "crisis".

The choice of study area for this research is significant. Bushbuckridge has been identified as an Integrated Sustainable Rural Development Programme (ISRDP) node by the national government (RSA, 2000) and was specially mentioned by the Presidency as needing special development intervention (Mbeki, 2001). Under the ISRDP the South African government identified 13 high-poverty priority areas that were underdeveloped but had potential for economic growth and facilitated conditions to upgrade infrastructure and investment (RSA, 2000). As a flagship area, the success of such interventions, including the efficacy of household electrification in improving human wellbeing and stimulating socio-economic development, will determine if similar programmes will be rolled out nationwide (Harmse, 2010). The communal lands within the buffer zone are hemmed in by state and private conservation areas. This effectively makes land in the K2C a high-value, limited resource since it restricts the space available for outward village expansion in line with population growth, as well as increasing pressure on the remaining, ever-shrinking communal woodland space, to provide fuelwood and other essential livelihood resources.

2. Methods

2.1. Study area

The case-study villages Athol (24° 43′S 31° 21′E) and Welverdiend (24° 36′S 31° 07′E) are located in the Bushbuckridge Municipality of

Mpumalanga Province, South Africa (Fig. 1). Economic development is marginalised, unemployment is rife, monetary income is low and human settlements are densely populated with an average range of 150–350 people km^{-2} (Madubansi and Shackleton, 2006). Subsistence agriculture is widely practised, but unlike rural areas across the rest of Sub-Saharan Africa, this is not the mainstay of livelihoods, shortages of land being one of the main factors. Households rely heavily on remittances from migrant household members and on government social grants. The land tenure in the region, as in all former "homelands" is communal; the land falls under the authority of traditional leaders who determine local land use patterns (Shackleton and Shackleton, 2000).Village commons are defined by the boundaries of the original farms upon which the villages were established (Banks et al., 1996) and are fenced off from other neighbouring villages. The communal land is used by village residents for cultivation, grazing for livestock, and harvesting of a wide range of non-timber forest products. State or privately owned conservation initiatives are the next most common land use types in Bushbuckridge for nature conservation, commercial game hunting or eco-tourism.

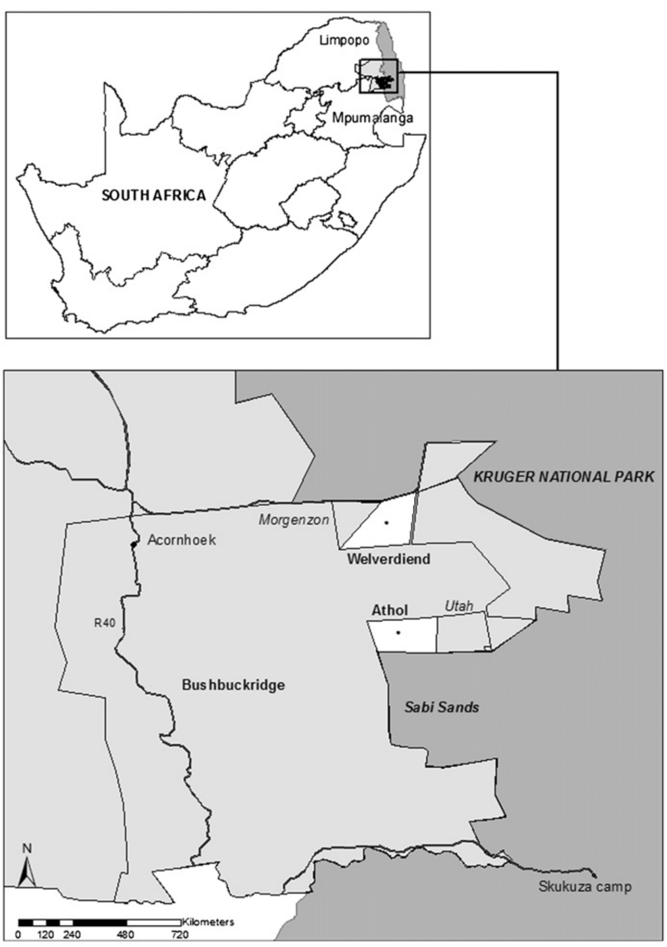

Fig. 1. The locations of Welverdiend and Athol villages, in Bushbuckridge, Mpumalanga Province, South Africa.

The estimated number of households has more than doubled in both settlements since 1992, although to a greater degree in Welverdiend (Table 1). Information on the number of households in each settlement was extracted from data provided by the Bushbuckridge Municipality. Measurements of the spatial extent of the village area were carried out on 2009 aerial photographs of each village in ArcGIS v9.3. Village area is the total area of the residential settlement and village commons. The communal woodlands are under three times the amount of extractive pressure in Welverdiend than in Athol to provide the entire suite of livelihood requirements per unit area of land, including cropland, fuelwood and traditional medicine.

2.2. Biophysical characteristics

The topography of the region is gently undulating with an average altitude less than 600 m above sea level (Shackleton et al., 1994). Soils are underlain by granitic gneiss with local intrusions of gabbro. The vegetation is Mixed Lowveld Bushveld and is mostly dominated by tree species of the *Combretum* and *Terminalia* genera (Rutherford et al., 2006a, 2006b).

Mean annual temperature is 22 °C; rainfall is received during the summer season (October to May), mainly in the form of convectional thundershowers and averages 650 mm annum^{-1} in the west and 550 mm annum-1 in the east along a rainfall gradient and droughts occurring roughly once every decade.

2.3. Data collection and analysis

The household surveys in both Athol and Welverdiend were conducted as part of a larger research project (The Volkswagen Foundation Biomodels Project) studying woody biomass energy use in southern Africa (South Africa, Zambia and Mozambique). Data collection in South Africa was carried out in 2009 between May and August on a per household basis using a structured and semi-structured interview format. Participating households were selected randomly using aerial photographs of the settlements. The questionnaires were administered with the aid of local Xitsonga translators from both villages. If household members were not at home or declined to participate in the survey, another randomly selected household was chosen to replace it and enumerators moved on to the next household on the list. In total, 125 (24%) households were interviewed in Athol and 139 households in Welverdiend; however, irregularities in the interview process by one of the enumerators reduced the Welverdiend sample size to 120 households (8% sampling intensity). Generally the adult females of the household were interviewed as they are most often responsible for the daily household chores requiring energy use and household income expenditure. In the case where there were no adult females available or present the person responsible for these tasks was interviewed regardless of gender.

This study formed part of a larger three-country comparative research project (the BioModels Project, funded by the Volkswagen Foundation) comparing fuelwood consumption behaviour in Zambia, Mozambique and South Africa. In Zambia and Mozambique

Table 1
The spatial extent of the case study villages as given by the total farm area and the actual extent of the communal rangelands related to the number of households in 2009.

