DRAFT

BIOFUEL USE AND FUELWOOD COLLECTION TIMES IN SOUTH AFRICA

STEPHANIE WALDHOFF

ABSTRACT

Few studies have examined the reasons consumers choose biofuels over cleaner, more convenient energy sources. This study uses data from the 1993 Living Standards & Measurement Survey from South Africa to understand consumers' motivations in their fuel choices. Results from a logistic regression suggest that increasing the electric-grid connectivity by one standard deviation from the mean would reduce the predicted probability of using biofuel by nearly 5% for a "typical" biofuel user. Increasing total monthly expenditures by one standard deviation would reduce the predicted probability of biofuel use by 2.4%, roughly half the effect of improving connectivity. Time spent collecting fuelwood is also examined in order to appreciate the direct costs associated with fuelwood use. Improving electrical connectivity in villages by 50% reduces time spent collecting between one-half and one and a half hours per week. Although household size itself is not significantly correlated with collection time, the number of females age 10 and over does influence collection time, with each additional woman increasing household collection time between 20 minutes and 1 hour per week. Policies with the intent to move consumers away from biofuels and to more modern fuels must take into account constraints imposed by access and income.

I. INTRODUCTION

Energy and the environment are intricately connected. A large volume of literature examines many of the environmental problems resulting from different methods of energy production. Studies have addressed problems involving storage of nuclear waste from energy generation (Rhodes and Beller, 2000; Proops, 2001), fossil fuel combustion and global warming (Nordhaus, 1993; IPCC, 1990), and coal combustion and acid rain (Schmalensee *et al*, 1998; Ackerman and Hassler, 1981). A smaller number of studies have considered the relationship between biofuel use and the environment, such as atmospheric pollution (Streets and Waldhoff, 1999) and deforestation as a result of over-harvesting of fuelwood (Linde-Rahr, 2003; Kohlin and Parks, 2001). Even fewer have analyzed why consumers choose to use biofuels over cleaner, more convenient sources of energy (An *et al*, 2002; Brouwer *et al*, 1997). Many assumptions have been made as to why consumers choose one fuel over another, but it is important to analyze real data to support or refute those assumptions. Once the reasons behind consumers' choices are understood, policy makers will better be able to implement policies that will encourage consumers to switch to cleaner and more efficient fuel types.

There are three principle hypotheses concerning the choice of biofuels over other, cleaner, more convenient forms of energy: income, access, and preferences. The first reason seems logical enough—if canisters of LPG (liquefied petroleum gas) cost more than a week's worth of wages for an low income consumer, he is very likely to choose less costly sources of energy, such as fuelwood or animal waste. Access to alternative energy sources such as electricity or LPG could be another significant constraint. Some consumers may desire and be willing to pay for electricity, but may lack a connection to the electric grid. Finally, consumers may choose to use biofuel because it is seen as a better or more traditional source of energy for traditional cooking practices (for instance, fuelwood is used in Mexico for making tortillas). If the policy goal is to move consumers to cleaner energy sources, the policy action must be tailored to the cause underlying the consumer's choice.

The primary goal of this paper is to use data from South Africa to determine which, if any, of these reasons determines the use of biofuels there. The secondary goal is to use these data to examine time spent collecting fuelwood to better understand the true price paid by consumers for this energy source.

II. POLICY CONTEXT

First, it is important to address *why* it would be desirable for consumers to switch from biofuels, such as wood, crop residues, and animal waste, to other forms of energy—especially when the negative environmental effects of fossil fuels are so well known. In order to do this, a slightly scientific digression is necessary. It is fairly well known that CO_2 is connected with global climate change. The theory is that CO_2 acts as a "greenhouse gas" trapping heat in the atmosphere and altering global climate patterns. What may be less well known is that there are other greenhouse gasses, primarily gasses that are products of incomplete combustion (PICs). These PICs (including methane (CH_4), carbon monoxide (CO), and non-methane hydrocarbons (NMHC)) as the name suggests, are released when fuels are not fully combusted. PICs have Global Warming Potentials (GWPs) several times higher than CO_2. In other words, in terms of climate altering properties, each molecule of CH_4 released is equivalent to 62 CO_2 molecules over a 20-year time span (IPCC, 2001). Certain fuels and methods of combustion tend to release much higher levels of PICs. Biofuels and open combustion are among the worst culprits. In addition, despite the popular notion of biofuels as a renewable source of energy, this is rarely the case. Although in theory, it is possible for all of the CO_2 emitted during burning to be reabsorbed during the next growing season (for instance with crop residues) sustainable harvesting is rarely done, so CO_2 released in burning is not necessarily reabsorbed in future growth. These environmental effects represent a true externality, as the full cost is borne not only by the biofuel users, but by society as a whole.

