Household Fuel Consumption and Resource Use in Rural-Urban Ethiopia

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To the memory of my parents

ABSTRACT

Fuel scarcity and land degradation are intertwined problems of global concern. Land degradation affects some 2 billion hectares of land world-wide. In Africa some 500 million hectares of land have been affected by land or soil degradation, including about 65 percent of the continent's agricultural land. Land degradation has different facets, one of which is nutrient loss (depletion). In Ethiopia, indirect estimates suggest that the reduction in agricultural productivity from lost nutrients associated with the use of animal dung for household fuel accounts for about a 7 percent reduction of agricultural GDP.

By piecing together the various aspects of the puzzle, this thesis quantitatively analyzes the behavioral factors underlying household fuel demand and supply in rural-urban Ethiopia. It contributes to the existing literature in four important respects. Firstly, it provides insights into the role of using an improved stove in redressing land degradation, besides determining the factors that affect the stove adoption decision. Secondly, the thesis empirically analyzes the role that household and community tree planting play in redressing the fuel problem. It also investigates two attributes of household tree growing, i.e., a household's decision to grow trees and the extent of tree growing, in an econometrically consistent framework. Thirdly, it investigates the potential of environmentally clean technologies such as biogas installation at farm level as an opportunity to redressing land degradation. Fourthly, it draws empirically the implication of urban fuel demand for rural hinterlands using a demand system approach.

Empirical results indicate that the adoption of an improved stove reduces harvest pressure on local forests and that adoption is an economic decision related to savings in time spent in collecting fuel and cooking, and cattle required for everyday purposes. The thesis reveals a clear positive relationship between household tree plating and fuelwood consumption of the household. Consequently, tree planting might reduce the future use of manure as fuel. Biogas installations are only profitable for a few farm households. Profitability might increase if family farms were to combine their efforts. Findings also reveal that redressing the urban fuel problem cannot be seen in isolation from broader development policies aiming at raising the levels of education and income. Higher urban incomes, however, increase fuel demand.

Although data are from northern Ethiopia, conclusions drawn may have a wider application in other parts of the country as well as in the broader context of the African Sahel.

PREFACE

May I take this opportunity to thank the individuals and institutions that contribute to my career and that assisted me in the successful completion of my PhD study. First and foremost, I would like to thank my sincere wife Wro Azeb Kahssay for her endurance, patience and encouragements during my PhD study and for giving love to my kids in my absence. She was also the one who handled my data entry with diligence and accuracy. My daughter Deborah and sons Naod and baby for the sacrifice they paid in my absence. I am thankful to the BoANR (now BoARD) for giving me the study leave to pursue my PhD.

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I am thankful to God for finishing job of PhD study. *Being a PhD student is both joyful and challenging*. It is *joyful* because it gives you the opportunity and freedom to shaping your career the way you would like to be. It is *challenging* not only because the requirement for novelty and rigor is quite demanding but also the diversity of opinions of supervisors sometimes quite uneasy to catch.

Zenebe Gebreegziabher
Wageningen, September 2007

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Chapter 1 Introduction

1.1 Ethiopia: from Breadbasket to Food Aid Dependence

Two features that are both salient and striking characterize present-day Ethiopia: it is a country often known for its domestic supply problems and recurring drought; and, it is a country with a tremendous biodiversity. Ethiopia is also acknowledged as being at the heart of the origin for some of domesticated biodiversity (Harlan, 1971) and has made significant contributions to the world's genetic heritage resources (Keyzer *et al*., 2000). However, more importantly, Ethiopia was a net exporter of grain until the early 1960s and was once regarded as the "*breadbasket*" of the Middle East (Amha, 1994; Habtewold, 2001).

Ethiopia is typically an agrarian country, with agriculture continuing to be the largest sector in its economy. It contributes over 40 percent of GDP (Gross Domestic Product), about 80 percent of employment, more than 80 percent of commodity export earnings and 70 percent of raw materials supply for agro-based industries (Gebreegziabher *et al*., 2005; Table 1.1). Except for the lowlands and nomadic areas, mixed crop-livestock farming is the dominant farm type in the country. Eighty-one percent of the peasant farmers - particularly concentrated in the Ethiopian highlands - practise mixed farming. Crop production contributes over 50 percent to agricultural GDP and the rest comes mainly from the livestock sub-sector (CSA, 2004). The bulk of the agricultural output, i.e., well over 90 percent of the total agricultural output, comes from individual smallholder peasant farmers. Cereals - mainly *teff*, maize, sorghum, wheat, and barley - are the most important crops in the country in terms of land area. For example, they accounted for about 70 percent of the total area under crops in 2004 (see Appendix Tables 1A.1).

Table 1.1 Real GDP growth rate and sectoral distribution of GDP (in %)

	1999/00		2000/01		2001/02		2002/03		2003/04		2004/05	
	Growth	Share	Growth	Share	Growth	Share	Growth	Share	Growth	share	Growth	Share
GDP	5.4		7.4		-0.3		-3.3		11.1		8.8	
Agriculture	3.2	48.2	10.6	49.8	-2.5	48.8	-11.2	44.8	17.4	47.4	12.2	49.8
Industry	3.6	12.2	4.8	11.9	4.7	12.6	5.4	13.8	6.8	13.2	6.5	12.2
Distributive Services	4.7	18.4	6.1	18.2	1.5	18.6	3.0	19.9	6.6	19.1	6.3	18.3
Other Services	12.7	21.1	1.8	20.1	-0.4	20.0	3.7	21.6	5.0	20.4	5.3	19.7

Source: NBE (2006) and CSA (2006)

Table 1.2 Domestic production and food aid in Ethiopia by year ('000 metric tonnes)

Year	Food aid	Food grain production	Share of food aid (%)
1985	1272	4855	26.2
1986	926	5404	17.1
1987	277	6684	4.1
1988	1096	6902	15.9
1989	461	6676	6.9
1990	657	6579	10.0
1991	925	7078	12.0
1992	840	7055	11.9
1993	519	7619	6.8
1994	980	6945	14.1
1995	683	7492	9.1
1996	150	10328	1.5
1997	205	10217	2.0
1998	417	8103	5.2
1999	1320	10523	12.5
2000	860	11781	7.3
2001	224	10960	2.0
2002	1506	8157	18.5
2003	0	11823	0.0
2004	160	13300	1.2
Average 1985-04	673.9	7759.3	8.7

Source: MEDaC (1999), FDRE (2002) and FAO/WFP (2004)

Despite the impressive gains in export crops production (Debello, 2007) the performance of the country's agricultural sector, and in particular its food production has been low and its growth has failed to keep pace with the growing population particularly during the last four decades of the twentieth century. Per capita food production has been low and food production far from sufficient. Additionally, average annual growth rates of production of major food crops, in volume terms, during the last decade have been very low. As a result, domestic supply problems and "*dependence on food aid*" have been typical manifestations of the country. Table 1.2 presents imports of food aid in relation to domestic production in the country during the last two decades. Amid continued improvements both in terms of a declining trend in food aid and an increasing trend in domestic food grain production, food self-sufficiency still remains a challenge. The fact that agriculture is largely traditional and rain-fed so that weather conditions play an important role, could be one reason for the low performance in domestic food production (Diao and Pratt, 2007). Furthermore, a deteriorating natural resources base and land degradation stand to be among the prominent causes of the problem (Mekonen, 1998; Sonneveld and Keyzer, 2003; Yesuf *et al*., 2005).

Ethiopia is one of the few countries in Africa with an immense potential for producing hydro power. Although the total endowment or capacity of the hydro power resource is estimated to be up to 30,000 MW (mega Watt) per annum (Wolde-Giorgis, 2002), only approximately 1% of this capacity is currently being exploited. Furthermore, Ethiopia also has a vast potential of other alternative energy resources that are still unutilized, and the country is one of the least energy intensive countries in the world. In 1998/99 traditional biofuels (fuel wood, animal dung, crop residues and charcoal) constituted over 94 percent of the country's energy consumption (see Appendix Table 1A.2). In 2001 solid biomass still accounted for about 93 percent of the country's energy consumption and over 95 percent of the population relied on solid biofuels (see http://earthtrends.wri.org/pdf_library/data_tables/ene1_2005.pdf) There is heavy dependence on these biofuels. As is clear from the columns under primary energy in Appendix Table 1A.2, most of these biofuels are also consumed at the household level and mainly in rural areas.[1] Such heavy dependence or reliance on biofuels also contributes to the environmental and land degradation (Mekonen, 1998).

The remainder of the chapter is organized as follows. The next section presents a conceptual framework of the fuel problem, land degradation and rural poverty in Ethiopia. Section 1.3 household tree planting, fuel demand and stoves: literature review. Section 1.4 describes research objectives and research questions; and Section 1.5 is the outline of the thesis.

1.2 Fuel Problem, Land Degradation and Rural Poverty in Ethiopia: A Conceptual Framework

The links between environmental degradation and poverty in developing countries have been well established (Reardon and Vosti, 1995; Scherr, 2000). Environmental degradation resulting from unsustainable use of forests and failure to replenish (recycle) the soil nutrients removed in the production cycle are widespread in Africa (Sanches *et al*., 1997). Likewise in Ethiopia *land degradation* is the major cause of agricultural stagnation and rural poverty (Hagos *et al*., 1999; Hengsdijk *et al*., 2005). Land degradation has different facets. One of these - nutrient loss (depletion) through the removal or burning of dung, which was a source of soil humus and fertility, for fuel purposes - brought about a progressive decline in land quality and agricultural productivity.

[1] Appendix Table 1A2 also makes a distinction between *primary energy* and *secondary energy*. *Primary energy* consists of any natural energy sources available in nature such as biomass, hydro, solar, coal, etc which can be transformed into a useful energy form whereas *secondary energy* is energy in a form ready for transport or transmission or use (RWEDP, 1997).

Scherr (2000) identifies soil erosion, soil fertility (nutrient) depletion, de-vegetation, loss of biodiversity, soil compaction, acidification, and watershed degradation as common problems of land degradation in the densely-populated marginal developing regions. This study focuses on the soil fertility (nutrient) depletion aspect of land degradation. Scherr found out that conditions affecting the adoption of resource-conserving technologies, local endowments as well as local institutions that are supportive to the poor are key factors that determine the interactions between poverty and environment. She argues that, among others, improving the productivity of poor people's natural resources assets as the main strategy to simultaneously address poverty and environmental (land) degradation. In addition, Scherr also argues that more research is needed to explore and understand the agriculture-environment-poverty nexus.

In their synthesis of woodfuels, livelihoods and policy interventions, Arnold *et al*. (2006) argue that the fuelwood discourse or crisis has shown a classic pattern of thesis and antithesis over the last few decades. That the use of fuelwood in developing countries is apparently not growing at the rates assumed in the past. Nonetheless, they also acknowledge that the complex reality in developing countries could seldom be captured in such a clear-cut narratives. For example, it might not he the case for Ethiopia, hence the need for location or country specific studies. They argue that responses to fuelwood shortage are largely conditioned by the household's capacity to access resources such as labor, land, and money as well as other factors such as access to common pool resources availability and price of substitute fuels. That, particularly in rural areas, users switch first to less preferred alternatives (tree species) and then to crop residues, animal dung, and even noxious weeds, as supplies of the preferred types of fuelwood (tree species) diminishes. That such switching or substitution is diverting dung and crop residues from their high value uses in agriculture, such as soil fertility maintenance, and causes ecological (environmental) damages. They also argue that energy strategies and programs in the past have also emphasized on or given attention to measures to improve the efficiency with which the woodfuels are used and that efforts to promote stoves for this purpose have shown success only in towns, where the stoves are seen as saving money, but not in rural areas, where they are merely saving time or biomass. That there is uncertainty –knowledge gap- about the potential for further interventions to promote stoves. Arnold *et al*. also argue that, in selected situations, there appears to be the scope for interventions that could increase the spectrum of low cost, multi-purpose woody species and husbandry options available to farmers, to enable them to increase supplies of fuelwood as a co- or bi-product of managing trees and shrubs on-farm for other benefits.