Village	Households (1992)	Households (2009)	Village area (ha)	Total woodland area (ha)	Woodland availability (woodland area ha/household)	Woodland extraction pressure (households/ha)
Welverdiend	564	1508	3945	2284	1.52	0.67
Athol	292	517	3432	2208	4.27	0.23

three distinct seasons are recognised: cool, dry season, coinciding with winter (May–August); hot, dry season (August–October) and hot rainy season (November–April). Although the climate in the study area is often described as summer and winter, the authors tested the use of three seasons with focus groups in the study area. Members of the focus groups in both villages recognised a difference in their fuelwood consumption behaviours within the constraints of these seasons. As such these seasons, rather than the traditional winter and summer seasonal divisions were applied in questions in the survey relating to seasonal use of fuelwood.

The first part of the questionnaire provided information on household demographics and income streams through formal and informal employment, remittances and government social grants. Household fuelwood consumption profiles were determined through data concerning frequency and duration of fuelwood collection trips, harvested species and quantities of fuelwood used and collected daily, making allowance for seasonality. The household member responsible for these tasks was asked to set aside a fuelwood pile that represented daily use and this was weighed by the enumerators using a spring balance and recorded in kilograms, accurate to the nearest 0.1 kg, except where the household had no fuelwood available for measurement. The questionnaire also provided information describing the sources of fuelwood used within the household, whether purchased or collected as well as quantities that were purchased per household; data on the use of alternatives particularly electricity as well as cooking habits were also collected. Fuelwood was measured in kilogrammes; households described amounts collected in headloads, wheelbarrows, or *vrag* loads, which corresponds to the carry bin of a pick-up vehicle. The weight of a headload was determined to be 14.5 kg ($n=40$), the weight of a wheelbarrow load 39.6 kg ($n=20$) and the weight of a *vrag* was taken to be 532 kg from Twine et al. (2003), following a study in neighbouring villages within Bushbuckridge. These values were used for all related computations.

Data were captured in Microsoft Excel (MS Excel 2007) and analysed using SAS Enterprise Guide 4.2. For discrete variables the responses were coded and frequency analyses were carried out for each response. Normality of continuous variables was tested using the Kolmogorov–Smirnov test and summary statistics were calculated for all numeric variables; descriptive analyses were carried out for each village separately. Since many of the numeric variables failed the tests for normality the non-parametric Two Sample Wilcoxon tests were used for the comparative analyses of household demographic and fuelwood collection and consumption characteristics between villages. Comparisons of categorical data between the villages were tested for significance using Chi-Squared tests although for ease of interpretation the results may be reported in terms of percentage values in each village.

Average daily household fuelwood consumption was tested for significant differences between seasons and between villages by Two-Way Analysis of Variance (ANOVA). The annual fuelwood consumption (kg/household/annum) was calculated by summing the daily use values as given for each season. Log-transformation was carried out on the annual household use values and thereafter a 2-way Analysis of Variance (ANOVA) was carried out to test the significance of village and access to electricity on annual fuelwood consumption. Purchasing fuelwood is a characteristic of fuelwood-scarce communities, as is fuel substitution (Madubansi and Shackleton, 2006). Thus buying fuelwood and access to electricity were tested for significant effects on annual household fuelwood consumption. This was carried out on the subset of households that purchased fuelwood (as well as collected it) in Welverdiend only, since the sample size in Athol was insufficient to allow statistical comparison.

Household fuelwood collection strategies that were considered were trip duration (hours/trip/household) and frequency (number of trips/week). Frequency of collection trips was collated to the weekly temporal scale since the majority of households do not collect fuelwood daily. The average values were compared between villages at both the weekly and annual time scales. The opportunity cost of fuelwood collection to the household as a unit, incorporates both of these factors (time per collection trip and the frequency of collection trips) into one numerical variable with an intrinsic value attached to it (Rands annum^{-1}). Following Dovie et al. (2004), the opportunity cost of fuelwood collection was taken as the product of the time spent collecting fuelwood per household per annum and the shadow price of casual labour in the area. In South Africa minimum wages are prescribed per sector per area; for the purposes of this study, the shadow price of labour was taken at R6.74/hour, the prescribed hourly rate for casual farm labour in the area. Studies in south Asia showed that of the time used in fuelwood collection, when given alternatives- women would use only 50% of the saved time in income-generating activities (Baland et al., 2010). This value was used a proxy for our study area since no similar studies have been carried out in southern Africa. Thus the actual value of the time spent, or the opportunity cost of collecting fuelwood was calculated based on 50% of the time spent in fuelwood collection activities each year. The opportunity cost of fuelwood collection was calculated for each household as a unit (irrespective of the number of fuelwood collectors). Two-Way ANOVA was used on the log-transformed value of household opportunity costs to compare between villages and household with or without access to electricity. The savings represented by transitioning to electricity were calculated by comparing the actual financial costs paid in electricity bills between households using fuelwood only and those using a mix of fuelwood and electricity, these values were also compared against the fuelwood-use investment costs to the household (opportunity costs and purchase costs).In comparing the total economic cost of maintaining household fuelwood supply (where this value includes the cost of purchasing fuelwood), between the two case-study sites it was possible to investigate whether households in Welverdiend invested more to ensure household energy security than those in Athol.

3. Results

3.1. Household demographics and socio-economic characteristics

There were no significant differences in the demographic profiles between the villages at the household level with respect to the mean number of people living in the homestead as well as the number of men, women and children (Table 2). All household characteristics refer to individuals that reside within the household permanently and exclude migrant members. Of the sampled

Table 2
The household demographic and socio-economic characteristics for Athol and Welverdiend villages; medians with S.E. tested using Wilcoxon 2-sample tests.