Secondly, policy makers should be especially concerned about biofuel use in areas where market imperfections exist—for instance, lack of explicit property rights. Economic theory tells us that when property rights are absent or imperfect, the market will not be in equilibrium. In particular with collective goods, such as fuelwood, equally available to all consumers, demand will exceed sustainable supply, depleting the stock, eventually causing the flow of fuelwood from these public sources to be less than it would under a system with explicit property rights.

In addition to negative environmental effects, biofuel combustion also imposes negative health effects upon its users. Health may be negatively impacted through two mechanisms—indoor air pollution and collection related effects. Negative health effects from indoor air pollution caused by biofuel combustion include aggravation of asthma from increased levels of particulate matter (Mishra, 2003), increased rates of acute respiratory infections (Ezzati and Kammen, 2001), and decreased birth weights (Boy *et al*, 2002). Collection of fuelwood can lead to snake or tick bites, poison ivy, and other collection-related injuries, including rape—an especially serious problem for young girls in South Africa. These effects increase the implicit cost to the consumer of using biofuels. While these health related costs might be seen as part of the true cost paid by consumers using biofuels, these costs may not be well recognized by consumers as part of the "price" of using biofuels. Even when consumers recognize the negative health effects associated with biofuel use, when access to other fuels is an issue consumers may be forced to accept these costs for lack of reliable alternatives. Finally, to the extent that states pay for the negative health effects (through national health care) society as a whole will incur some of the costs associated with biofuel use.

III. THEORY

Given the many negative effects associated with biofuel combustion it is important to understand why consumers choose to use biofuels when other, cleaner alternatives exist. Policies implemented without first understanding the motivations of consumers are less likely to have the desired results. Three possible reasons are examined in this paper: economics, access, and culture.

The economic reason seems plain enough—if the cost of cleaner or more convenient fuels is outside the consumer's budget constraint, these fuels will not be used. More likely than this scenario is that consumers would have to sacrifice very significant items in order to purchase cleaner fuels such as LPG or electricity. If using electricity for cooking meant that a family must forego a week's worth of groceries, it is easy to see why fuelwood would be the preferred cooking fuel.

Access may be less obvious on the surface because "access" may mean different things in different areas. Access to electricity may mean that there is no electric grid in the area, so it is simply not an option for consumers. In other areas, while consumers may be willing and able to pay the usage fees associated with electricity, high connectivity costs are prohibitive. Finally, access may not be merely having a grid connection, but it may mean access to reliable electricity. If access problems exist in any of these forms consumers may choose biofuels over less available sources of energy.

Finally, biofuels may simply be the preferred source of energy in some areas. Tradition or tastes influence consumers' preferences and this may cause biofuels to be used even when other forms of energy are readily available and within the consumer's budget constraint.

An *et al* (2002) examined consumers' motives for using fuelwood over electricity. In their model to predict fuel-switching in the Wolong Nature Preserve, China, they found that households' willingness to switch from fuelwood to electricity was primarily related to income, price of electricity, reliability and voltage levels of electric grid, and the distance to wood collection sites.

Brouwer et al (1997) study household fuelwood collection times and the correlation between these times and the distance to collection sites in Ntcheu District, Malawi. They found that, on average, households spend 6-10 hours/week collecting fuelwood. Further, as distance to collection sites increased, time spent collecting increased, but as collection distance continued to increase, households spent less time collecting wood—substituting inferior quality, but proximal wood sources. They also found the number of adult females to be positively correlated with the time households spent collecting fuelwood.

IV. DATA AND DESCRIPTIVES

The data used for this work are the South African Living Standards and Measurement Survey, 1993. These data are nationally representative, with a sample size of 8,812. Each household answered a detailed questionnaire. In addition, community and price questionnaires are available for each village cluster. These data were chosen because, in addition to detailed energy-use questions, households were asked how much time was spent collecting fuelwood each week. Because fuelwood is often collected rather than purchased, this question is useful in addressing the costs associated with fuelwood use.

Table 1 shows means for biofuel users vs. non-users, where a biofuel user is defined as a household that answered fuelwood, charcoal, or animal waste to any of the eight fuel categories. (Each household is able to pick both a primary and a secondary fuel source for four fuel use categories: cooking, heating water, heating home, and lighting). Households that use biofuels look very different from those that do not. T-tests for differences in means were significant at $p < 0.001$ for all categories. Demographic variables were significant in the expected directions, with non-using households having monthly expenditures 2.3 times greater than biofuel-using households. Biofuel users were more likely to live in a rural area (84% vs. 30%), have larger family sizes (6.6 vs. 3.7 members), have older heads of household (52.5 vs. 44.0 years) who have less education (2.7 vs. 6.9 years) and are less likely to be employed in the formal sector (44% vs. 76%). Finally, only 18.6% of households that use biofuels are connected to the electric grid, while 70.3% of households that use no biofuels have a grid connection.