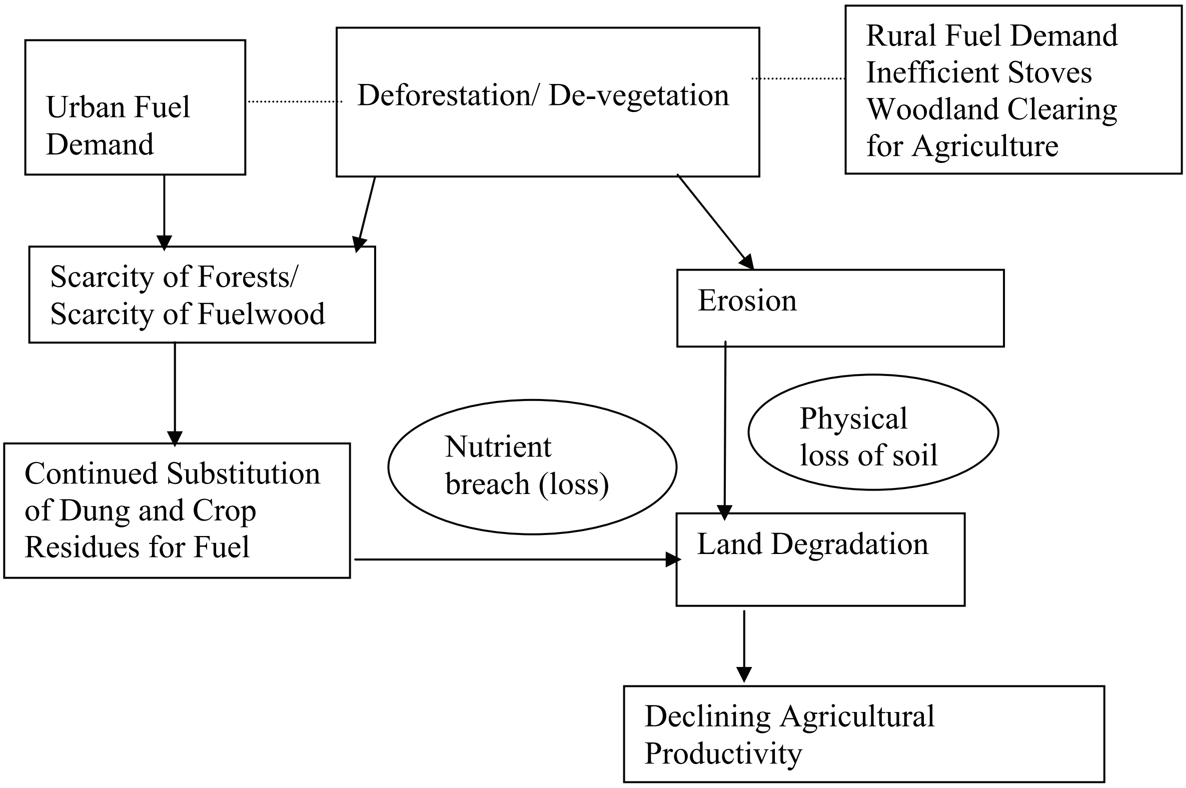

Figure 1.1 *Conceptual model of land degradation in Ethiopia*[2]

The conceptual model in Figure 1.1 helps us to grasp or visualize the channels through which the fuel problem affects land quality (degradation), agricultural productivity and rural poverty. After many years of deforestation, about 12 percent of the country's surface is covered with forests (FAO, 2006) compared to 40 percent some 100 years ago. Among all others, the use of inefficient stoves also contributed to the deforestation (de-vegetation) (see upper right corner of figure). The deforestation (de-vegetation) has led to the existence of two major consequences. That is, two major channels through which the fuel problem affects land quality and agricultural productivity: a shortage of fuelwood (or fuel crisis) and erosion (or loss of topsoil) (see upper part, Figure 1.1). Fuelwood has increasingly been replaced by dung and crop residues. This burning (removal) of dung and crop residues which were previously sources of soil humus and fertility in turn resulted in a progressive decline in land quality and agricultural productivity. This has increased farmers' vulnerability to shocks, food insecurity and poverty (Amsalu, 2006). The reduction in agricultural productivity from lost nutrients associated with the use of animal dung for household fuel in Ethiopia accounts for about 7

[2] Legend: Arrow lines stand for causation; dotted lines imply connections (underlying factors); a rectangular box stands for phenomenon (cause) or outcome of the phenomenon (causation); an oval box implies a facet of land degradation.

percent of agricultural GDP (Berry *et al*., 2003).[3] The use of animal dung for fuel is so widespread and severe especially in the northern parts of the country. The growing shortage of fuel wood for household consumption in these areas has led to most of the dung produced in the area being principally used for cooking.

Moreover, urban centers have long been dependent on the rural hinterlands for their fuel. The growing fuel scarcity has resulted in higher firewood prices in urban centers, thereby undermining the livelihoods of the urban poor. The dependence of urban centers for their fuel on the rural hinterlands has also aggravated the deforestation (Barnes *et al*., 2004). Especially in the environments of very limited wood resources, such as the African Sahel, the increasing dependence of the urban centers on rural hinterlands has a much more serious environmental consequence. Even with lower levels of per capita consumption of fuelwood the concentration of a large number of people in smaller areas combined with the preference of urban households for charcoal over wood intensifies the pressure on the existing forests resources (Arnold *et al*., 2006).

Four issues (topics) stand out quite apparent from the foregoing reviews (discussion) and the conceptual model presented in Figure 1.1 above. Firstly, that land degradation is a major concern which is undermining the livelihoods of the rural people in the densely populated marginal developing regions like Ethiopia. The diversion of dung and crop residues from their high value uses in agriculture for fuel purposes, because of the shortage of fuelwood, is the main cause underlying the problem. That innovations such as resource-conserving technologies and other technological alternatives that improve the productivity of poor people's natural resources assets and simultaneously address poverty and environmental (land) degradation could be thought as a means to deterring the environmental (land) degradation and redressing the problem.

Secondly, that, among all others, the use of inefficient stoves also contributed to the deforestation (de-vegetation). In fact some further argue that, particularly in urban areas, poorer people are paying higher prices for useable energy than more well off consumers because of the inefficiency of the traditional or biofuel using cooking stoves and kerosene lamps, and that inefficient stoves also involve financial burden or inequity (Barnes *et al*., 2004). However, in spite of the scope for reducing the demand for biofuels such as fuelwood and, hence, the pressure on natural resources through improvement in the efficiency of the

[3] Alternative accounts of economic or financial costs of land degradation and of the reduction in agricultural productivity from lost nutrients associated with the use of animal dung for household fuel in Ethiopia can be found in Newcombe (1989), Sutcliffe (1993), Bojö and Cassells (1995), and Yesuf *et al*. (2005).

stoves and despite the attempts in the past to popularize the improved stoves, evidences about the success of these stoves are mixed. That there is a knowledge gap about their effectiveness and the potential for further interventions to promote these stoves and the need for such study.

Thirdly, that in some situations, there appears to be the scope for supply-side interventions that could increase the spectrum of low cost, multi-purpose woody species and husbandry options available to farmers, to enable them to increase supplies of fuelwood as a co- or bi-product of managing trees and shrubs on-farm for other benefits. Nevertheless, the scope for such options and the status of agro forestry and the extent of private tree planting in the study region (Ethiopia) have not been well documented. More importantly, it is not clear whether the household (private) and community tree plantings transpire into more wood being available for fuel. These all are important issues that require empirical investigation.

Fourthly, it has been clear and Figure 1.1 also demonstrates that the fuel problem and land degradation also involve an urban dimension. This implies that rurally conceived and rurally focused solutions would be insufficient to reduce the environmental damage and address the problem; therefore, there is a need for a broader rural-urban approach to the problem. However, previous studies have focused more on the rural-side and little has been done with respect to the urban dimension of the problem (cf. Amacher *et al*., 1993 and 1996; Heltberg *et al*., 2000; Kohlin and Parks, 2001). This research combines both the rural-side and urban-side of the problem.

1.3 Household Tree Planting, Fuel Demand and Stoves: Literature Review

Amacher *et al*., (1993); Bluffstone, (1995); Amacher *et al*., (1996); Heltberg *et al*., (2000); and Chen *et al*., (2006) are among the more interesting empirical works on biomass fuel supply and demand. The first four studies mentioned were based on data from Nepal and the last from China. Amacher *et al*., (1993) base their research on three important hypotheses; (1) community forests are crucial source of fuelwood, (2) women and children are the crucial collectors of fuelwood, and (3) agricultural residues and improved stoves are substitutes for fuelwood. They used a separable household model and concluded, amongst others, that the role of community forests and of women and children in fuelwood collection are important but not unique. Both fuelwood and combustible crop residues tend to be inferior goods depending on the level of income of the household, and that households substitute residues for fuelwood only reluctantly. However, although it could be argued that residues are less preferred materials as well as being inferior, it is doubtful that fuelwood is an inferior good in the context of rural areas with little or no access to modern energy sources.

Amacher *et al*., (1996) found out that improved stoves significantly decrease fuelwood consumption and can be an important curb on deforestation. They also found that responses to policy intervention by collecting and purchasing households are alike, and acknowledged the need for recognizing such behavioral distinction for policy targeting. Bluffstone (1995) examined the deforestation behavior of small-holder farmers as conditioned by off-farm labor market functioning, by employing three different dynamic models for three different scenarios: A rural agro-forestry system with classic open access problem and a perfect off-farm labor market; a model of forest dynamics and household behavior; and an alternative behavioral model under open access without off-farm labor market. Bluffstone concluded that agro-forestry is likely to be stable as long as off-farm labor market exists, and that changes in technology of production and prices also profoundly influence the time path of agro-forestry systems, besides the functioning of the labor market. Based on experience from Western Kenya, Scherr (1995) made three main generalizations: that agroforestry evolved historically in response to land-use intensification, that differing livelihood strategies and resource constraints implied differing choices of agroforestry practice on particular farms, and that associated risks affect farmers' adoption of agroforestry technologies particularly in the case of new technologies.

Using data from India Heltberg *et al*., (2000) found that households respond to forest scarcity by substituting fuels from private sources for fuelwood from forests. Based on data from three villages (i.e., one remote and two with good market access) in rural Jiangxi Province of China, Chen *et al*., (2006) found out that more education decreases fuelwood consumption and time spent on collection in both the remote village and villages with good market access. They also found that possession of an improved stove does not affect fuelwood consumption in the remote village whereas it increased fuelwood consumption in the villages with good market access. This was contrary to the arguments promoting improved stoves. In addition, these studies never considered the case of animal dung given that it constitutes an important fuel source in the context of our study area and its profound implications on land degradation and agricultural productivity. Barnes *et al*. (1993) found out that improved stove programs have been most successful when targeted to specific areas where fuelwood prices or collection time are high. Involving local artisans, field testing and consumer surveys were critical to the adoption of the stoves.

Patel *et al*. (1995) analyzed tree growing and tree planting decision of households. They found out that farmers are responsive to incentives to plant trees, and tree planting is competitive with other production activities. They also attributed the differences among farm households in this regard to differences in factor costs owing to different factor endowments and poorly functioning factor markets. Mekonen (1998) also analyzed tree growing and tree planting decisions of households. But neither of them dealt with the question of whether or not household tree planting (growing) translates into their use for fuel. Kidanu (2004) found out that planting *Eucalyptus* as field (plot) boundaries leads to stabilizing the livelihoods of resource poor farmers and would help smallholder farmers increase their income and achieve food security. Kidanu also suggested that short rotation of *Eucalyptus* based agroforestry system could be practiced in the seasonally waterlogged highland vertisols of Ethiopia to meet wood demand, without inducing significant nutrient depletion and crop yield loss.

1.4 Research Objectives and Research Questions

As pointed out in the earlier section, fuel problem (scarcity) and land degradation are intertwined problems leading to agricultural stagnation and rural poverty. The problems are multi-faceted and transcend from rural-urban through demand-supply of biofuels and technological considerations such as cooking (stove) appliances used. This research will examine the determinants of household fuel supply and demand based on datasets from sample households in rural-urban areas of Tigrai.

1.4.1 Research objectives

The central goal of this research is to look for options to improve or address the fuel problem and land degradation through a broader understanding of the behavioral factors underlying household fuel demand and supply. It seeks to broaden our knowledge as to how these factors could be used as instruments to tackle the fuel problem and land degradation and the dimensions that need to be envisaged in tackling the problem especially in the context of Ethiopia. The intention is, therefore, to look for simultaneous options that act on both the supply-side and the demand-side through an in-depth analysis of the rural-urban side of the fuel problem. More specifically, the following research objectives are envisaged:

- To evaluate the effectiveness of the improved stove diffusion activities.
- To assess the role of private and community tree planting and analyze the tree growing behavior of farm households.
- To examine alternative technology options for the improved availability and use of biofuels.
- To analyze energy consumption patterns and identify the important determinants of household energy consumption in rural-urban Ethiopia.

1.4.2 Research questions

In light of the aforementioned research objectives this study strives to answer the following key research questions:

1. How effective is the improved stove being promoted as a remedy to the fuel problem and land degradation?
2. Would household or private tree growing imply more wood being available for fuel?
3. What technological alternatives could be envisaged in light of alleviating the fuel problem and the attendant land degradation?
4. What is the potential to reduce the pressure of urban centers on the rural hinterlands (or, in general, how should the urban fuel issue be addressed)?

1.5 Outline of the Thesis

The thesis contains eight chapters including the foregoing introductory chapter. Chapters 2 and 3 are all about the broader issues in relation to study area contexts as well as the datasets used and the methodological approach pursued. They, therefore, set the stage as a backgound for the ensuing empirical chapters, and the emprical chapters 4-7 tackle specific research questions posed in this chapter. The remainder of the thesis is organized as follows.

Chapter 2 gives an overview of economy and environment of Tigrai. It provides a description of the study area, helping acquaint readers with the study region Tigrai.

Chapter 3 deals with the research process, the survey methodology and data.

Chapter 4 examines the potential of the strategy of disseminating improved stoves in the rehabilitation of agricultural and forests lands in Ethiopia.

Chapter 5 examines the potential of the tree growing strategy, i.e., both at the community and household levels, as a remedy to the fuel problem.