Socio-economic characteristics	Athol	Welverdiend	Results
Household size	5.0 ± 0.2	5.0 ± 0.2	$Z=0.6945$, $p>0.05$
Number of adult males	1 ± 0.1	1 ± 0.1	$Z=3.465$, $p>0.05$
Number of females	1 ± 0.1	2 ± 0.1	$Z=1.429$, $p>0.05$
Number of children	2 ± 0.1	2 ± 0.1	$Z=0.8539$, $p>0.05$
Income (R annum^{-1})	$18{,}060 \pm 1390$	$17{,}280 \pm 1646$	$Z=-1.2147$, $p>0.05$

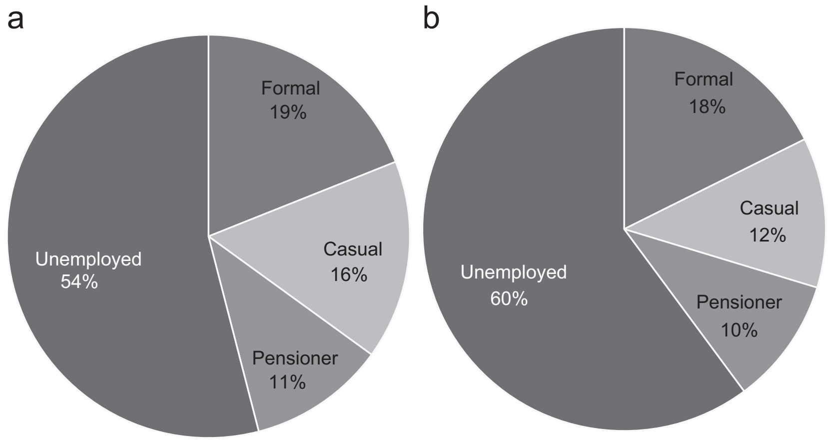

Fig. 2. Income streams amongst the entire adult populations of (a) Athol and (b) Welverdiend villages, respectively. Percentage values are of all adults from the surveyed households.

households children (less than 18 years old) make up 44% and 40% of the populations in Athol and Welverdiend, respectively, adult men make up 22% and 28% and adult women make up 34% and 32%, respectively, and the village demographic profiles are not significantly different from each other ($DF=2$, $X^2=2.1312$, $p>0.05$).

The patterns of employment amongst the adult populations are similar ($X^2=0.8564$, $DF=3$, $p>0.05$) with the greater proportion of adults being unemployed (Fig. 2), highlighting the value of alternative income streams such as remittances, government social grants and the informal trade sector within these communities. There is no difference in the average household income (the sum of all cash streams including remittances in R annum^{-1}) in both villages (Table 2) thus the average annual income (of the pooled dataset) is R18,000 ± R1075 annum^{-1}. Based on the total annual household income, 36.4% of households in Athol survive on less than US$1/person/day compared to 17.2% in Welverdiend. However, when remittances are excluded from the income stream then these proportions increase to 42.1% in Athol and to 36.8% in Welverdiend, emphasising local household dependence on remittances from migrant labour.

3.2. *Village household energy consumption patterns*

All surveyed households use predominantly fuelwood, electricity or a mix of both to satisfy the entire suite of domestic thermal energy requirements (Fig. 3). The fuelwood is either collected or purchased or both (Fig. 4). Gas and paraffin are available as energy alternatives to fuelwood and electricity and are used to supplement the main energy sources, but no households reported using them exclusively, and only 1% made mention of them for use in cooking only. Of the households that have been connected to the national electricity grid, 91% in Welverdiend and 82% in Athol still use fuelwood as their main source of energy. Significantly more households in Athol than in Welverdiend have transitioned to exclusive use of electricity ($X^2=6.6902$, $DF=1$, $p<0.05$). Although the reason for the difference is not clear, the most commonly cited reasons for making the complete transition to electricity in both villages were the high opportunity cost of using fuelwood (too much effort-time and distance, to collect fuelwood) as well as the ready availability of electricity as an alternative. Households in Athol that use fuelwood as well as electricity, spend on average, R600.00 ± R53.46 annum^{-1} on electricity, compared to R1200.00 ± R146.00 for those households that use electricity only ($Z=2.6515$, $p<0.01$). A similar pattern emerges in Welverdiend where households using fuelwood report

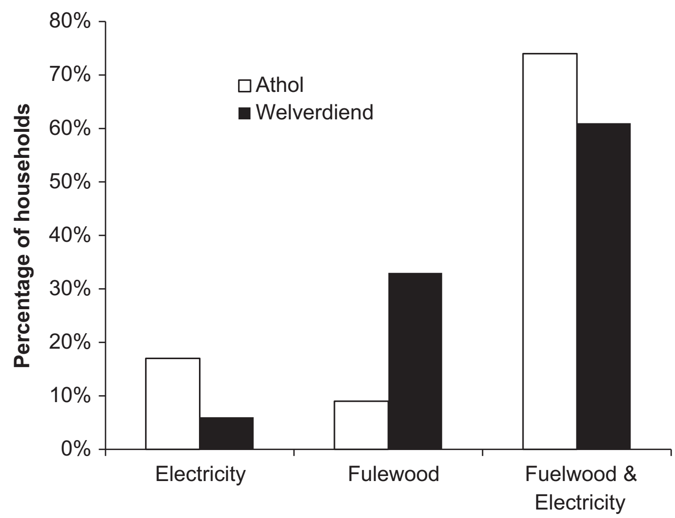

Fig. 3. Energy mix characteristics of households in Athol and Welverdiend based on the proportion of all interviewed households mentioning the use of either fuelwood or electricity, or both as the main source of energy.

spending significantly less on electricity (R840 ± R85.08) than households that have transitioned to exclusive use of electricity (R1200.00 ± R215.71), ($Z=2.8041$, $p<0.01$). Thus using the pooled village dataset the average household, using electricity only ($n=27$) spends an average of R1200 ± R130 pa on electricity (energy) which is significantly more than the households that also use fuelwood, these households spend R600 ± R52 annum^{-1}, ($Z=-5.3095$, $p<0.0001$).

Households in Welverdiend are more economical in terms of one of the uses of fuelwood, cooking significantly fewer meals than households in Athol (Table 3) at an average of one cooked meal a day (1 ± 0.05) in Welverdiend compared to two (2 ± 0.06) cooked meals per day in Athol. That the average annual fuelwood consumption per household is not different between the villages suggests that the other uses of fuelwood such as water heating and space heating may in fact account for more of the household consumption than previously thought.

3.3. *Household fuelwood consumption*

There is a marked seasonal pattern of fuelwood consumption (kg/day) which is not different between the two villages ($F_{5,546}=19.21$, $p<0.0001$) with significantly lower consumption