Table 1 Descriptive Statistics

Descriptives	**Biofuel Users**	**Non-Users**
N	3583	4279
Total Monthly Expend. w/ Remittance	970.98 Rand	2,238.45 Rand
Connected to Grid	21.2%	68.0%
African	98.1%	69.6%
Rural	83.8%	30.0%
Household Size	6.6	3.7
Head of Household Age	52.5	44.0
Head of Household Education	2.7	6.9
Head of Household Employed	44.0%	75.7%

Table 2 Average Time Spent Collecting Fuelwood (Minutes/Week)

	Collector 1	Collector 2	Collector 3
Sample Average	90.3	38.5	14.2
Not Connected to Grid	165.2	71.1	26.4
Main Cooking Fuel*	303.5	130.9	47.8
Secondary Cooking*	126.8	48.1	22.7
Main Lighting*	481.6	170.6	89.2
Main Heating-Water*	306.2	134.8	48.3
Main Heating-Home*	294.6	131.7	48.7

* Fuelwood

Table 2 shows average time spent collecting fuelwood per week for each of three collectors per household, including those that spend no time collecting at all (there are more zeros in the second and third collector categories because not every household has three collectors, additionally, households with

> 3 collectors were censored in the survey questionnaire). The highest collection times are for those households that use fuelwood as their primary lighting source (n=45), spending a total of 12.4 hours per week collecting fuelwood. On average, families that use fuelwood as their main cooking fuel spend 8.0 hours per week collecting fuelwood.

V. METHODS AND RESULTS

Predicting Biofuel Use

In order to understand which households will be more likely to use biofuels, a logistic regression using biofuel (as defined above) as the dependent variable was run. Because of the dichotomous nature of the dependent variable (defined as "0" for non-users and "1" for biofuel users) it is necessary to use a logistic regression, rather than OLS, to examine these data. This model predicts the probability that a household uses biofuel based on the independent variables:

$$\Pr(\text{Biofuel} = 1|\mathbf{X}) = \frac{e^{(\beta\mathbf{X} + \varepsilon)}}{1 + e^{(\beta\mathbf{X} + \varepsilon)}}$$

Independent variables include connectivity rates within clusters (number of households with an electric grid connection/total number households), log of total monthly expenditures (including remittances), number of children in different age categories, and demographic controls (race, household size, metropolitan status, regional dummies, and controls for the age, age squared, educational attainment, gender, and employment status of the head of household). Table 3 presents the results of this regression. Results are corrected for within-cluster heteroscedasticity.

Interpretation of logit coefficients is not straightforward because of the non-linear specification of the model. However, the sign of the coefficient is interpretable, and the signs on the coefficients are in the expected directions. One surprise was that the coefficient for race was not significant. In every specification of the model that controls for other demographic characteristics, race was not a significant predictor of biofuel use.

In order to better interpret the meaning of these results changes in predicted probabilities with connectivity, expenditure, and household size are calculated for a household with "typical"[1] characteristics among biofuel users. Table 4 shows these effects for both a one standard deviation change for biofuel users ($\text{Mean}_{\text{User}}$ + 1 SD_{User}) and a change to the mean of non-users. The base predicted probability of biofuel use for this "typical" household is 0.908.

[1] This "typical" biofuel user is defined as having the mean characteristics (among biofuel users) for connectivity, expenditure, household size, number of children, HHH age and education, as well as being rural, African, female, employed, and living in Northern Transvaal.

Table 3 Logit Results

	Biofuel Use	
Observations	6771	
Log Likelihood	-2584.51	
Pseudo R2	0.4365	
	Coefficient	Standard Error
Connectivity	**-1.536**	**0.280**
ln(total expend)	**-0.373**	**0.101**
HH Size	**0.150**	**0.035**
Children 0-4	0.064	0.068
Children 5-9	0.048	0.064
Children 10-14	**0.186**	**0.063**
Children 15-19	**0.125**	**0.061**
White	0.132	0.301
Rural	**2.413**	**0.337**
Suburban	**0.792**	**0.341**
HH Age	**0.038**	**0.016**
$(\text{HH Age})^2$	**-0.0003**	**0.0001**
HH Education	**-0.115**	**0.015**
HH Gender	0.120	0.092
HH Employed	**-0.282**	**0.114**
West Cape	-0.373	0.649
North Cape	-0.822	0.772
East Cape	**-1.324**	**0.392**
Natal	**-1.169**	**0.379**
Orange Free State	**-1.858**	**0.427**
Eastern Transvaal	-0.797	0.449
Northern Transvaal	-0.145	0.362
Northwest	**-2.165**	**0.460**
Constant	**-1.691**	**0.533**