Chapter 6 discusses the potential of the biogas innovation for redressing the problem of land degradation in Ethiopia.

Chapter 7 assesses the potentialities for reducing the pressure of urban centers on the rural hinterlands.

Finally, Chapter 8 discusses the results, draws conclusions, outlines policy implications and puts forth issues for further research.

Appendix 1A

Table 1A.1 Estimates of area under all crops by size of holding for individual peasant holders Ethiopia in 2003/04 ('000 ha)

Size of holdings (ha)	Cereals									Pulses (total)	All annual crops	All perennial crops	All crops
	Teff	Barley	Wheat	Maize	Sorghum	Millet	Oats	Rice	Total				
Under 0.10	0.92	1.12	0.99	6.90	1.10	0.11	*	*	11.13	1.79	13.44	7.521	24.29
0.10-0.50	81.45	49.30	53.05	112.55	82.43	7.08	1.65	*	397.65	61.85	473.36	144.544	664.71
0.51-1.00	267.81	145.35	168.40	266.67	252.00	35.26	3.30	0.60	1,139.39	169.07	1,362.16	190.159	1,625.34
1.01-2.00	710.66	322.62	371.56	492.25	468.12	113.35	8.51	*	2,490.18	392.86	3,066.04	210.823	3,373.18
2.01-5.00	826.74	348.02	427.31	434.90	435.88	136.32	12.76	1.42	2,623.35	428.74	3,327.98	115.173	3,518.86
5.01-10.00	92.79	48.74	69.50	41.88	40.85	11.75	3.74	*	309.28	41.84	391.93	9.448	411.47
10.01 and above	8.69	*	*	2.00	*	*	*	-	27.99	3.38	34.37	*	36.31
Total	1,989.07	920.13	1,098.91	1,367.11	1,283.65	304.76	30.05	*	6,998.98	1,099.53	8,669.29	679.09	9,654.16

* Estimates not reported due to high coefficient of variation

Source: CSA (2004)

Table 1A.2 National energy balance of Ethiopia 1998/99 (in Tera-Joules)

	Primary energy						Secondary energy			
	Woody biomass	Crop residues	Process residues	Dung	Hydro	Crude oil	Briquette & biogas	Charcoal	Electricity	Petroleum fuels
Gross supply	685,531	5,449	NA	469,840	6,803	0	0	0	0	43,364
Production	685,321	5,449	NA	469,840	6,803					
Imports						0				43,364
Stock changes										0
Inputs to conversion	38,210	10	0	8	6,803	0	0	0	0	715
Refinery fuel										0
Out-puts from conversion	0.00	0	0	0	0.00	0	2	8,788	5,910	0
Losses from conversion	29,422	10	0	6	1,020					587
Transmission & distribution loss									1,066	0
Exports										0
Fertilizer		NA		NA						0
Other non-energy uses	65,759	NA	NA	NA	0	0	0	0	0.00	0
Net energy supply	581,351	54,450	0	56,333	0	0	2	8,788	4,843	40,475
Final energy consumption	581,352	54,450	0	56,333	0	0	2	8,788	4,843	40,475
Households	542,141	52,010	0	53,891			2	8,565	1,832	7,332
Urban	34,969	2,824		3,263				5,856	1,832	4,161
Rural	507,172	49,186		50,629				2,709		3,170
Agriculture	0.00	0.00	0	0.00			0	0	0	1,497
Transport	0.00	0.00	0	0.00			0	0	0	26,743
Industry	17,101	1,409	0	1,396			0	112	1,864	4,573
Services and other	22,110	1,032	0	1,046			0	108	1,145	331

Source: ADC (2003)

Chapter 2 Economy and Environment of Tigrai: An Overview

2.1 Background

Tigrai is the most northern region of Ethiopia with Axum at its heart. The area is known for its ancient human settlement history (Phillipson, 2000). As explained earlier the Axumite civilization parallels ancient civilizations in the Middle East and Greece. The region's environmental resources particularly forests have been exploited at a more intensive scale for human use. As a result fuelwood has increasingly been substituted by dung and crop residues. Household fuel consumption in Tigrai over the past several decades indicates a rapid growth in the share of animal dung. For instance, the share of dung increased from about 10 percent of total household fuel in the 1980s to about 50 percent by 1999 (see Chapter 5).

The intentions of this chapter are twofold: firstly, to explain about relevant issues; and, secondly, to function as descriptive and first step towards the analytical parts of the thesis. The remaining of the chapter is organized as follows. Section 2.2 describes location, climate, demography and infrastructure. Section 2.3 is agriculture, land degradation and environment. Section 2.4 property rights in Ethiopia. Section 2.5 is energy and forestry and section 2.6 concludes.

2.2 Location, Climate, Demography and Infrastructure

2.2.1 Location

The Tigrai region is situated between $12^0 15^1$ and $14^0 57^1$ N latitude and $36^0 27^1$ and $39^0 59^1$ E longitude. It is bordered to the North by Eritrea; to the West by the Sudan, to the South by Amhara and to the East by Afar Regional States of Ethiopia. It covers a total of about 50,079 square km surface area. It belongs to the African drylands (African Sahel), which are often referred to as the *Sudano-Sahelian* Region (BoPED, 1998; Hunting, 1976a). Administratively, the region is divided into six zones as Western, Northwestern, Central, Eastern, Southern zones and the Mekelle Metropolitan Zone. Included in these six zones are 45 districts of which 33 are rural and 12 are urban (see Figure 2.1). A *tabia*[4] is the lowest administrative unit below *Woreda*/ district.

[4] *Tabia* is the name for Local County which constitutes about 1000 to 1500 households.

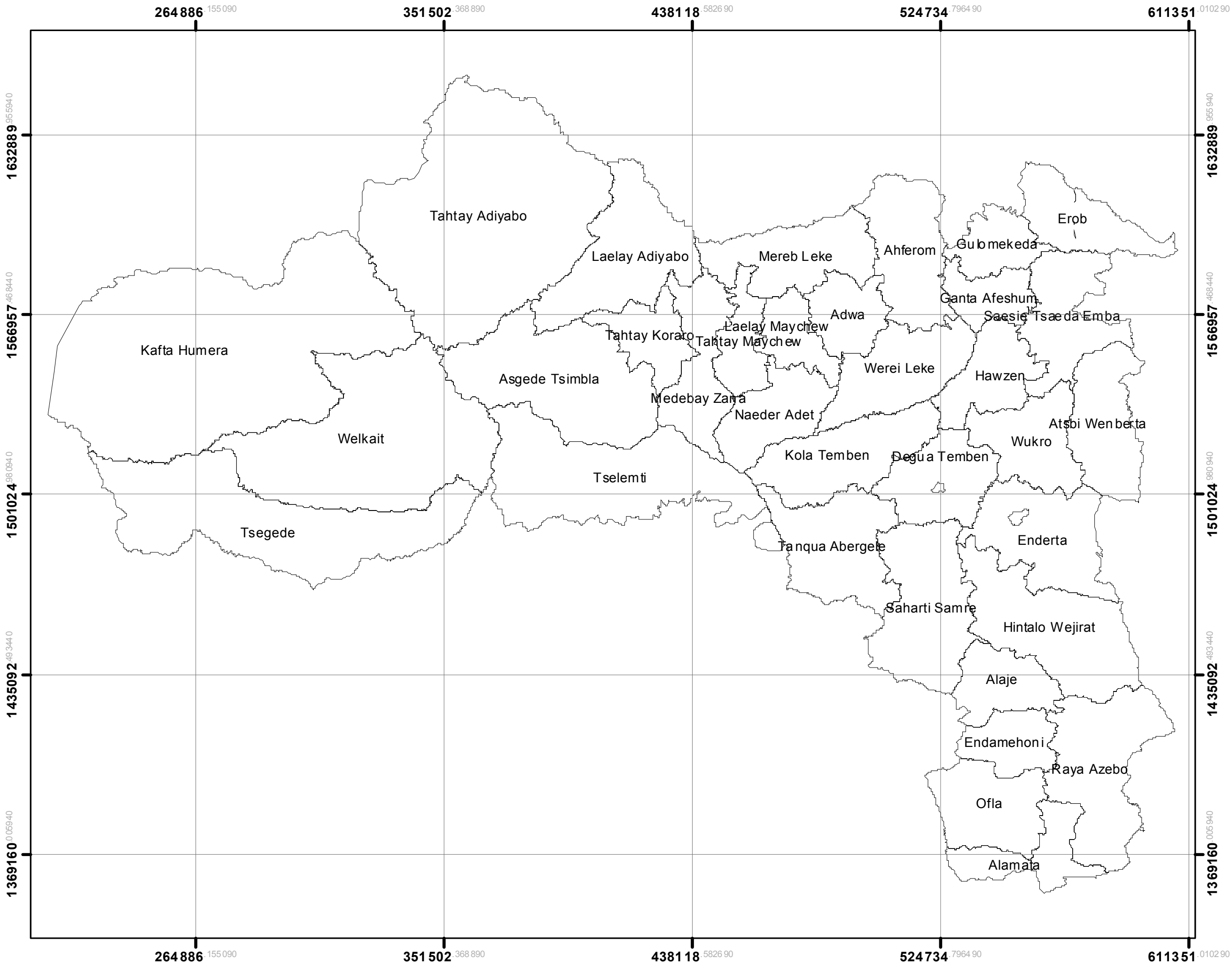

Figure 2.1 *Map of Tigrai by Woreda*

2.2.2 Climate (rainfall) and topography

Although most parts of Tigrai experience a mono modal type of rainfall, there are areas characterized by bimodal pattern with a small peak in April /May and a maximum peak in August. Spatially speaking, mean annual rainfall in the region varies between 600mm and 1600mm. Some parts of western Tigrai are the areas which receive relatively heavier rainfall. The amount of rainfall is moderate (700-1200mm) for most highlands in southern and western Tigrai, and very few parts in Eastern Tigrai. However, there are also areas experiencing less than 600mm mean annual rainfall. Rainfall risk or variability between years is the distinguishing characteristics of the region. In addition, most of it falls within three months and in high intensity. Generally, the wet period of the region can be taken as April/May to August/September (BoPED, 1998).

The topography of the region is characterized by highly undulating and variable landform. The rugged topography makes the land more prone to erosion. Altitude range in the region varies from less than 500 m[5] in the Eastern tip to over 3900 m in the South.

2.2.3 Population and demographic characteristics

According to the 1994[6] Census, the region had a total population of about 3.14 million of which about 81 percent were rural population. Table 2.1 provides population structure by age group and sex. The region had a total of about 0.72 million households out of which slightly over 83 percent were rural households. The total population of the region was estimated to be about 4.2 million by July 1, 2005 of which still about 81 percent are rural (CSA, 2004). The dependency ratio for the region is 94.9 percent (CSA, 1995). The population density is calculated to be 84.3 persons per square km (Table 2.2). The total fertility rate for the region is about 5.4 children per women. The corresponding figure for urban and rural areas of the region is 4.2 and 5.6, respectively. The infant mortality rate was 123 per thousand live births and under five-mortality rate for the region. The average life expectancy at birth for both sexes for the region was found to be 49.4 years, with 48.2 years for males and 51.5 years for females. (TRBIDMP 1997b)

Table 2.1 Population structure by age group and sex, Tigrai 1994 (‘000)

	Population			Share in total (%)		
	Male	Female	Both Sexes	M	F	Both sexes
0-9 years	502	486	988	16.0	15.5	31.5
10-14 "	219	198	417	7.0	6.3	13.3
15-24 "	283	312	595	9.0	10.0	19.0
25-49 "	340	404	744	10.8	12.9	23.7
50-64 "	130	138	268	4.1	4.4	8.5
65 & above	68	57	124	2.2	1.8	4.0
Total	1542	1595	3136	49.1	50.9	100.0

Source: CSA (1995)

[5] m is an abbreviation for meters above sea level
[6] It is important to note that years throughout this thesis refer to Gregorian (Western) calendar and not to the Ethiopian calendar, unless otherwise explained.

Table 2.2 Population size by sex, area and density, Tigrai overall and by zone: July 2005

Zone	Population ('000)			Area	Density
	Male	Female	Total	(square km)	(persons/km^2)
Tigrai overall	2,080.0	2,143.0	4,223.0	50,078.64	84.3
Western	135.0	129.6	264.6	12,441.26	21.3
Northwestern	359.3	354.9	714.2	12,267.58	58.2
Central	614.6	637.5	1,252.1	10,353.50	120.9
Eastern	378.4	408.6	787.0	5,705.34	137.9
Southern	510.7	532.6	1,043.3	9,286.52	112.3
Mekelle (Metropolitan)	82.0	79.7	161.7	24.44	6,617.8

Source: CSA (2004)

2.2.4 Physical infrastructure

The region is also catching up in terms of infrastructural development. Most areas of Tigrai which were poorly accessible by vehicle are now better accessible. The regional road density which was 15km/1000km^2 in 1995 has grown to 25km/1000km^2 by 2005. It is clear that there are not enough roads to connect places and the already existing roads are also of low quality. This implies poor market integration and high transaction costs both from the input and product markets perspectives. There are about 130 thousand fixed phone lines in the region. Moreover, mobile phone and broad band services have recently been introduced.