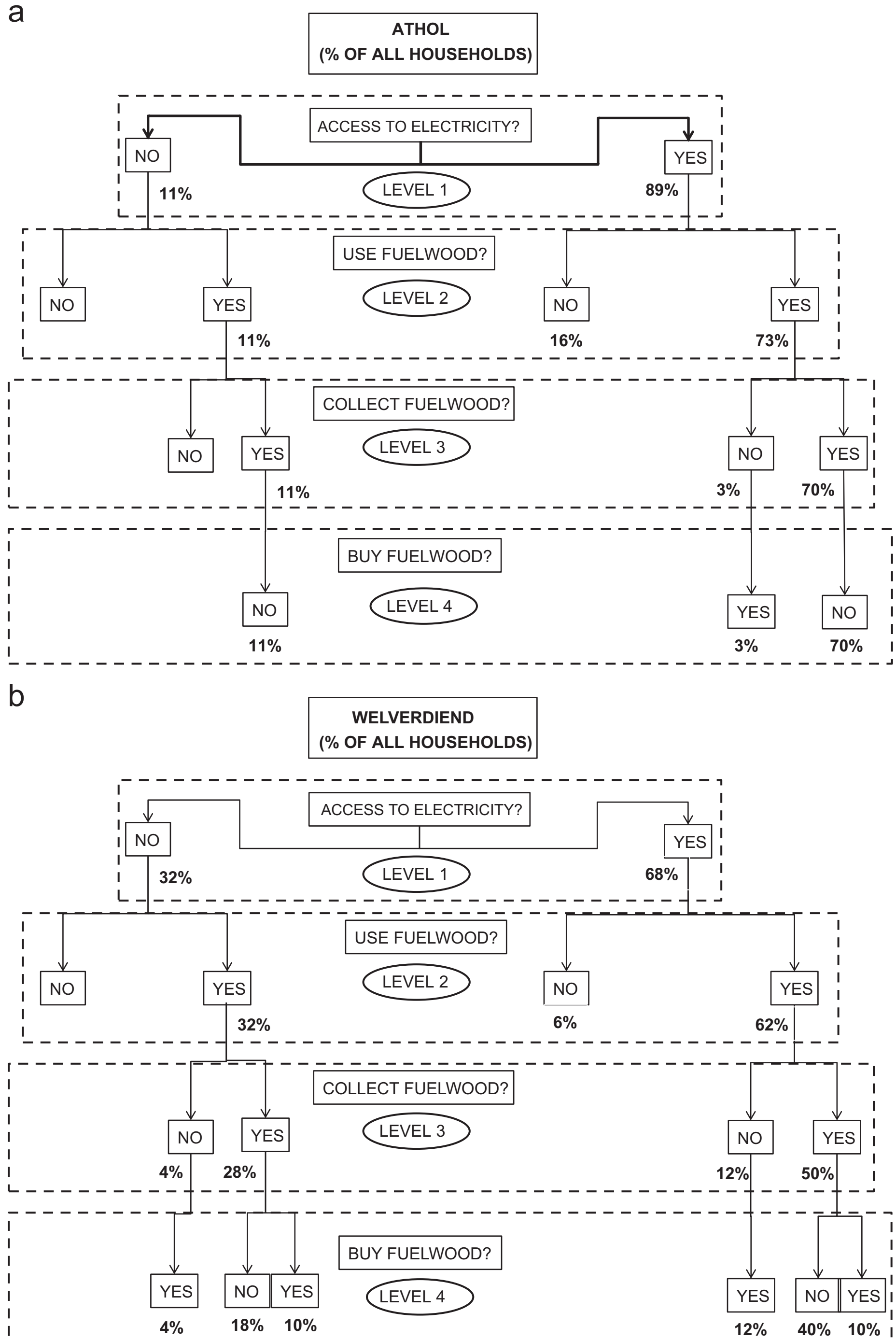

Fig. 4. Fuelwood and electricity village-level percentage-use characteristics in 2009 for (a) Athol and (b) Welverdiend villages; percentage values at each level refer to percentage of all surveyed households.

during the summer season (7.8 ± 2.8 kg) than both the winter (10.5 ± 4.5 kg) and rainy season (10.2 ± 3.6 kg) daily consumption. Annual household fuelwood consumption does not differ significantly between Athol and Welverdiend (Table 3). Whether a household has access to electricity has a significant bearing on annual fuelwood consumption, irrespective of which village the household belongs to ($F_{3,207}=4.53$, $p<0.01$). Households with access to electricity use less fuelwood annum^{-1} (2898.26 kg $\pm$ 130.42 kg) compared to those that do not (3451.45 kg $\pm$ 203.70 kg) representing a 16% reduction.

Thirty-six percent of all households in Welverdiend buy fuelwood in order to meet their needs (Fig. 4). They report buying 1880 ± 232 kg annum^{-1} at an average cost of R800 $\pm$ R144 annum^{-1}. A significantly lower number of households buy fuelwood in Athol (3%, D$F=1$, $X^2=43.6$, $p<0.0001$), buying 1596 ± 532 kg annum^{-1} at a cost of R R705.00 $\pm$ R213.00 annum^{-1}. Households in Athol that buy fuelwood ($n=4$) have made a deliberate choice not to collect fuelwood as they can afford to buy it instead. In contrast, the most common reasons for buying fuelwood in Welverdiend are insufficient resources within the communal woodlands and fear of being arrested if caught cutting livewood (29%). In Welverdiend, the source of the fuelwood, that is, whether it is bought or collected does not influence annual household fuelwood consumption ($Z=-0.1512$, $p>0.05$) as there is no significant

Table 3
The household fuelwood consumption profiles of user households showing collection trip frequency, duration per trip and time and opportunity costs, annual household fuelwood use and the average number of meals cooked for Athol and Welverdiend. Unless otherwise stated all variables refer to the per annum temporal scale.

Variable	Athol (n=97)	Welverdiend (n=88)	Results (W 2-sample test)
Fuelwood consumed (kg)	3193.1 ± 114.9	3285.0 ± 186.2	$Z=-0.7780$, $p>0.05$
Number of meals cooked	730 ± 24	365 ± 19	$Z=-4.1190$, $p<0.05$[a]
Fuelwood collected (kg)	3502 ± 362	4154 ± 299	$Z=-1.47$, $p>0.05$
Number of trips per household	117.0 ± 5.6	91.0 ± 6.8	$Z=-3.3013$, $p<0.0001$[a]
Length of collection trip (minutes/trip)	180.0 ± 5.9	240.0 ± 14.0	$Z=6.1499$, $P<0.0001$[a]
Time collecting fuelwood (hours)	351.0 ± 17.5	364.0 ± 30.4	$Z=0.0551$, $p>0.05$
Opportunity cost (R)	R1051.44 ± R55.14	R1095.25 ± R98.10	$Z=0.5217$, $p>0.05$
Household investment cost of fuelwood use (R)	R1051.44 ± R53.74	R1213.34 ± R108.76	$Z=-1.6652$, $p<0.05$[a]

[a] Denotes statistical significance of the Wilcoxon Two Sample test (W 2-sample test).

Table 4
The fuelwood consumption characteristics of the pooled village dataset separated by whether households have been connected to the national electricity grid. All variables are analysed at the per annum temporal scale.