Bold and Highlight: Significant at p = 0.01
Bold: Significant at p = 0.05
Regional Comparison Group is Pretoria

The changes in predicted probabilities for a one standard deviation change range from a low of 2.4 percentage points (for total expenditures) to a high of 5.3 percentage points (for household size). The combined effect of a one standard deviation change in all three variables is 17.3 percentage points. The largest single effect is a change in connectivity to the mean of non-biofuel-users.

Table 4 Changes in Predicted Probabilities

	Δ 1 SD from Mean	Δ User Mean to Non-User Mean
% Connectivity (Increase)	-0.049	-0.079
Total Monthly Expenditures (Increase)	-0.024	-0.029
Household Size (Decrease)	-0.053	-0.042
Combined Effect	-0.173	-0.211

Predicting Collection Times

Because fuelwood is often a non-market good it is difficult to determine its full acquisition price. However, it is important to understand the true price of using fuelwood, in terms of both the direct costs to the consumers and the indirect costs to society. This section examines one of the direct costs of fuelwood use—time spent collecting wood. Work by Brouwer *et al* (1997) also examined this question. The present study differs from the work done by Brouwer *et al* in several respects. While Brouwer *et al* examined correlations between variables, the present study attempts to control for several factors simultaneously using multivariate ordinary least squares regression. Secondly, the South African data do not have information regarding either quantities collected or information about distances to wood collection sites.

Traditionally fuelwood is collected by women and children, and the price is actually the cost of their time, plus externalities as discussed above. In this sense the main price of fuelwood to the users is the opportunity cost of their time—the cost of the activities foregone in order to collect the fuelwood. Detailed time-use information is not available from these data, so it is difficult to determine what the collectors would be doing in the absence of collection duties. Unemployment rates are high in South Africa, so it is unlikely the collectors would be employed in the formal market. Given that more than 25% of the fuelwood collectors are 15 or under, formal educational opportunities are likely to be forgone by the collectors. However, it is difficult to place a price on time when it is unknown what would be done with that time instead of collecting fuelwood. In other words, the opportunity cost is unknown. In addition, no information regarding the *quantities* of fuelwood collected or used is available from these data, so it is impossible to accurately estimate the unit price fuelwood.

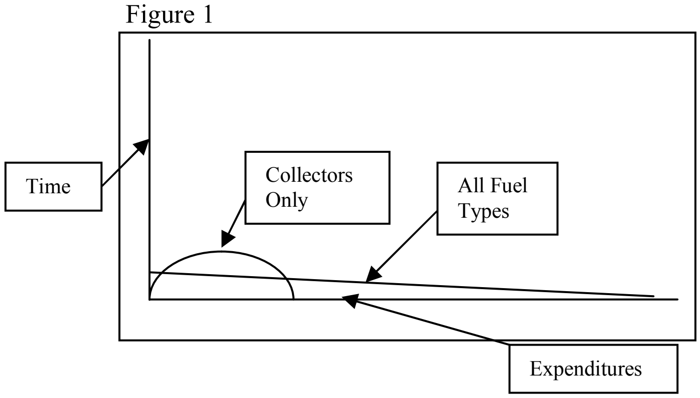
This section examines what factors influence the amount of time spent on fuelwood collection. OLS is used to address this question. The sample used for this regression does not contain any white, Indian, or colored respondents.

Indian and colored were previously removed from the sample (as described above). In this section, white respondents were removed because only 2 white households reported collecting any wood.

Table 5 shows the results of the regressions predicting fuelwood collection times (total hours per household per week). The first set of coefficients is for the full sample (n = 5130, as restricted above), regardless of which fuels the household uses. The second set of coefficients is for the subset of the sample that reported collecting fuelwood (n = 1645).

The first observation that can be drawn from these regressions is noted in the difference in significance of the expenditure variables (total expenditure and expenditure squared) across the regressions. In the full sample, total monthly expenditures is not a significant predictor of time spent collecting fuelwood, but in the sample restricted to collecting households only, total expenditures is a significant predictor of time spent collecting fuelwood. It is probable that expenditure has an inverted "U" shape, at the lower end of expenditures, and flattens out as expenditures increase. (Figure 1) Given the difference in sample size, the regression including non-collectors is does not detect to this inverted "U" in the smaller sample of collectors.