2.3 Agriculture, Land Degradation and Environment

2.3.1 Agricultural resource base

Agriculture and allied activities (crop, livestock and forestry) have the largest contribution to regional GDP (Gross Domestic Product). Its average share for the last five years has been 57% in real terms (BoPED, 2000). Within the agricultural value added, crop and livestock constitute the greatest share; with nearly 95 percent in the regional agricultural GDP and 54 percent in the total regional GDP. Within the overall regional GDP crop and livestock constitute 40 and 14 percent, respectively. Also industry, distributive services and other services are of considerable importance. Table 2.3 below presents real growth rate of the region's economy with reference to fiscal years 1995/96 to 1998/99. Considering these four fiscal years, the industry and distributive service sectors appear to be the fast growing relative to agriculture.

Table 2.3 Real growth rate of regional GDP by sector (at factor cost) during the years 1995/96 to 1998/99

	Growth rate (in %) by year				
Economic Activity	1995/96	1996/97	1997/98	1998/99	Average
1. Agriculture, forestry and fishing	0.42	24.55	-13.01	12.55	6.13
2. Industry	11.11	4.48	7.32	5.64	7.14
3. Distributive services	18.55	6.95	8.44	19.40	13.33
4. Other services	6.71	-0.79	6.41	6.26	4.65
Regional GDP	5.01	15.37	-4.94	10.87	6.58
Population (000,000)	3.00	2.94	2.89	2.83	2.92
Regional per capita GDP (*Birr*)	1.96	12.08	-7.60	7.81	3.56

Source: BoPED (2000)

Table 2.4 Distribution of land under various uses in Tigrai

Use	Area ('000 ha)	% of the Region
Cultivated land	1,299.4	25.2
Forest land	436.2	8.5
Grazing and browsing	1,458.7	28.3
Un-utilizable land	1,495.2	29.0
Others	464.0	9.0
Total	5,153.5	100.0

Source: Assefa (2000)

Table 2.4 gives details on the distribution of land under different uses in Tigrai. Crop production in the region is cereal dominated. Cereal crops account for about 84 percent of the cultivated land, while oil crops and pulses constitute 9 percent and 7 percent, respectively. Perennial crops constitute for about 0.4 percent of total cultivated land. Regionally speaking, sorghum, barley and *teff* are the three most import cereal crops in terms of area coverage (Table 2.5). However, the role may differ or be the other way around depending on area specific conditions. Sesame is the single most important crop within the oilseeds, accounting for 7.5 percent of the total cultivated land and 83 percent of the area under oil seeds. Traditional technology which existed already for centuries and low level of capital input are used in farming. The average farm size in the region is 0.97 hectares. Table 2.6 provides comparison of the relationship of size land holding and average household size of the region with the country level average.

Table 2.5 Distribution of area by crop type in relation to area under cereal crops and total cultivated land, Tigrai (1994- 1998 and 2001/02) (in %)

Crop type	1994-1998		2001/02	
	Area under cereal crop	Total cultivated land	Area under cereal crop	Total cultivated land
Teff	12.0	10.0	26.9	23.0
Wheat	10.4	8.7	13.4	11.5
Barley	14.4	12.1	11.7	9.9
Mixed Barley -wheat	4.3	3.6		
Oats	0.04	0.03	0.08	0.07
Sorghum	28.9	24.3	24.3	20.8
Maize	8.5	7.5	12.0	10.3
Millet	1.5	1.3		
Finger Millet	12.7	10.7	11.5	9.8

Sources: Gebreegziabher (2001) and CACC (2003a)

Table 2.6 Comparison of size of land holding and average household size in 2001/02, country level and Tigrai

Size of holding (hectare)	Country level		Tigrai region	
	% of households	Average hh size	% of households	Average hh size
Under 0.10	7	3.6	6	3.4
0.10 - 0.50	28	4.5	32	4.3
0.51- 1.00	26	5.1	31	5.2
1.01- 2.00	25	5.6	22	5.6
2.01- 5.00	13	6.4	8	6.2
5.01-10.00	1	7.6	1	6.3
>10.0	0	7.6	NA	NA
Total	100	5.1	100	5.0

NA= not available

Source: CACC (2003a).

Livestock also constitute an important part of the region’s economy. The species composition of the region's livestock population in comparison to country overall has been provided in Table 2.7. Livestock are kept partly as capital, which can be turned into cash when required, but, most importantly, cattle are kept as breeding stocks to provide draught power for agricultural operations (Hunting, 1976b). Donkeys serve as the principal pack animals complemented by camels, mules and occasionally horses. In some instances, however, these pack animals are also used for ploughing (BoANR, 1999b). Crop residues are the major livestock feed source in the region followed by grazing lands, browse and crop aftermath, respectively. Free and uncontrolled grazing is the dominant system of grazing. Livestock graze/ browse in flock freely on grazing/ browse lands as well as on cultivated fields after harvest. However, a distinction may be observed between dry and wet season.

During the rainy season, when most arable lands are under crops, livestock are restricted to graze on valley bottoms, farm strips and on hillsides herded by children.

Table 2.7 Livestock population of Tigrai in relation to country overall (in number of heads) in 2001/02 ('000)

Species	Country overall	Tigrai	Share of Tigrai (in %)
Cattle	41,527	2,668	6.4
Sheep	14,656	687	4.7
Goats	13,662	1,759	12.9
Horses	1,504	8	0.5
Asses (Donkeys)	3,963	403	10.2
Mules	354	16	4.5
Camels	448	37	8.3
Poultry	42,916	5,000	11.6
Beehives	4,602	229	5.0

Sources: CACC (2003b)

Considerable resources are being invested on modern inputs and technology packages delivery through the regional agricultural extension program to boost production. Based on data from two districts of Tigrai, Gebreegziabher *et al*., (2005) found that the discrepancy between the observed level of output and the maximum attainable level of output is dominated by random factors out side the control of the farmer justifying the need for provision of modern inputs and technology packages to boost production. Moreover, the possibility for increased production through area expansion seems to have reached to its limit, making increasing production through sustainable land management the only alternative.

2.3.2 Land degradation and environment

Three set of evidences witness the Axum Empire was rich in resources base and the environment at the first millennium (even earlier) was significantly different from what is now. From paleoclimatic or geo-archaeological evidence Butzer (1981) found that at the peak of Axumite civilization stronger and more reliable spring rains allowed two crops yearly without irrigation, compared to only one with modern summer rains. However, later towards the end of first millennium intense land pressure and erratic rainfall triggered soil destruction and ecological degradation. Butzer concluded that two factors climate change and environmental degradation contributed to the decline of Axumite civilization.

Upon paleoenvironmental reconstruction based on several infilled valley deposit sequences Machado *et al*., (1998) found out that the past 4000 year was comprised of three major wetter periods during which soils were formed, two degradation episodes during which there was an increase of sediment yield from the slopes into the valleys, and pattern of increasing aridity. By matching stratigraphic records together with historical chronicles they found a pattern of increasing aridity for the past 1000 year, in general, and since the early 17th century in particular. Based on pollen and charcoal analysis of sediment cores from two lakes in the highlands of northern Ethiopia, Darbyshire *et al*., (2003) established sequence of vegetation change for the last 3000 years. They found the natural, pre-disturbance vegetation of the area was *Podocarpus-Juniperus* forest. Then, forests were cleared and replaced by a secondary vegetation of *Dodonaea* scrub and grassland at about 500 BC, following the population movement and Semitic migration to northern Ethiopia. This vegetation persisted for about 1800 years. Between 1400 and 1700 AD *Juniperus* forest, with *Olea* and *Celtis*, expanded as a result of drought-induced depopulation followed by increased rainfall. Two issues drawn out of this review are: one, mainly the human impact but also environmental factor were responsible for the vegetation change (degradation) observed in Tigrai; two, the findings also implied that the area is capable of supporting forest under appropriate practices of sustainable management.

Soil erosion and soil nutrient depletion appear to be the major land degradation problems currently facing the region. Most of the soils in the region have low nitrogen and phosphorus content (TRBIDMPP, 1997a). The major cause for such high loss of nutrients is the use of dung and crop residues as household fuel sources. The burning of dung and crop residues which were sources of soil humus and fertility has brought about a progressive decline in land quality and agricultural productivity. TFAP (1996a) and BoANR (2003) attempted to quantify the magnitude of the damage on agricultural output of the region caused by land degradation. It was estimated that the losses caused by nutrient removal, that is, due to the use of dung and crop residues for fuel purposes accounts for about 10 percent of the annual grain output of the region.[7] In addition, the lower humus content of the soils results in poor water holding capacities and hence accelerated erosion. Given the topography and the very low vegetation cover of the region, the likely impacts of erosion would also be relatively greater in Tigrai compared to rest of the Ethiopian highlands.

[7] Nutrient content of crop residues and dung annually burned for fuel is converted into its Urea and DAP equivalent and this Urea and DAP equivalent is then used to calculate the amount of grain output forgone as a result.

Table 2.8 Annual soil (crop) nutrient losses and crop production foregone due to nutrient losses and physical soil erosion in Tigrai

Zone	Crop Residue		Dung		Total Urea (tons)	Total DAP (tons)	Gain production forgone (tons)	
	Urea Equal (N) (tons)	DAP Equal (N) (tons)	Urea Equal (N) (tons)	DAP Equal (N) (tons)			Nutrient Loss	Soil Erosion
Southern	342	34	2926	920	3267	954	7473	305
North Western	206	21	934	294	1140	314	2609	118
Central	501	50	3363	1057	3864	1107	8840	681
Western	72	7	201	63	273	70	625	106
Eastern	157	16	1839	578	1996	594	4565	115
Mekelle	0	0	0	0	0	0	0	0
Region	1277	128	9263	2911	3039	3039	24112	1324

Source: BoANR (2003)[8]

2.3.3 Agro ecology and farming systems

Agro ecology

Tigrai can be divided into five traditional agro ecological zones based on altitude, desert (less than 500 m), lowland, midland, highland and frost (over 3200 m)[9]. There is a pocket of desert land in the eastern tip of Erob, east Tigrai. The lowland agro climatic zone is mainly found in the western block excluding the Wolkait and Tsegede area. It also includes the gorges in the eastern block. The region has a big area of midland agro climate in the eastern landform. This constitutes the area that has been cultivated for several years. The highland agro climatic zone is found in three different areas of the region, except than central zone. There exist some mountain areas that can be designated as frost in western and southern Tigrai. A more detailed account of different agro climatic zones in the region is given in Table 2.9 below.

Table 2.9 Traditional climatic zones and their physical characteristics

Traditional Zones	Altitude (m)	Climate	Average annual temperature (C^0)	Average annual rainfall (mm)
Desert	< 500	Hot arid	> 27.5	< 200
Lowland	500-1500	Warm semi-arid	27.5 - 25.0	< 700
Midland	1500- 2300	Cool Sub-humid	25.0 - 18.0	500 - 1000
Highland	2300- 3200	Cool and humid	17.5 - 10.0	700 - 1200
Frost	> 3200	Cold and moist	< 10.0	> 1200

Sources: BoANR (1999a)

[8] Urea and DAP (Diammonium Phosphate) are commercial fertilizers. Urea is a white crystalline solid nitrogen fertilizer containing 46% nitrogen and DAP is mainly phosphate fertilizer with 18% nitrogen.

[9] The traditional/ local nomenclatures Bereha, Kolla, Woina Dega, Dega and Wurch are translated as desert, lowland, midland, highland and frost zones, respectively.

Farming systems

A Small-holder mixed farming system is dominant in the Region. There are also farmers who own larger populations of cattle and goats and depend totally on livestock production. At the other extreme, there are farmers who totally depend on crop production. In this latter system, the farmers either lease-out their land to others who own oxen and receive an agreed proportion of the produce or hire oxen from others and work on the land by themselves. These farmers depend directly or indirectly on oxen traction for their crop production. Following TRBIDMPP (1997a) six major farming systems may be identified in Tigrai. These are the (i) cereal based oxen-plough single cropping system; (ii) cereal based oxen-plough double cropping system; (iii) irrigated agriculture; (iv) commercial farming; (v) agro-pastoral; and (vi) gum, incense and honey collection.

The *cereal based oxen plough single cropping system* constitutes the major and dominant farming system in the region. It is practiced by peasant farmers in a wide range of agro-ecologies and altitudes ranging from below 500 meters in the semi-arid Humera plains up to over 2800 meters. It is a mixed farming system where peasant farmers produce crop and livestock by using traditional methods at a substantial level. Single cropping is the dominant feature of the farming system. Farmers grow mainly cereals under rain-fed conditions and crop production takes place in the main (*Meher*) cropping season. The *cereal-based oxen-plough double cropping system* is practiced in the southern part of the region, especially in the Wofla, Endamehoni and Alagie districts. The double cropping system is characterized by two crop growing seasons - the *Belg* (short rainy season) and *Meher* (long rainy season). Under this system farmers grow and harvest crops twice a year. Oxen power is the major means of land preparation and seeds are spead during planting time. Livestock are kept on natural pasture and stable throughout the year. Crop and livestock production is carried out in the traditional way mainly for subsistence. In general, *Belg* crops cover 4 percent of the area and constitute 3 percent of the total crop production.