Variable	Electricity (n=160)	No electricity (n=49)	Results
Time collecting fuelwood (h)	280.15 ± 17.9	364 ± 39.2	$Z=1.8671$, $p<0.05$***
Opportunity cost (R)	R941.91 ± R60.47	R1226.65 ± R131.94	$Z=2.9813$, $p<0.01$***
Economic cost of fuelwood use (R)[a]	R1051.44 ± R61.73	R1676.20 ± R167.67	$Z=-1.6652$, $p<0.05$***

[a] The economic cost incorporates both the opportunity cost and the financial cost of purchasing fuelwood to the household.
*** Denotes statistical significance.

difference in the amount of fuelwood consumed by these two groups; households purchasing fuelwood use on average 3651 ± 210.6 kg annum^{-1} and those that do not, use 3649 ± 192.8 kg annum^{-1}.

3.4. Fuelwood collection strategies

Collecting fuelwood from the communal woodlands is the most common method to secure households supply in both villages (Fig. 4). A greater proportion of households in Welverdiend (26%) stated that they could not collect sufficient fuelwood for their needs from the communal woodlands relative to Athol residents (5%) yet household in Welverdiend does not invest more household labour to collect fuelwood. The size of the fuelwood collecting party ranges between 1–4 people (Welverdiend) and 1–5 people (Athol) per household, respectively, averaging two people in either village ($Z=-1.5297$, $p>0.05$). Mostly adult women carry out the bulk of the fuelwood collection duties in both Welverdiend (73%) and Athol (68%) and there is no significant difference in the amounts of fuelwood collected per collection trip (Table 3).

3.5. Household investment into fuelwood collection

All households that collected fuelwood were included in this analysis, regardless of whether they also buy fuelwood since buying fuelwood had no influence on the duration ($Z=0.876$, $p>0.05$) nor on the frequency ($Z=0.655$, $p>0.05$) of fuelwood collection trips. Households in Welverdiend have consolidated the time they spend collecting fuelwood, making significantly fewer collection trips per annum but spending more time per trip than households in Athol (Table 3). Harvesters in Welverdiend, although making less frequent trips per week, invest more effort in terms of energy to walk longer distances and/or collect more fuelwood, (Table 3). However, when the time per collection trip (hours) and number of trips taken per annum was tallied to give the annual time invested per household to collect fuelwood, there was no significant difference between Athol and Welverdiend (Table 3) and consequently no difference in the opportunity cost to the household of fuelwood collection either (Table 3). The average opportunity cost for households collecting fuelwood (pooled village dataset) is R1051.44 ± R55.17 annum^{-1}. However, when the cost of buying fuelwood is factored in together with the opportunity cost, giving the total economic cost to the household, it becomes apparent that households in Welverdiend are forced to invest more and bear a greater cost, in terms of their time and money to secure household fuelwood supplies than in Athol (Table 3).

However, incorporating the effect of household access to electricity dampens the difference in economic cost of fuelwood between the two villages, the Two-Way ANOVA is significant ($F_{3,181}=4.12$, $p<0.01$) and shows that village in itself is not a significant factor ($F=2.43$, $p>0.05$) but that access to electricity is ($F=6.24$, $p<0.05$) and the interaction between them is weak ($F=3.71$, $p=0.054$). Generally, in these two villages, households that do not have access to electricity spend 30% more time collecting fuelwood (84 h) and invest up to 60% more in terms of the opportunity and financial costs of securing fuelwood for the household than those household that have access to electricity (Table 4).

3.6. Social mobilisation in response to fuelwood scarcity

An unexpected significant result that was not initially part of the investigation into how communities cope with resource shortages came to light in the course of this study. The residents of Welverdiend have coped with this resource shortage in a twofold manner, the creation of a fuelwood market (this will be discussed further below) and the outward expansion of their woodland resource base to an adjacent parcel of land named Morgenzon that was unused at the time (Rex Mnisi, deputy chairman of the Welverdiend Community Development Forum, pers. comm.). This parcel of land (19 km^2) was designated as a nature reserve but the animals were removed to the neighbouring Kruger National Park in the late 1980s in response to a severe drought. Consequently Welverdiend residents also listed Morgenzon as a fuelwood collection site along with areas within the original village boundaries effectively increasing their woodland resource base by 48%. This social response to fuelwood scarcity implies that woodland area availability is the defining factor in determining the sustainability of rural fuelwood use. The issue is that if indeed such processes are occurring concurrently in the many rural villages lying in close proximity to each other within this area, there is potential for great conflict once the land as a resource is no longer available for outward communal expansion. Similar behaviour has been observed in Athol during times of drought when residents expand their cattle grazing and resource extraction area to include the communal land of neighbouring Utah (Fig. 1; Giannecchini et al., 2007). In this region, the next most available land areas are conservation areas – large tracts of land upon which woodland resources are in abundance due to careful and deliberate management. “Poaching” occurs when local residents are prevented from active involvement in the sustainable use of essential, available resources that they consider vital to securing their livelihoods (Misana et al., 1996). There is a need for proactive response by conservation managers and practitioners to put in place mechanisms to allow local communities to partake of managed, sustainable harvesting activities for fuelwood or other resources (thatching, medicine, etc.) before conflicts arise in the future (Williams and Shackleton, 2002).

4. Discussion

4.1. The dichotomous nature of “sustainable” fuelwood use

In comparing the fuelwood consumption profiles of households in Welverdiend against Athol, it becomes evident that these two villages are within the same socio-economic context at different points on the same fuelwood supply–demand trajectory (Banks et al., 1996), although the higher unemployment rate in Welverdiend may be a significant driver of fuelwood use. The primary quantifiable difference between these two villages is that the human population of Welverdiend is almost thrice that of Athol; consequently the ecological footprint of Welverdiend residents on their village landscape is greater due to sheer number and the requirements for space for homesteads and subsistence agriculture (Petit et al., 2001). Although the total area of communal woodland for both villages is similar, the area of woodland relative to village size differs resulting in a lower ratio of woodland to household in Welverdiend. It is worrying that as the human populations grow in both villages (indeed in many communal areas across southern Africa with similar land tenure), land availability will become the limiting factor, as the demands for space for residential and agricultural needs as well as the multitude of ecosystem services provided by the continuously decreasing communal woodlands, particularly fuelwood grow in parallel with the human population growth (Banks et al., 1996, Karekezi et al., 2004).

Although the fuelwood use behaviours in Athol are sustainable that is demand does not appear to be in excess of what the woodlands can supply (Shackleton et al., 1994), if village expansion and the accompanying woodland clearing continue along this trajectory, demand may become unsustainable leading to localised fuelwood shortages, relative to the available woodland supply. There is room for policy intervention to encourage a change in the conditions that could lead to this. Several factors may change, leading to a decline or reversal of this trend including declining human population growth rates, cessation of residential and agricultural expansion or a dramatic shift in use of alternative energy source (e.g. electricity). Since the greater study area (Bushbuckridge) is an ISRDP node, the national government has already begun to implement some interventions to address these issues. These include the accelerated roll-out of electricity to villages in the municipality in a bid to improve access to electricity and the development of integrated spatial development plans by the local government body to improve land-use planning (BLM, 2010) with a view to mitigating residential sprawl and the loss of the natural habitat providing essential ecosystem services, such as fuelwood. The efficacy of these interventions remains to be seen in the future.