Figure 1



A second important observation is that village-level connectivity plays an important role in determining the amount of time spent collecting fuelwood. In the second regression, with the subset of the data that includes only those households that collect fuelwood, increasing connectivity by village 50% reduces the amount of time spent collecting fuelwood by roughly one and a half hours per week. It is possible that this answer is the result of omitted variable bias—for instance, villages in milder terrain may be more likely to be well connected to the electric grid and also have better access to fuelwood supplies.

Table 5 OLS Results

	Wood Collection (Hours/Week)			
	All Fuel Types		Wood Collectors Only	
Observations	5130		1645	
R2	0.2474		0.1739	
	Coefficient	Std. Error	Coefficient	Std. Error
Connectivity	**-1.080**	**0.334**	**-2.929**	**0.920**
Total Expenditure	-0.336	0.215	**2.644**	**0.824**
$(\text{Expenditure})^2$	0.021	0.026	**-0.345**	**0.133**
HH Size	**0.215**	**0.059**	0.140	0.117
Infants	0.160	0.184	0.249	0.374
Females >10	**0.386**	**0.126**	**1.018**	**0.241**
Rural	**2.327**	**0.373**	0.168	1.216
Suburban	-0.086	0.317	**-2.690**	**1.146**
HH Age	**0.068**	**0.026**	0.085	0.077
$(\text{HH Age})^2$	**-0.001**	**0.000**	**-0.001**	**0.001**
HH Education	**-0.182**	**0.031**	**-0.412**	**0.086**
HH Gender	0.109	0.186	-0.256	0.445
HH Employed	**-0.438**	**0.222**	-0.943	0.531
West Cape	**0.770**	**0.369**	(dropped)	
North Cape	**-1.987**	**0.477**	-0.896	1.117
East Cape	0.649	0.517	**3.153**	**0.854**
Natal	-0.718	0.399	**2.586**	**0.994**
Orange Free State	**-1.671**	**0.420**	-0.434	0.800
Eastern Transvaal	**-1.194**	**0.493**	0.904	0.795
Northern Transvaal	**3.031**	**0.730**	**5.161**	**0.890**
Northwest	**-1.871**	**0.460**	1.364	0.835
Constant	0.073	0.687	0.625	2.393

Bold and Highlight: Significant at p = 0.01
Bold: Significant at p = 0.05
Regional Comparison Group is Pretoria

Finally, the number of females in the household increases the amount of time spent collecting fuelwood, even with a control for household size. Each additional female age 10 or above increases the time spent collecting wood by about one hour per week in the sub-sample of wood collectors. As mentioned above, wood collection is principally seen as women's work, so girls would be more likely to go out collecting with other women in the household, increasing total collection time, but reducing the amount of work per person.

VI. CONCLUSIONS

The results of this work demonstrate that access to the electric grid is at least as important, and possibly of greater importance than income constraints in consumers' decisions to use biofuels. Although it is often assumed that incomes must increase before households will switch to cleaner and more convenient fuels, this paper demonstrates that much can be accomplished through improved access to the electric grid. This was the approach taken in the United States in the 1930's, with the Rural Electrification Administration. There is even reason to believe that increasing connectivity would indirectly increase incomes. As households have increased access to electricity, children, especially girls, are less likely to leave school to help with household duties such as fuelwood collection and food preparation. Remaining in school longer will improve their future employment opportunities, thus increasing their expected future incomes.

The importance of access cannot completely override concerns about income constraints, however. In areas where incomes are desperately low, access to grid electricity is unlikely to have much impact on consumers' fuel choices, since electricity will likely lie outside many households' budget constraints. This has been seen recently in South Africa with access to water supplies. A recent New York Times article (Thompson, 2003) stated that as many as 10 million people in South Africa had been affected by water cutoffs since the end of Apartheid in 1993. Although water services are available nearly everywhere in South Africa, many households lack the ability to pay for clean water and must therefore collect it themselves. This same phenomenon would be likely to occur in many areas even with electrification.

There is little evidence that consumers in South Africa prefer biofuels and choose them over more modern fuels when there are not constraints imposed either by access or income. This work demonstrates that both access and income are important predictors of consumers' fuel choices. Any policy aimed at influencing these choices must address both of these constraints in order to be effective. Attempting to change one without the other will result in significantly less improvement than when both constraints are regarded simultaneously. Including programs to increase contraception will have an even greater effect. When improvements in all three of these areas are taken together, this model predicts significant reductions in the probability of households using biofuels.

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