Small-scale traditional *irrigation agriculture* has existed in the region for a long time. However, the area covered and the irrigation management levels have been very limited, thus having little impact on total crop production of the region. For most traditional irrigation systems, water is diverted from perennial streams using temporary diversion structures during the dry season. But flood spreading or flood diversion using run-off water from higher altitudes and upper catchments is also practiced, especially in the Raya Valley, southern Tigrai. Except for the flood irrigation systems where sorghum, maize and teff are the major crops (ReST, 1996b), horticultural crops and maize are the main crops grown under the traditional small holder irrigation systems. There have been considerable efforts to develop and introduce micro-dams since 1999.

Commercial or large-scale farming is mainly found in Humera area, western Tigrai. A few commercial farms also exist in parts of Southern Tigrai. The total area under commercial farming is about 0.11 million ha. Sorghum, cotton and sesame are the most important crops grown in these large-scale farms. Semi nomadic and nomadic *agro-pastoral* systems are also practices in the region in lowland areas such as the northern tip of Humera and Wolkite weredas, in areas bordering Eritrea and the Mereb Basin as well as in Abergelle lowlands. Livestock production is a major occupation under this system with crop production being a minor undertaking. Hence, livestock and livestock products constitute the major income and food source for the people. *Collection* of gum, incense and, rarely, honey is minor farming activity that is practiced mainly in western Tigrai and parts of central Tigrai. However minor, honey *collection* is also practiced in eastern Tigrai. Subsistence crop production is the main occupation of the peasant farmers engaged in these activities. There are some elements of shifting cultivation in Humera and Abdrafi areas where the cut and burn system is used in order to change forests and bush lands into farming lands.

2.4 Property Rights in Ethiopia

2.4.1 Land

Historically, property rights to land in Ethiopia were vested in either *risti* system, the *gulti* system (private land holding), or the church. The *risti* system was the dominant type of land tenure in Tigrai before the 1975 land reform. It was a communal land tenure in which the right to land was not exclusive but shared. Members of each community have a common cognatic descent and lineage to a certain pioneer father who originally established a recognized claim over that defined unit of land. Under this system, an individual had usufruct rights to land (*risti* rights) in a given community only if he was able to establish a direct line of descent from the recognized original holder of the land. As was the case in the rest of Africa (Besley, 1995), *risti* system (communal land tenure) may be regarded as egalitarian in the sense that the distribution was based on the principle of equality, with the land allocated by lottery after being divided into parcels according to quality. The total land available is classified into three traditional soil (land) quality classes as good, moderate and low quality so that each lot includes a proportionate share of the three quality classes. Nevertheless, the individual's usufruct rights to land were not transferable to others through sale or mortgage, though there was room for temporary lease. Moreover, as the right to land under the *risti* sytem didn't imply a right to any specific parcel, land redistribution was undertaken periodically to ensure that new entrants (family members) were granted access. This implied land fragmentation. In addition, the fact that anybody's land parcels might be reallocated to a distance kinsmen and that no one could sell them for a profit nor leave it to a heir reduced a farmer's incentive to invest in long-term land improvements and, hence, implied land quality deterioration (Hoben, 1995; Hagos *et al*., 1999).

With the 1975 land reform (Proclamation No. 31, 1975), the previous system of tenancy was abolished. The proclamation made all land the collective property of the Ethiopian people and a concomitant measure of land redistribution was taken all over the country. Land was redistributed to the tillers (Nickola, 1988). The 1975 land reform gave rise to a class of free-holder subsistence producers having only usufruct rights. Land transfer rights through mortgaging, leasing, selling, or bequests as well as hiring of labor was prohibited. In addition to this countrywide phenomenon, subsequent land redistribution measures were also undertaken by the then rebels TPLF (Tigrai People Liberation Front) in Tigrai in the years between 1980 and 1990.

After the change in regime in 1991 a new constitution was drafted. Article 40 of the Constitution states: "the right to ownership of rural and urban land is exclusively vested in the state ... and shall not be subject to sale or exchange" (FDRE, 1995). The constitution guarantees the rights of access to land for peasants and pastoralists. It also specifies the right of individuals to improvements they made on land including the right to bequeath, transfer, remove or claim compensation for such improvements as the right expires. The mechanisms as to how these rights can be assured and other details on land issues are left to the regional states. Following the constitution, the current land policy of Tigrai states that land is collectively owned by the state and the people (TNRS, 1997). Hence, land is public property. Land redistribution stopped in Tigrai since 1991. The current land policy of the region officially prohibits further redistribution except for areas where public irrigation or other major infrastructural investments have been built. The current policy has certain merits in a sense that it allows some transfer rights relative to the 1975 land reform. It provides the holder the right to lease, the use of hired labor as well as the rights to rent and bequest. However, land cannot be sold or exchanged. The policy also prohibits the leasing (renting) of land for an indefinite period of time.

To counter the feeling of tenure insecurity among farmers, land titling or registration and issuing of land certificates has been undertaken in Tigrai since 1998 (Haile *et al.*, 2005). Nevertheless, whether farmers feel more secure in their tenure now than before? That is, to what extent the land policy and the recent attempts of land titling and issuance of certificates have contributed to investment efficiency are empirical questions which call for further research. Furthermore, there appear to be two opposing and perhaps diverging views as regards to property rights to land in the country. One favors state stewardship of land and the other favors a freehold system. A recent survey has showed that an average farmer prefers public ownership with improved security (Gebremedhin and Nega, 2005).

2.4.2 Forests

The 1975 land reform had loopholes in defining ownership or use rights with respect to trees grown on cultivated land. While it gave responsibility for further land redistribution and management of common property resources such as forests to the newly formed local peasant associations (PAs), no any mention was made about trees grown on cultivated land. The newly formed PAs were entrusted with the responsibility for managing forest resources of less than 80 hectares within their boundary (Nickola, 1988; Dejene, 1990). A formal use regulation regarding forest areas was lacking. Moreover, as the PAs were suddenly given the responsibility without any guidelines and had neither the institutional capacity nor the manpower to manage the forest resources, it resulted in a greater abuse of forests in the years following the 1975. Comparatively, the subsequent land redistribution held in Tigrai under the TPLF tried to take into account trees (perennial crops) on cultivated lands. Cultivated lands with trees and other investments were left intact to their original holders.

Three distinctions are now made regarding rights to trees (forests) in the country at large and Tigrai in particular. These are *private (individual)* tree holdings, *community* woodlots, and *state* forests. The *private* tree holdings include trees privately grown around homesteads and cultivated land for various purposes that fall under the category technically referred to as agro forestry. It also includes indigenous trees grown or managed for various purposes. Arguably, property rights here are vested in the individual farm household, except for the policy restrictions. Article No. 10.1 of the current land policy of the region (TNRC, 1995) also gives the ownership of trees found on the cultivated land to the user or the farmer to whom the holding belongs. It restricts cutting of economically important indigenous trees such as *Boswellia papyrifera*, *Acacia senegal*, *Ficus vasta*, *Diospyros mespiliformis*, *Faidherbia albida (Acacia albida)*, *Ficus sycomorus*, and *Podocarpus gracilor* found on cultivated land. However, the holder (farmer) is free to make use of sell or rent the yield, berries or exudes of such trees found on her land. Nevertheless, despite the aforementioned merits, there appear to be ambiguities in two important respects of tree tenure rights: Firstly, a farmer is required to get permits from the local *baitos* for cutting trees grown by one self, in the event of a need to cut the trees. Secondly, it prohibits the planting of Eucalyptus trees on cultivated fields.

The *community* woodlots are area enclosures and community plantations where the rights are vested in the respective community. The story of community woodlots in Ethiopia goes to the period between 1975 and 1990 when area enclosures and community plantations were initiated primarily for ecological regeneration as part of the environmental reclamation program. However, these proved unsuccessful presumably not only because they were top-down oriented but because they were largely ecological oriented and lacked economic linkages with the respective communities (Hoben, 1995). Cognizant of the previous failures, *community* woodlots in Tigrai after 1991 were initiated through a better participatory process with both ecological and economic objectives (Gebremedhin *et al*., 2003). These *community* woodlots are more or less regulated by the respective communities with some form of local bylaws. These bylaws most often emphasize input contributions and protection against human and livestock interference. The critical challenges in these *community* woodlots appear to be the use restrictions. With few exceptions, uses such as cutting trees (branches), shrubs, collecting fuel wood, etc are not allowed in most woodlots. The benefits received currently by the community constitute mainly of cut grasses. The *community* woodlots hence collective action might be viewed as viable resource management arrangements in areas with intermediate population density and more remote markets. However, it turns out that a further step is needed for *community* woodlots to incorporate utilization and benefit distribution issues in their bylaws which in itself, in turn, call for another institutional arrangement to handle those issues.

State forests constitute natural high forests preserved for biodiversity conservation and other purposes in which the property rights are vested in the state. It could be either national forest priority area (NFPAs) or regional forest priority areas (RFPAs). Cross-boundary forest areas also fall within the category of *state* forests. The first priority within the context of these high forests is protection and conservation. Of the 58 most important high forest areas classified or designated as national forest priority areas (NFPAs), two are found in Tigrai (EFAP, 1994). However, the development and utilization of these two high forests in Tigrai has been constrained by the lack of implementation of management plans. In addition, as these areas were delineated without the consent of the local communities that lived with the forest perhaps for decades, integrating and involving the local communities in management and benefit sharing poses another challenge.

2.4.3 Pasture or grazing lands

Traditionally, grazing lands in the region have been common property resources as in much of the rest of the world (Runge, 1986). The 1975 agrarian reform also left the rights on grazing lands to the discretion of the PAs, either to be used collectively or redistributed for use by individual farmers (Hagos *et al*., 1999). In general, grazing lands are common property resources for most parts of Tigrai. They are collectively owned and managed by the respective communities. Nevertheless, a distinction needs to be made between regulated and unregulated grazing lands. Unregulated grazing lands are hillsides on which livestock graze during the wet season. The fact that they serve as a wet season sources of forage implies that they are free for use anytime unless other, better feed sources are available. The regulated grazing or pasture lands are reserved (protected) during wet season to provide forage during the dry season and freed for use either communally or individually during the dry season. They are governed by local bylaws established by each community that apply to all members. The bylaws specify protection from interference, input contributions from members, use regulations and restrictions, and penalties in the event of violations, as well as institutional arrangements for enforcement of bylaws (Gebreegziabher *et al*., 1998). Not surprisingly, the experiences in grazing lands management appear to be richer than in the *community* woodlots. As observed in some instances, traditionally the bylaws for grazing management have integrated aspects of protecting and utilizing forest trees inside the grazing lands (Gebreegziabher, 1999).

However, private ownership of grazing lands is also practiced to varying degrees, either partly or all year round, in the eastern zone of the region. In parts of the zone where temporary (seasonal) private ownership is practiced, the privately held grazing areas are converted to communal grazing lands after about two months of private grazing (Gebremedhin *et al*., 2001). Tenure rights to grazing lands also vary by season. During the wet season from June to September, livestock feed sources such as weeds and green grasses on farm strips and bunds are considered private property, and hence grazing rights are vested in the individual holder.

2.4.4 Dung and crop residues

As a result of the free and uncontrolled grazing system that is prevalent in the region, livestock stay outside for most of the day, both grazing (browsing) and searching for feed. Eventually, the animals leave their manure (dung), which is free for use by any one and there is no defined ownership right to it. Even on regulated grazing lands where the cattle tend to concentrate for some period during the year and, larger quantities of manure (dung) are expected, dung remains an open access resource with no defined owner. In the end, manure (dung) decomposes, which is unlikely, or most often it is collected freely by the villagers, or people from nearby towns, primarily for fuel purposes. Dung from rural hinterlands accounts for a significant portion of total household cooking fuel in some towns in Tigrai (Newcombe, 1989; Gebreegziabher, 2001). In addition to the energy loss of livestock searching for forage, the free grazing system reduces the availability of dung for the owner, which represents a negative externality. If it gets decomposed, whether the animals leave their dung on grazing lands or cultivated lands, it represents a positive externality to the system. It is not clear if the costs exceed the benefits. Who should be compensated or how should the externalities be internalized? These are important empirical issues.

After harvest cultivated lands are considered to be grazing lands without access restrictions. As crop residues constitute the major livestock feed source in the region, farmers attempt to collect all of the residues right after harvest. But, most often, farmers do not clean away all the residues and a considerable proportion is left on the field especially in the case of corn stocks and sorghum stalks. The leftovers and the aftermath are considered free access resources without restrictions. Therefore, livestock graze freely on these leftovers and aftermath during the period October to December (Gebremedhin *et al*., 2001). Collecting crop residues by women and children from these fields for fuel purposes is also a common practice.

2.5 Energy and Forestry

2.5.1 Energy

Energy consumption for domestic uses in Tigrai could be divided into two as modern fuels and traditional biofuels. However, the traditional biofuels dominate despite their presence and that modern fuels such as petroleum and electricity are also used.