The direct causes of localised fuelwood scarcity are woodland clearing for agricultural and residential expansion (Arnold et al., 2006, Dewees, 1989; Geist and Lambin, 2002) and the penetration of market forces (Davidar et al., 2010). Rural households in conditions of scarcity adjust their immediate fuelwood consumption profiles to mitigate the social impacts on their livelihoods (Dewees, 1989) but these changes are largely cosmetic, rearranging household time and financial budgets and minor substitutions of alternatives into the household energy mix (Brouwer et al., 1997; Davis, 1998; Madubansi and Shackleton, 2006; Thom, 2000; Vermeulen et al., 2000; White et al., 1997). On the surface, it appears that the households in Welverdiend have made the predicted adjustments to their fuelwood consumption profiles in response to scarcity (Arnold et al., 2006; Brouwer et al., 1997; Dewees, 1989; Mlambo and Huizig, 2004). Welverdiend households invest more of their household resources into accessing fuelwood, have consolidated their fuelwood collection strategies to make it more efficient, purchase fuelwood to supplement that which is collected from the woodlands, cook less often and have incorporated electricity more into their household energy mix (Madubansi and Shackleton, 2006). However, inspite of perceived scarcity in Welverdiend, the demand for fuelwood remains comparable to that of households in Athol where fuelwood is in abundance. The actual household demand for thermal energy and therefore fuelwood remains inelastic despite high population pressures and therefore resource shortages. This may be attributed to the multi-use nature of fuelwood and the limited ability of these rural households to make effective use of offered alternatives, such as electricity due to financial constraints (Arnold et al., 2006; Gundimeda and Köhlin, 2008; White et al., 1997; Williams and Shackleton, 2002).

Poverty is linked to environmental degradation and is inextricably linked to the use and the unsustainability of fuelwood use across rural landscapes (Geist and Lambin, 2002; Mataya et al., 2002). The undervaluation of woodland ecosystem services and benefits by these rural communities is associated with poverty (Geist and Lambin, 2002) and unsustainable, resource-poor agricultural practices. This is manifest by over-cultivation leading to over-expansion, to sustain productivity and overharvesting of woodland products leading to woodland deforestation and degradation (Grainger, 1999; Mlambo and Huizig, 2004) and inevitably the development of fuelwood crises (Arnold et al., 2006, Davidar et al., 2010).

4.2. Adjusting to fuelwood shortages

As fuelwood becomes increasingly scarce, rural households alter their fuelwood collection and use patterns (Dewees, 1989; Brouwer et al., 1997); beginning with increasing collection effort through more frequent trips and longer collection times, investing more household resources through labour for collecting and the development of fuelwood markets (Abbott and Homewood, 1999; (Brouwer et al., 1997; Madubansi and Shackleton, 2006). In our study reduced access to wood may also have forced households to become more economical in their use of fuelwood and incorporate more of the available alternative as is economically permissible for them (Brouwer et al., 1997; Madubansi and Shackleton, 2007). Inspite of the immediate changes in fuelwood collection strategies, the opportunity costs (time) borne by households in Welverdiend and those in Athol are not significantly different. Rather the difference is seen in the total household investment cost as more income is diverted to pay for fuelwood and electricity tariffs where the household is connected. It is therefore ironic that the provision of electricity, which should result in an improvement in wellbeing by freeing household time for other pursuits such as education and income-generating activities, becomes a financial cost. In comparison, time is the one resource that many rural households may have in abundance and the value of the time saved, although significant, is heavily discounted income and employment opportunities are severely limited. The continued use of fuelwood even when households have electricity represents a tangible saving, allowing money to be invested into other household necessities such as education, food and clothing, rather than invested into energy security.

Gupta and Köhlin (2006)cite convenience, price and reliability of supply as being the major attributes influencing the transition of Indian rural households to electricity from traditional woody biomass energy sources which corresponds with answers given by respondents in this study. Despite the observed reduction in average household fuelwood consumption by those households with access to electricity, they still use fuelwood and in some instances even purchase fuelwood rather than transition completely (Welverdiend). In some parts of Zimbabwe, where fuelwood reserves are limiting, in the presence of electricity, most households still use fuelwood for the major thermal demands such as cooking and space heating but electricity may take up the load for other requirements such as boiling water for tea and bathing, e.g. using electric kettles (Vermeulen et al., 2000), as the technologies are relatively inexpensive and may be easily attainable (Howells et al., 2003; White et al., 1997; Williams and Shackleton, 2002). However, the relatively high cost of electricity through monthly tariffs and the need to purchase and maintain such technologies such as stoves, poses a deterrent to financially strained rural households from fully transitioning (Williams and Shackleton, 2002). Thus alternatives to collected fuelwood are used to supplement what can be harvested at relatively lower economic costs (time or cash) to the households, even when the communal woodlands have become so degraded as to be unable to provide adequate fuelwood Matsika and Erasmus (in press). This reiterates the notion that wood harvesting is widespread because it is often free, relatively cheap and easily available in comparison to alternatives such as electricity (Williams and Shackleton, 2002)). This comparative ''abundance makes it reliable'' (Davidar et al., 2010) and sustains rural demand.

4.3. Fuelwood markets sustaining household demand

The development of urban fuelwood markets has been linked to communal woodland degradation and deforestation (Davidar et al., 2010; Shackleton et al., 2005; Twine et al., 2003). Fuelwood markets develop in response to fuelwood scarcity and market responses convert a subsistence activity into an income-generating livelihood strategy (Shackleton et al., 2006; Twine et al., 2003). The motivations behind wood extraction for these two activities are different; fuelwood for a commercial market is removed on a larger scale as harvesters often use motor-vehicles and harvest larger, live trees (Shackleton et al., 2006), often using mechanised equipment firewood traders remove larger quantities than subsistence harvesters would to satisfy the market, these resources are not replaced and consistent extraction pressure makes this system unsustainable (Davidar et al., 2010). This fuelwood is often not harvested from the depleted woodlands but from villages where fuelwood is more abundant (Twine et al., 2003) thus placing unaccounted-for pressure on other village's woodland resource bases and increasing the likelihood of fuelwood shortages in these areas (exacerbating the syndrome of woodland degradation and fuelwood shortage). Once fuelwood becomes a livelihood option, it becomes increasingly difficult to change the extraction cycle and successfully introduce alternatives (energy and livelihood options, Davidar et al., 2010). The sustainability of traditional rural fuelwood harvesting practices in rural areas may become eroded over time due to growing populations, market pressures, land and resource shortages and weakening traditional land management institutions (Davidar et al., 2010; Geist and Lambin, 2002; Kaschula et al., 2005).