Modern fuels

Electricity and petroleum products are the main modern energy sources currently used in the region. Among the petroleum products, naphtha (diesel) and kerosene are consumed in both rural and urban areas of the region. In rural areas, both kerosene and diesel are predominantly used for lighting but only in rare cases for cooking. The rural sector was found to account for about half of the total kerosene demand in the region (BoITT, 1999a). In large towns, such as Mekelle, Adigrat and Adwa, kerosene is used for cooking by some households. Also in medium to small towns kerosene is most often used for lighting and in some cases for cooking.

Electricity is the other important modern energy sources used in the region. The EEPCo (Ethiopian Electric Power Corporation) is the major supplier of electricity. There are also few community and privately owned systems. At present there are two power supply systems in the region, the interconnected system (ICS), which has grid connections and is mainly supplied from hydropower plants, and the self contained system (SCS), which constitutes isolated power generating units operating with diesel (EEPCo, 1999). EEPCo has about 95 thousand (dominantly urban) customers in Tigrai, ranging from domestic users to high voltage large industries. Electricity supply in the region has considerably improved during the past few years, but there is a long way to go. In the household sector, lighting is the dominant end use. The use of electricity for *injera* baking is limited to larger towns and to a very limited number of households. That the electric *mitad* or stove technology is too expensive has the main reason identified for non-adoption and hence for the limited use of electricity for baking (see Chapter 7).

Traditional biofuels

Biofuels are the dominant sources of energy in the household sector in urban and rural areas of the region. The traditional biofuels used in the region include firewood, tree residues, animal dung, crop residues and charcoal. Besides, free collection accounts for the majority of the traditional fuels consumed by rural households. In urban areas, the share of "free" fuels especially fuel wood declines as one goes up from the smaller to the larger towns and cities (ENEC and CESEN, 1986c; TFAP, 1996b). Yet, dung continues to be free collected even in the larger towns such as Adigrat, Adwa and even Mekelle. Dung transported (collected) from rural hinterlands accounts an important part of total household cooking fuel for some towns in Tigrai. In towns such as Alamata, crop residues are less freely collected. This could be due to the fact that crop residues constitute important sources of fuel for the rural households and, as a result, are less accessible to urban dwellers. Leftovers by households (individuals) who make charcoal to be supplied to nearby major towns results in being free collected by some rural households. Except for Mekelle, *injera* baking accounts for over 50 percent of the total domestic fuel consumption in all settlement typologies (Table 2.10).

Table 2.10 End use share of total fuels in Tigrai by settlement 1993/94 (%)

Settlement typology	End Uses				
	Baking	Cooking	Lighting	Beverage preparation	Others
Mekelle	43.49	54.47	0.91	0.77	0.36
Large towns	52.06	44.81	2.31	0.72	0.07
Medium towns	54.34	43.11	1.70	0.83	0.03
Small towns	53.53	42.35	3.38	0.68	0.06
Rural areas	60.54	35.47	2.44	1.55	0.00

Sources: EESRC (1995)

Table 2.11 Estimates of area and incremental yield of vegetation resources in Tigrai 1996

Vegetation	Area ('000ha)	Mean annual incremental	
		m^3/ha/annum	Total (‘000m^3)
Natural high forest	21.6	3.0	64.8
Woodland	92.5	0.73	67.8
Bush land	130.0	0.35	45.5
Shrub land	677.0	0.35	236.95
Wooded grassland	632.5	0.17	105.63
Scrub land	235.0	0.17	39.25
Plantation	5.0		48.0

Sources: TFAP (1996a)

2.5.2 Forestry

As explained earlier substantial area of the region was covered with forests (see also TFAP, 1996a). Particularly the highland plateaux was covered by *Junipers*, *Olea* and *Cordia*, alternating with montane covered by Acacia-Andropogon savannah. However, these have virtually disappeared leaving a few remnants here and there. For instance, natural high forests constitute only 21,600 ha, which is insignificant in terms of the total land area of the region (Table 2.11). The clearing of forests to expand agricultural land and tree cutting for fuel wood, timber and agricultural implements were the causes for the decline in forest cover of the region. The increase in livestock population and the free grazing system that prevails in the region have also had a considerable influence on the degradation of vegetation resources. Moreover, the forests have been largely open access resources and this has also contributed to the devastation of these resources. Agro forestry and private tree planting appear to be most stable alternatives to ameliorating the rural fuel problem. Nevertheless, the status of agro forestry and the extent of private tree planting have not been well documented. In addition, as it could be envisaged, farmers might have multiple objectives or purposes such as fuel, fodder, timber, farm boundary, etc in mind when growing trees on their farms. Hence, it is not clear whether household (private) tree planting transpires into more wood being available for fuel.

The region is endowed with large areas of incense (*Boswellia papyrifera*) and gum Arabic (*Acacia senegal*) trees (EFAP, 1996a). For instance, in the western and northwester Tigrai 500,000 ha area was estimated to have 30 million stands or trees. It was also estimated that 50,000 quintals of gum olibanum could be tapped annually from these stands (Hagos *et al*., 1999). Woody biomass in Tigrai constitutes woodland and degraded forests. Hence, it might necessary to provide the typology of forest resources:

1. Wooded grassland includes land covered with grasses and herbs with scattered or more rarely patches of woody plants.
2. Scrub land is a vegetation cover consisting of low shrubs mixed with grasses, herbs and geophytes.
3. Shrub land is a land dominated by supporting stands of shrubs with height of 2 meters or more.
4. Bush land is a land covered by an open stand of trees and/or taller shrubs 2-5 meters high and a canopy cover of more than 20 percent.
5. Woodland is an area with an open stand of trees of 5-10 meters height and has and canopy cover of at least 20 percent.
6. Forest is a vegetation cover dominated by trees forming a closed canopy, deep, complex and often multi-storied canopy. The height of the largest tree might exceed 45 meters.

Generally, vegetation cover (resources) in Tigrai is dominated by shrub land and wooded grassland. Both accounted for 73 percent and 56 percent in terms of area and annual wood production, respectively (Table 2.11).

2.5.3 Energy technologies

Energy conversions and efficiency

The basic feature of energy is that it has many forms and can be converted from one form to another. However, some of the conversions may not have practical value (RWEDP, 1997). Energy conversions are just the ways in which we human beings utilize or harness energy.

When dealing with energy conversion one would be concerned with two things: the quantities of energy involved and the rate at which energy is converted from one form to another. When one form of energy is converted into another form for a particular purpose, not all the energy ends up where one would like. It all depends upon the type of device or appliances used. Rather, some energy is wasted or lost in the conversion process in the form of heat. The ratio of the useful energy output to the required input is what is called as the efficiency of the process. The higher the efficiency, the less is the loss of energy. Figure 2.2 provides a schematic picture of the energy conversion process.

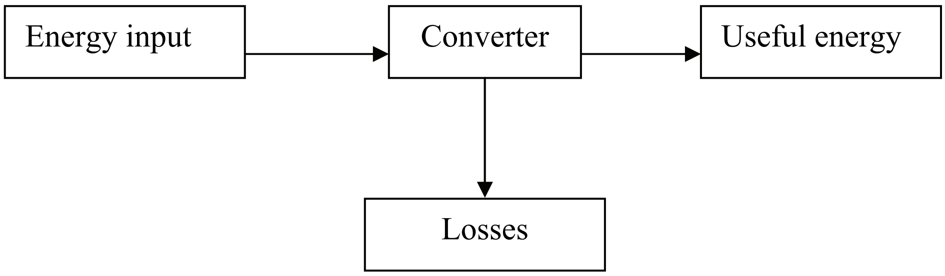

Figure 2.2 *The energy conversion process*

In general, the efficiency of a given energy conversion process may be as high as 90 percent, but never 100 percent. Although some losses are inherent in the nature of energy conversions, it is possible to reduce inefficiency by good equipment design and use. Hence, an understanding of these inherent inefficiencies is the key to improve energy use efficiency. Much of the traditional uses of wood as cooking (plus baking) fuel in most developing countries are also carried out in campfires or stoves where the efficiency of heat use is very low. Dunkerley *et al*. (1981) argued that wood and crop wastes in these countries are typically used with efficiencies not exceeding 10 percent.[10]

Evolution and diffusion of improved stoves in Tigrai

Except for Tigrai, the traditional '*tripod'* constitutes the dominant stoves for millions of rural and urban households in Ethiopia both for cooking and baking. These open fire stoves have very low energy efficiency, about 10 to 15 percent for cooking and 7 percent for baking. This shows that most of the potential energy, 85 percent or more is wasted. The low utilization

[10] However, this need not be confused with the broader concept of energy efficiency as a link between level of energy consumption and economic growth. In the broader concept that links level of energy consumption to economic growth, energy efficiency is defined as the ratio of rate of change in energy consumption to rate of change in economic growth (GDP) (Mather *et al*., 1995).

efficiency of the open fire stoves have resulted in a higher demand for biomass, particularly for households that primarily or entirely rely on biofuels.

The traditional *Tigrai type injera* stove was an indigenous innovation in response to the growing problem of fuel scarcity in the region. This traditional stove has been used since then. It is enclosed with a clay wall, and had a relatively better performance in fuel saving compared to the more common *open fire* stove (ENEC and CESEN, 1986c). Later, an improved stove was introduced, but it had only limited modifications to the *Tigrai type* stove. Given doubts about the efficiency of the improved stove, the introduction of a new kind of improved stove, *Tehesh*, was initiated in 1998/99 in eight districts of the regions (Gebretsadik *et al*., 1997; RTPC, 1998). However, except for these attempts, it is not yet clear whether the stoves being disseminated actually have the desired level of efficiency in terms of fuel saving and whether there is a scope for further improvements in fuel efficiency. Moreover, it is not yet clear what factors determine the adoption of these fuel saving stoves.

2.6 Conclusions

Besides providing a detailed description of the study region, this chapter highlights about the relevant issues and an understanding as to why choices were made with respect to research objectives and research questions (Chapter 1) and serves as first step towards the analytical parts of the thesis. Therefore, the following conclusions and main issues could be drawn from the foregoing discussion.

Soil erosion and soil nutrient depletion turn out to be the major land degradation problems currently facing the region. Most of the soils in the region have low nitrogen and phosphorus content. The major cause for such high loss of nutrients is the use of dung and crop residues as household fuel sources. Such burning of dung and crop residues which were sources of soil humus and fertility has brought about a progressive decline in land quality and agricultural productivity. TFAP (1996a) and BoANR (2003) estimated that the losses caused by nutrient removal, that is, due to the use of dung and crop residues for fuel purposes accounts for about 10 percent of the annual grain output of the region. The dependence of urban centers on the rural hinterlands for their fuel coupled with property rights failure also aggravated the problem. This calls for that research needs to take a broad rural-urban approach to the fuel problem, as rurally conceived and rurally focused solutions will be insufficient. It also calls for an understanding of the determinants of household energy consumption.

Intuitively, simultaneous measures both on the supply-and the demand-side might be seen as a plausible option in addressing the problem. However, the choice of appropriate instrument(s) requires a clear understanding and empirical investigation of the behavioral factors underlying supply and demand. On the supply side, for instance, private property based arrangements such as agro forestry and private tree planting might appear to be necessary at the same time stable alternatives to ameliorating the fuel problem, especially in circumstances where community resource management arrangements might not be worthwhile. On the demand side, dissemination of fuel efficient stoves could be envisaged. Nevertheless, the status of agro forestry and the extent of private tree planting have not been well documented in the region. However, more importantly, it is not clear whether household (private) tree planting transpires into more wood being available for fuel. These all are important issues that require empirical investigation.

It has been quite apparent from the foregoing discussion that, arguably, the household fuel demand is also a function of the stove efficiency, among all others. It would be expected that, holding all other factors constant, the household fuel demand increases or shifts by a factor of the inefficiency. Hence, theoretically speaking, it is clear right away the scope for reducing the demand for biofuels and, hence, the pressure on natural resources through good equipment design and improvement in efficiency of the stove technologies. Despite some attempts disseminating improved stoves, it is not yet clear whether the stoves being disseminated actually have the desired level of efficiency in terms of fuel saving. In addition, it is not clear what factors condition the adoption of these stoves. Moreover, given that *injera* baking accounts over half of the household fuel consumption for most households in Tigrai, both urban and rural areas, focusing on baking stoves appears to be feasible, at least to start with.

The *communal* land tenure system that prevailed for decades as well as the lack of appropriate property rights in the years following the 1975 land reform have contributed to land degradation by reducing farmers incentives to invest in land improvements. Moreover, following the constitution, the region has its own land policy which officially prohibits further land redistribution unless for some exceptions. Subsequent measures of land titling or registration and issuing of land certificates has been undertaken since 1998, as a way of countervailing the feeling of tenure insecurity among farmers. Nevertheless, whether farmers feel more secure in their tenure now than before? That is, whether or not and to what extent the land policy as well as the recent attempts of land titling and issuance of certificates has contributed to investment efficiency are empirical questions which call for further research.