5. Conclusion

Ensuring rural household access to sustainable and affordable energy resources is a national development priority for South Africa (RSA, 2000). In this study up to 68% of electrified rural households still use fuelwood as the primary source of energy to meet daily household needs, even as the resource becomes more expensive to use in terms of opportunity-costs in collecting fuelwood and/or financial costs in buying it. In rural settlements where electricity is available, the factors sustaining fuelwood use are primarily socio-economic, one of the most significant being the major cost-saving to the household by using fuelwood rather than electricity. This enables rural households to invest their limited financial resources into other necessities – education, food and clothing – rather than monthly electricity tariffs. Providing electricity in areas where household incomes cannot accommodate these additional costs will not immediately reduce the burden of the majority of these households to secure domestic energy services from the environment. The immediate implication being that the majority of rural households in communal landscapes will remain dependent on fuelwood into the foreseeable future inspite of the presence of a household electricity connection. There is a need for greater incorporation of these factors into national domestic energy policy in South Africa in order to break the prevailing energy poverty cycles linking high fuelwood use rates to localised environmental degradation, at ever-increasing cost to the well-being of rural households. The long-term sustainability of which is still to be determined.

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References

Abbott, J.I.O., Homewood, K., 1999. A History of change: causes of miombo woodland decline in a protected area in Malawi. The Journal of Applied Ecology 36, 422–433.

Arnold, M., Kohlin, G., Persson, R., 2006. Woodfuels, livelihoods and policy interventions: changing perspectives. World Development 34, 596–611.

Aron, J., Eberhard, A.A., Gandar, M.V., 1991. Fuelwood deficits in rural South Africa. Biomass and Bioenergy 1 (2), 89–98.

Baland, J.M., Bardhan, P., Das, S., Mookherjee, D., Sarkar, R., 2010. The environmental impact of poverty: evidence from firewood collection in rural Nepal. Economic Development and Cultural Change 59 (1), 23–61.

Banks, D.I., Griffin, N., Shackleton, C.M., Shackleton, S.E., Mavrandonis, J., 1996. Wood supply and demand around two rural settlements in a semi-arid savanna, South Africa. Biomass and Bioenergy 11, 319–331.

BLM (Bushbuckridge Local Municipality), 2010. Spatial Development Framework. Bushbuckridge, Mpumalanga Province, South Africa.

Brouwer, I.D., Hoorweg, J.C., van Liere, M.J., 1997. When households run out of fuel: responses of rural households to decreasing fuelwood availability, Ntcheu district, Malawi. World Development 25, 255–266.

Cooke S.t.Clair, P., Hyde, W.F., Köhlin, G., 2002. ''A Woodfuel Crisis: Where and For Whom?'', Fuelwood-Crisis or Balance? In: Workshop Proceedings, Marstrand June 6–8, 2001, Environmental Economics Unit, Department of Economics, Göteborg University, Sweden 〈http://www.hgu.gu.se/files/nationalekonomi/eeu/publications/cifor/chapter2.pdf〉 (Accessed 05/06/2011).

Davidar, P., Sahoo, S., Mammen, P.C., Acharya, P., Puyravaud, J., Arjunan, M., Garrigues, J., Roessingh, K., 2010. Assessing the extent and causes of forest degradation in India: where do we stand? Biological Conservation 143, 2937–2944.

Davis, M., 1998. Rural household energy consumption: the effects of access to electricity—evidence from South Africa. Energy Policy 26, 207–217.

De Montalambert, M.R., Clement, J., 1983. Fuelwood supplies in the developing Countries, Food and Agriculture Organisation, Rome, Italy, Forestry Paper No. 42. .

Department of Minerals and Energy, 1998. White Paper on Energy Policy for South Africa. Department of Minerals and Energy Affairs, Pretoria, South Africa.

Department of Minerals and Energy, 2007. Powerpoint Presentation by M P Masemola on the DME's Universal Access Plan. Department of Minerals and Energy, Pretoria. (accessed on-line on 10/09/2012)〈http://www.dme.gov.za〉.

Dewees, P.A., 1989. The woodfuel crisis reconsidered: observations on the dynamics of abundance and scarcity. World Development 17, 1159–1172.

Dovie, D.B.K., Witkowski, E.T.F., Shackleton, C.M., 2004. The fuelwood crisis in Southern Africa- relating fuelwood use to livelihoods in a rural village. GeoJournal 60, 123–133.

Eckholm, E.P., 1975. The Other Energy Crisis: Firewood. Worldwatch Paper 1. Worldwatch Institute, Washington DC.

Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52, 143–150.

Giannecchini, M., Twine, W., Vogel, C., 2007. Landcover change and human-environment interactions in a rural cultural landscape in South Africa. The Geographic Journal 173, 26–39.

Grainger, A., 1999. Constraints on modelling the deforestation and degradation of tropical open woodlands. Global Ecology and Biogeography 8, 179–190.

Gundimeda, H., Köhlin, G., 2008. Fuel demand and elasticities for energy and environmental policies: Indian sample survey evidence. Energy Economics 30, 517–546.

Gupta, G., Köhlin, G., 2006. Preferences in urban domestic fuel demand: the case of Kolkata, India. Ecological Economics 57, 107–121.

Harmse, A., 2010. Node Selection for the integrated sustainable rural development programme in South Africa. Development Southern Africa 27 (3), 429–445.

Howells, M.I., Alfstad, T., Victor, D.G., Goldstein, G., Remme, U., 2003. An Energy Model for a Low Income Rural African Village, Energy Research Centre, University of Cape Town. Cape Town, South Africa, Working Paper Number 18. .

Karekezi, S., 2002. Poverty and energy in Africa – a brief review. Energy Policy 30, 915–919.

Karekezi, S., Lata, K., Coelho, S.T., 2004. Traditional Biomass Energy: Improving its Use and Moving to Modern Energy Use. Thematic Background Paper for the International Conference for Renewable Energies, Bonn, Sweden.

Kaschula, S., Twine, W.C., Scholes, M.C., 2005. The effect of catena position and stump characteristics on the coppice response of three Savanna fuelwood species. Environmental Conservation 32, 76–84.

Leach, M., Mearns, R., 1988. Beyond the woodfuel crisis: people, land and trees in Africa. Earthscan Publications, London.