Property right failures or the free access condition of fuel resources such as dung and crop residues also contribute to the problem. The free grazing system reduces the availability of manure (dung) for the owner, which represent negative externality. If it gets decomposed, whether the animals leave their dung on grazing lands or cultivated lands, it represents positive externality to the system. But, most often it is collected freely by the villagers, or people from nearby towns, primarily for fuel purposes. As to which outweighs the costs or the benefits? Who should be compensated or how should the externalities be internalized? Which incentive mechanisms would be appropriate to control the free access condition? All appear to be important issues from empirical and policy view point. Dung transported (collected) from rural hinterlands accounts an important part of total household cooking fuel for some towns in Tigrai. How could the pressure from urban centers be reduced? Or how should the urban fuel issue, in general, be addressed? All are quite very relevant questions of further research.

Chapter 3 Research Process, Survey Methodology and Data

3.1 Research Process

The entire research process began from development of conceptual framework. Details are presented in Figure 3.1 below.[11] Once important research questions were identified and respective analytical method thought then followed the actual research work. As could be clear from the middle loop of figure, the research work involved essentially three stages, from questionnaire design through to data analysis. Stage 1 was design of (survey) questionnaire. In this stage, questionnaires that were used to gather the data required to meet the research questions were constructed or developed. Because the research covered rural and urban households, separate questionnaires were developed for the rural and urban households' survey. Then, the questionnaires were pre-tested at field level for verification and further modifications. The questionnaires were initially developed in English and later on translated into Tigrigna (local language) to be conveniently administered to the participating households.

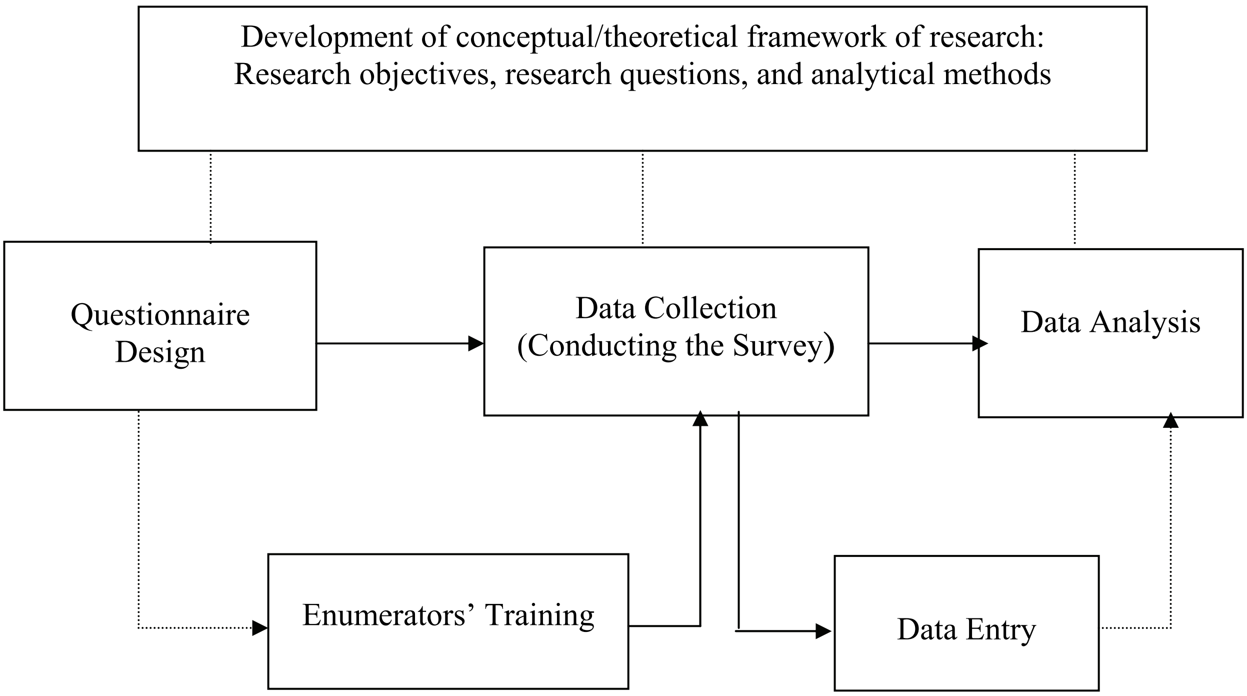

Figure 3.1 *The research process*

[11] Legend: Dotted lines indicate the connection between development of conceptual framework and the stages. The full line arrows on middle loop of Figure 3.1 used to indicate the stages in sequence. Whereas the one-side dotted line arrows on lower two loops, left and right, of the figure are used to imply that it is an intermediate stage, respectively, ante ceding and preceding the immediate stages.

Stage 2 was data collection or conducting the survey. This was the stage where required data were actually collected. Meantime between questionnaire design and data collection was enumerators' training. See lower left loop of Figure 3.1. Enumerators were recruited and trained for the data collection. It consisted of reaching house-to-house participating households and administering the questionnaire. The data collection was also augmented with field measurements. That is, actual measurements of local fuel units were taken along with administering the questionnaire to participating households to minimize measurement errors. To be specific, at first responses on the amount of the different types of fuels collected and consumed by the household were recorded in local units. Then, using a hand balance fuels collected and/or consumed measured and converted into metric units, by asking each respondent (household) to display respective fuels collected and/or consumed. This was done in order to facilitate conversion into metric units while at the same time minimizes error.

Stage 3 was data analysis. The analytical methods employed in addressing each of the research objectives are explained in detail in the respective chapters. Before the data analysis, data collected was entered into electronic database. MS Access software was used for data entry. Prior to data entry was desk work involving data editing and data coding. The data entry also involved steps consisted of developing (designing) data structure (electronic format) for data entry and entering the data. That is, first the electronic format (data structure) that could conveniently handle the data entry was developed (prepared) based on the questionnaire and with the analytical objectives in mind. And, then, data collected was entered into this electronic format.

3.2 Survey Methodology

This research emphasizes on a broader rural-urban approach to the fuel problem. This, in turn, meant the need for different data sources transcending from rural to urban. Moreover, even within rural data source the diversity of research questions to look at also meant multi dimensionality of the data needed including fuels used, tree growing and technological considerations such as use of improved stoves.

3.2.1 Rural household survey

This research used survey method as the main methodological approach in the generation of the research material. A structured interviewing technique was employed. Both qualitative and quantitative data were collected with the help of the questionnaires. The rural household survey covered a stratified sample consisting of 200 households selected from Enderta and Hintalo-Wajirat districts of the region. This survey was a continuation of ‘farm and off-farm employment survey’ conducted by Woldehanna (2000) and ‘rural transition under risk survey’ by Haile (2007). However, there was a necessity for another round of own rural household survey on these same households because the focus of these previous works was different and issues like household fuel consumption/ production, tree growing, etc were not considered. The particular places covered in their survey constituted *Felegeselam*, *Maytsedo* and *Shebta tabias* from Enderta district and *Araasegeda* and *Fekrealem tabias* from Hintalo-Wajirat district. The details about the sampling procedure and the composition of the sample households by districts, *tabias* and *kushets* can be found in Woldehanna (2000).

3.2.2 Urban household survey

A one period data was collected from stratified sample three hundred fifty urban households in case of urban household survey. Urban centers in the study area were categorized into four settlement typologies as city, large town, medium town, and small town, based on their population. The 1994 Population and Housing Census (CSA, 1995), identifies a total number of 74 urban centers in Tigrai. All these urban centers could be stratified into city, large, medium, and small towns based on their population (Table 3.1) and then a two stage sampling technique could be applied in selecting the sample households. That is, first select sample towns and then selected sample households from the sample towns in such a way that every household have the same chance of being included in the sample. However, the choice of towns was not random. This procedure might lead to the selection of a town at the western tip of the region, which might be unaffordable given the time and budget limitations.

Table 3.1 Criterion for classification of urban center(s) into settlement typologies

Settlement typology	Criterion (population or number of inhabitants)
City	$> 100 \times 10^3$
Large town	$25 - 100 \times 10^3$
Medium town	$5 - 25 \times 10^3$
Small town	$< 5 \times 10^3$

Source: EESRC (1995)

Given the gaps in the depth of our understanding of the urban dimension of the fuel problem the focal towns were identified to provide this depth and to get the desired rural-urban link. Two of them (Kuha and Adigudem) fall in the study areas of our rural household survey. To have an idea of the current population and to base the sampling on this figure of the current population, the population of the focal towns was projected to 2000 and 2003. The details about sample towns and sample size determination have been provided in Table 3.2.

Table 3.2 Sample towns and sample size determination by town (urban household survey)

Town		Population 2003 (Projected)				Total	
		Both Sexes	Male	Female	% of Total	Sample	Sample size/ town
	(1)	(2)	(3)	(4)	(5)	(6)	(7)=(5)*(6)
Mekelle	City	139292	65709	73583	0.558	300	167
Adigrat	Large town	53765	24933	28832	0.216	300	65
Wukro	Medium town	23596	10672	12924	0.095	300	28
Kuha	Medium town	14178	6230	7948	0.057	300	17
Adigudem	Medium town	9798	4450	5348	0.039	300	12
Hagereselam	Medium town	5704	2308	3396	0.023	300	7
Samre	Small town	3072	1338	1734	0.012	300	4
Total		249405			1.00		300

3.3 Description of Datasets

This research benefited from different datasets. Essentially the research involved the use of two broad types of data sets. Data sets for rural households and a data set for urban households. The overall picture of datasets used and data sources for rural and urban households has been presented in Table 3.3. In addition to these datasets secondary data were also obtained from relevant institutions as well as from national and regional statistics.

Table 3.3 Description of data sources (rural and urban households)

	Year	Data type
Farm and off-farm employment survey (rural)	2 years (1996 and 1997)	General
Rural transition under risk survey (rural)	2 years -(1st year) 2001 -(2nd year) 2002	Focused on risk With additional observations on fuel and wood
Household survey (rural)	-(3rd year) 2003	General observations on production, consumption and labor with observation fuel, wood, manuring, etc.
Household survey (urban)	2003	General observations on household characteristics, food and non-food expenditure with observations on fuel expenditure, cooking appliances used

3.3.1 Datasets for rural households

Concerning the datasets for rural households, this research built on previous works done (data collected) by Woldehanna and Haile. In addition, few pages additional observations on fuel and wood were included when her second year data collection of Haile was already going on. The outline of the main items included in the questionnaire for additional observations on these fuel and wood related issues has been provided in Appendix A3.1. For downloadable full text pdf we refer the reader http://www.aep.wur.nl/NR/rdonlyres/82AD13B0-A8E5-40FF-960D-A26F33CD9556/28491/Additionalobservations.pdf

Because of lack of sufficient number of households using improved stove(s) in the Woldehanna-Haile data, a dataset of stratified sample 200 households selected from 50 *Tabias* of the region, collected during the year 2000 was used for the research objective concerned with the role of improved stoves. The data was collected with the intention to analyze the energy consumption pattern and to identify important determinants of household energy consumption in rural Tigrai. A two-stage sampling was used to select the sample households. At first 50 *tabias* of the region were selected out of 600 *tabias*. Then, a sample consisting of 200 households was selected from 50 *tabias* of the region. The survey questionnaire used in collecting this data along with the codebook used for data interpretation can be accessed by following the link http://www.aep.wur.nl/UK/Staff/Gebreegziabher/Master Thesis/SurveyQuestionnare/ (codebook) or by logging on http://www.aep.wur.nl/NR/rdonlyres/82AD13B0-A8E5-40FF-960D-A26F33CD9556/26775/SurveyQuestionnaire1.pdf for access to the questionnaire and http://www.aep.wur.nl/NR/rdonlyres/82AD13B0-A8E5-40FF-960D-A26F33CD9556/26776/Codebook1.pdf for the codebook.

ILRI (International Livestock Research Institute)-IFPRI (International Food Policy Research Intitute)-MU (Mekelle University) dataset for highlands of Tigrai from 500 households and 100 communities collected during the year 2000 was also one of datasets used in this thesis. This dataset was used for tackling research questions pertaining to household and community tree planting. Many papers have used this dataset, Gebremedhin *et al*. (2003) and Pender *et al*. (2002) are among the few to mention. The data was collected as part of the broader initiative on 'strategies for sustainable land management in the East African Highlands' (Pender *et al*., 2006). The main intention of the survey was to investigate and find out options for improving rural livelihoods and land management. A more elaborate description about this dataset can be found in Pender and Gebremedhin (2004).

3.3.2 Dataset for urban household

The dataset from own urban household survey was used with respect to research questions related to urban fuel issue. The outline of main items of the questionnaire used for the urban household survey is provided in Appendix A3.2. Readers with further interest for the full text of questionnaire can refer the website http://www.aep.wur.nl/NR/rdonlyres/82AD13B0-A8E5-40FF-960D-A26F33CD9556/28492/QuestionnaireforUrbanHouseholdSurvey.pdf.

3.4 Overview of Survey Results

Among the various fuels considered wood and dung turned out to be the prominent fuel sources in the case of rural households. A descriptive analysis of the survey data is presented in Table 3.4. Nearly all of the sampled households use dung as their fuel source. The scarcity of wood resulted into dung being main source of fuel. Fuel wood stood next most important fuel, next to dung, in terms of number of households involved. Most of the sample households use kerosene whereas charcoal appeared less important as far as rural households are concerned. None of the sample households were found using crop residues.