Madubansi, M., Shackleton, C.M., 2006. Changing Energy Profiles and consumption patterns following electrification in five rural villages, South Africa. Energy Policy 34, 4081–4092.

Madubansi, M., Shackleton, C.M., 2007. Changes in fuelwood use and species selection following electrification in the Bushbuckridge lowveld, South Africa. Journal of Environmental Management 83, 416–426.

Mataya, C., Gondo, P., Kowero, G., 2002. Evolution of land policies and legislation in Malawi and Zimbabwe: implications for forestry development. Zimbabwe Science News 36, 18–27.

Matsika, R., Erasmus, B.F.N., Twine, W.C., A tale of two villages: assessing the dynamics of fuelwood supply in communal landscapes in South Africa. Environmental Conservation. (Available on CJO doi:10.1017/S0376892912000264), in press.

Mbeki, T., 2001. Address of the President of South Africa at the Opening of Parliament. Delivered by the State President at the Houses of Parliament, February, The Presidency, Cape Town, South Africa.

Misana, S., Mung'ong'o, C., Mukamuri, B., 1996. Miombo woodlands in the wider context: macro-economic and inter-sectoral influences. In: Campbell, B. (Ed.), The Miombo in Transition: Woodlands and Welfare in Africa. Centre for International Forestry Research, Bogor, Malaysia, pp. 73–98.

Mlambo, D., Huizig, H., 2004. Household responses to fuelwood scarcity: a case study of two villages in Zimbabwe. Land Degradation and Development 15, 271–281.

Pachauri, S., Spreng, D., 2004. Energy use and energy access in relation to poverty. Economic and Political Weekly 39 (3), 271–278.

Pereira, M.G., Sena, J.A., Freitas, M.A.V., da Silva, N.F., 2011. Evaluation of the impact of access to electricity: a comparative analysis of South Africa, China, India and Brazil. Renewable and Sustainable Energy Reviews 15, 1427–1441.

Petit, C., Scudder, T., Lambin, E., 2001. Quantifying processes of land-cover change by remote sensing: resettlement and rapid land-cover changes in south-eastern Zambia. International Journal of Remote Sensing 22, 3435–3456.

RSA (Republic of South Africa), 2000. The Integrated Sustainable Rural Development Strategy (ISRDS). Office of the Deputy President, 17 November. 〈http://www.info.gov.za/otherdocs/2000/isrds.pdf〉 (Accessed 13/06/2011).

Rutherford, M., Mucina, L., Lotter, M.C., Bredenkamp, G.J., Smit, J.H.L., Scott-Shaw, C.R., Hoare, D.B., Goodman, P.S., Bezuidenhout, H., Scott, L., Ellis, F., Powrie, L.W., Siebert, F., Mostert, T.H., Henning, B.J., Venter, C.E., Camp, K.G.T., Siebert, S.J., Matthews, W.S., Burrows, J.E., Dobson, L.N., Schmidt, E., Winter, P.J.D., Ward, R.A., Williamson, S., Hurter, P.J., 2006a. Savanna Biome. In: Mucina, L., Rutherford, M.C. (Eds.), The vegetation of South Africa, Lesotho and Swaziland, 9. South African National Biodiversity Institute, Pretoria, Strelitzia1, pp. 439–539.

Rutherford, M., Mucina, L., Lotter, M.C., Bredenkamp, G.J., Smit, J.H.L., Scott-Shaw, C.R., Hoare, D.B., Goodman, P.S., Bezuidenhout, H., Scott, L., Ellis, F., Powrie, L.W., Siebert, F., Mostert, T.H., Henning, B.J., Venter, C.E., Camp, K.G.T., Siebert, S.J., Matthews, W.S., Burrows, J.E., Dobson, L.N., Schmidt, E., Winter, P.J.D., Ward, R.A., Williamson, S., Hurter, P.J., 2006b. Savanna Biome. In: Mucina, L., Rutherford, M.C. (Eds.), The vegetation of South Africa, Lesotho and Swaziland. Strelitzia19. South African National Biodiversity Institute, Pretoria, South Africa, pp. 439–539.

Shackleton, C.M., Shackleton, S.E., 2000. Direct use values of secondary resources harvested from communal savannas in the Bushuckridge Lowveld South Africa. Journal of Tropical Forest Production 6, 28–47.

Shackleton, C.M., Griffin, N., Banks, D.I., Mavrandonis, J.M., Shackleton, S.E., 1994. Community structure and species composition along a disturbance gradient in a communally managed South African savanna. Vegetatio 115, 157–168.

Shackleton, C.M., Guthrie, G., Main, R., 2005. Estimating the potential role of commercial over-harvesting in resource viability: a case study of five useful tree species in South Africa. Land Degradation and Development 16, 273–286.

Shackleton, C.M., McConnachie, M., Chauke, M.I., Mentz, J., Sutherland, F., Gambiza, J., Jones, R., 2006. Urban fuelwood demand and markets in a small town in South Africa: livelihood vulnerability and alien plant control. International Journal of Sustainable Development and World Ecology 13, 481–491.

Starr, C., 1996. Sustaining the human environment: the next two hundred years. Daedalus 125 (3), 235–253. (Accessed 03/06/2011).

Thom, C., 2000. Use of grid electricity by rural households in South Africa. Energy for Sustainable Development 4 (4), 36–43.

Thornton, R., 2002. Environment and Land in Bushbuckridge, South Africa. University of the Witwatersrand, South Africa.

Twine, W., Siphugu, V., 2002. There's a hole in my bucket: Increased harvesting of resources by outsiders in rural areas of the South African Savanna lowveld. In: Proceedings of the Natural Forests and Savanna Woodlands Symposium III, 2002.

Twine, W., Moshe, D., Netshiluvhi, T., Siphugu, V., 2003. Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a semi-arid area of Limpopo province, South Africa. South African Journal of Science 99, 467–473.

Vermeulen, S.J., Campbell, B.M., Mangono, J.J., 2000. Shifting patterns of fuel and wood use by households in rural Zimbabwe. Energy and Environment 11, 233–254.

von Maltitz, G.P., Scholes, R.J., 1995. The burning of fuelwood in South Africa: when is it sustainable? Environmental Monitoring and Assessment 38, 243–251.

White, C., Bank, L., Jones, S., Mehlwana, M., 1997. Restricted electricity use among poor urban households. Development Southern Africa 14, 413–430.

Williams, A., Shackleton., C.M., 2002. Fuelwood use in South Africa: where to in the 21st century? Southern African Forestry Journal 196, 1–7.

Zhang, S., Fu, L., 2011. Exploring an integrated approach to utilize indigenous renewable energy to improve energy self-sufficiency and emission reduction. Renewable and Sustainable Energy Reviews 15, 827–832.