Table 3.4 Fuel types (sources), households involved and mode of acquisition of different fuels, rural households 2002 (n=199)

Fuel type	Households involved (%)	Way acquired	
		Self collect	Buying
Wood	82.7	69.5	13.2
Dung	99.5	99.0	0.5
Crop residues	0.0	0.0	0.0
Kerosene	93.0	0.0	93.0
Charcoal	8.1	2.0	6.1

As regards to the mode of acquisition of the different fuels, nearly all the dung was found to be self-collected or prepared with own source constituting the largest part. Whereas fuel wood was either free (self) collected or bought. A lesser proportion of the households were found involved in fuel wood buying (Table 3.4) and free (self) collection was found to be the dominant mode of acquisition of fuel wood. Nearby woreda towns constitute the major market sources for kerosene buying. Most of the households reported to be using charcoal were found to be involved in buying charcoal and only few of them were found to be using homemade charcoal (or by product of fuel wood use). Table 3.5 also provides description of quantity consumed and time spent collecting fuels.

Table 3.5 Description of fuel variables, rural households 2002 (n=199)

Variable name	Mean	Std. Dev.	Min	Max
Quantity consumed dung (kg/year)	1364.59	790.71	0	3951.36
Quantity consumed wood (kg/year)	624.26	743.99	0	4129.92
Quantity consumed kerosene (lit/year)	12.94	6.18	0	48
Quantity consumed charcoal (kg/year)	1.62	5.52	0	50
Time spent collecting dung (in hours/year)	22.5	26.26	0	221.10
Time spent collecting wood (in hours/year)	5.27	20.0	0	163.35
Kerosene expenditure (Birr/year)	51.57	25.94	0	216

Description of most important variables characterizing the urban households has been presented in Table 3.6. As it could be clear from the table, average expenditure on food accounted for about two-third of mean total expenditure and fuel expenditure consisted about one-fifth of average total expenditure of household.

Considering education of head, about half of the sample households were found to have formal education of primary level and above. Nonetheless, quite considerable of the households were found to be illiterate. With respect to occupation of head formal and informal self employment were found to be the most important ones as far as urban households are concerned.

Table 3.6 Description of survey households (urban) 2003 (n=350)

Variables	Mean	Std. Dev.	Min	Max
Family size	4.92	2.20	1	10
Age	49.27	14.04	18	95
Total expenditure (Birr/year)	6,910.1	5,087.4	1,045.5	46,398
Food expenditure (Birr/year)	4107.8	5291.1	787.5	15628
Fuel expenditure (Birr/year)	1283.8	768.7	106	5204
Percent of male headed household	54			
Percent of female headed household	46			
Education of head/ highest grade completed				
Illiterate (in percent)	39			
Grade 1-3	15			
Grade 4-6	18			
Grade 7-8	11			
Grade 9-11	5			
Grade 12 and above	12			
Employment type/occupation of head				
Unemployed (in percent)	14			
Self employed (formal)	22			
Self employed (informal)	32			
Employed private (formal)	7			
Employed private (informal)	3			
Employed public sector	14			
Others	7			

Appendix 3A

Appendix 3A.1: Outline of Questionnaire for Additional Observations

'Household fuel consumption, stove use and tree growing'

1. Fuel type used, way of acquisition, collection frequency, quantity collected/ purchased and sources

2. Time spent in fuel collection/ preparation, fuel available from own source, quantity consumed, and fuel purposes

3. Quantity sold, fuel preferences and reasons

4. Use of improved stoves

5. Tree planting and ownership

Appendix 3A.2: Outline of Questionnaire for Urban Household Survey, 2004 (1996/97 EC)

General Description

PART I: Household Characteristics

PART II: Fuel Consumption in Domestic Uses, Changes in Patterns of Fuel Use,

Section 1: Fuel consumption in domestic uses during this year

Section 2: Ranking of energy sources by end use

Section 3: Fuel preferences by end use

Section 4: Wood species used as fuel

Section 5: Distance to fuel sources

PART III: Energy Technologies

Section 1: Use of cooking appliances (Injera Cookers)

Section 2: Use of energy appliances (Other Cooking)

PART IV: Household Expenditure (Jan-Dec 2003)

Section 1: Quantity and value of consumption: Food and Drinks consumed at home and Tobacco during the year

Section 2: Household expenditure on non-food items during the year

PART V: Cash Income and Receipts Received by the Household (Jan-Dec 2003)

PART VI: Farming

Section 1: Crops Produced and Consumed

Section 2: Livestock Expenditure and Income

Chapter 4 Land Degradation in Ethiopia: What Do Stoves Have to Do With It?♣

4.1 Background

Land degradation is a particularly vexing problem in developing countries because it leads to a poverty trap. Poverty is an ultimate cause of land degradation that, in turn, exacerbates poverty by reducing the quality of the most important resource available for economic development. In most developing countries, inefficient exploitation of the land reduces the amount of resource rent that can be collected, while lowering available future rents as land resources are degraded over time in a suboptimal fashion (van Kooten and Bulte 2000). Consequently, increasing poverty combined with lack of property rights to land causes peasants to invest too little in land improvements. A cycle of land degradation occurs because, as forests are mined, people turn to grasses, crop residues and livestock dung for fuel, which deteriorates the land further (Pearce and Warford 1993, p.25).

This is certainly true in Ethiopia where deforestation is a major problem, and many peasants have switched from fuelwood to dung for cooking and heating purposes, thereby damaging the agricultural productivity of cropland. Newcombe (1989) estimated that, by burning some 7.9 million metric tons of dung per year, the reduction in agricultural productivity from lost nutrients associated with manure amounted to some 6 to 9 percent of the country's GNP.

Ethiopia is one of the poorest nations on Earth with an annual purchasing power parity adjusted per capita GDP of $700. It has a history of civil wars and frequent droughts that have resulted in the starvation of millions. Only 11.8 percent of the country's surface (or 13.0 million ha of an available land area of 110.4 million ha) are forested, compared to 40 percent some 100 years ago (Hawando 2004). Standing timber amounts to some 285 million m^3, or about 22 m^3 per ha, indicating a preponderance of dry rather than wet tropical forest ecosystem. Total biomass in forest ecosystems amounts to 573 million metric tons (t), or 44 t per ha. In 2005, 108.879 million m^3 of timber were harvested for fuelwood (24.5% more than in 2000) along with 2.982 million m^3 for industrial roundwood (an increase of 21.3%), all of which were consumed domestically; harvests of timber for other uses were insignificant in comparison (FAO 2006). In 2005, timber removals accounted for 39.3% of total growing

♣ Contributed Paper Presented at the 26th Conference of the International Association of Agricultural Economists, 12-18 June 2006, Gold Coast, Australia.

stock, clearly an unsustainable state of affairs.[12] Between 1990 and 2005, the average annual rate of deforestation was nearly one percent, one of the highest rates in the world.

The Ethiopian government has embarked on a two-pronged policy in an effort to stem deforestation and the degradation of agricultural lands – tree planting or afforestation as a long-term strategy and dissemination of more efficient cook stove technologies in the short term. The purpose of the current study is to examine the potential of the second strategy. Using a unique data set covering 200 households in Tigrai province, northern Ethiopia, we analyze the impact of the use of a more energy efficient (improved) cook stove on household behavior. Our purposes are both to determine the propensity to adopt new stoves and to isolate how adoption of improved stoves changes behavior (including, e.g., the frequency with which households prepare hot dishes and the number of cattle they might keep). Because we cannot a priori exclude the possibility of a rebound effect – that use of more efficient stoves actually increases fuel demand rather than reducing it – we need to pay particular attention to the consequences for actual use of the improved stove.[13]

Improved stoves have been regarded as technological substitute for fuelwood particularly since the ‘oil price shocks’ of the 1970s (Barnes *et al*., 1993). However, whereas substantial growing literature characterizes the important features of adopting agricultural production technologies (Dadi *et al*., 2004; Barrett *et al*., 2004), knowledge about the characteristic of stove adoption is sparse. Moreover, empirical evidences on effectiveness or fuel saving efficiency of the improved stoves, particularly wood stoves, are also extremely scanty and mixed (Chapter 1). This chapter investigates at the role of using an improved stove in redressing land degradation, besides determining the factors that affect the stove adoption decision.

[12] Data for Ethiopia pose numerous difficulties (FAO 2006, 2003, 1997). It seems unreasonable that nearly 40% of total biomass is removed annually, but that is what the ‘official’ data indicate (www.fao.org/forestry /site/32046/en). Perhaps much of the fuelwood came from trees outside of forests, as FAO defines forests to have 10% or more canopy cover. Alternatively, FAO (2003) data indicated that there were 13.5 million ha of forest in 1995 but only 4.6 million ha in 2000. This could explain high rates of off-take, but it implies an extremely high (perhaps unreasonable) annual deforestation rate of about 19%. Later revisions indicated that forested area stood at 14.4 million ha in 1995, 13.7 million in 2000 and 13.0 million ha in 2005 (FAO 2006).

[13] The new technology might increase wood consumption because, as Wirl (2000) notes, people care only about the services a stove provides (e.g., heat generated) and not about wood use itself. A more efficient stove implies that the same heat is obtained from less wood, so the price of heating services declines and thus households increase their demand for cooking services. This can result in more wood use if the percentage change in services demanded is larger (in absolute terms) than the percentage change in fuel efficiency associated with the new stove.

In the next section, we review stove R&D in Ethiopia. Our model of the stove adoption process is provided in section 4.3, while the survey instrument and empirical results are discussed in section 4.4. The conclusions follow.

4.2 Stove R&D in Ethiopia

Stove R&D efforts in Ethiopia began in the 1980s with the World Bank Energy Sector Assessment (World Bank, 1984). Besides identifying short- to long- term options for alleviating the fuel problem or crisis in the country, the assessment also carried out kitchen-lab investigations of fuel-savings efficiency of various stoves. Stove types considered in the investigation and the test results are proved in Appendix Table 4A.1. As it was quite apparent that *injera* baking consumes about half of all the household fuel uses, *injera* cookers received priority. The *Tigrai* type stove was found to be twice as efficient as open fire tripods and was recommended to be part of the package of cooking efficiency program. Fuel savings of up to 25% was achieved with the *Tigrai* type[14] stove with no additional fire management. Moreover, the mission also did some cost-benefit analysis of improving stove efficiency

Two years later, a program of massive diffusion of efficient cooking stoves was designed, with the intention of disseminating of the *Tigrai* type stoves with little improvement (ENEC & CESEN, 1986b). It was assumed to extend essentially to all rural households within 20 years time and envisaged to allow an overall decrease in energy consumption by about a factor of two. This massive stove diffusion program was also envisaged to cover essentially all urban households using traditional fuels within the specified time period. Continuing improvement in stove designs was also expected in the years beyond the planning horizon, that is, beyond 2005 in order to allow a further decrease in the demand for traditional fuels of about 0.5 percent. The importance of an efficient extension service was recognized to support the diffusion of the efficient stoves.[15] Training of home agents on the construction and use of the improved stove was being offered at the Awassa College of Agriculture. The dissemination of improved stove to rural households was handled as part of the agricultural extension program in the Ministry of Agriculture (MoA).

However, these stoves had no chimney, which is detrimental to family health as cooking areas fill with smoke. Hence, a second generation stove arose as the partially clay-

[14] The '*Tigrai* type' stove was an indigenous innovation by the local people to the growing fuel scarcity and high fuel prices in the area.

[15] The extension service was regarded essential for providing assistance in the use of the stoves in new households and monitor the activities to determine the degree of appropriateness and utilization as well as the physical conditions of the stove.

enclosed stove was subsequently improved upon by the introduction of a '*three-stove*' model that included a chimney and an even lower grate height and was entirely enclosed. The 'three-stove model' consists of a baking 'oven', a stove for heating water and sauces, and a grain-roasting compartment. Thus, with little additional effort, the '*three stove*' *Tigrai* variant yielded more fuel savings.

The more recent -third generation -re-design of the *Tigrai* variant drops the separate compartments of the *three-stove* model, replacing it with a double-walled stove with a baffle that permits smoke (and heat) to recycle before it escapes out of the chimney – essentially a combined-heat stove, known as a *Tehesh*[16] stove. As a result, further fuel savings of 22 percent can now be realized compared to the *Tigrai* variants that have only a single wall. The stove design and efficiency tests including kitchen lab and field-testing were undertaken by the RTPC in Mekelle. Six stove designs of various attributes were considered in the testing with *Tehesh* stove identified having the highest efficiency as compared to all others (Gebretsadik *et al*., 1997). Then after "pilot" dissemination program was initiated for *Tehesh* stove during the 1998/99 in eight districts of the Tigrai province.

The fourth generation development of stove named *Mirte*[17] is a pumice-cement stove. It has the advantage of being easily assembled and need not be fixed. Initial laboratory tests of this stove demonstrated 35 percent fuel savings efficiency compared to the open fire tripod. Recent refinement on *Mirte* stove achieved further increases in efficiency and reached 50 percent fuel savings compared to open fire tripod (Bess & Kenna, 1994), which perhaps might give it a smaller margin over *Tehesh*.

Dissemination of improved stove in Tigrai also started before 1991. However, it was in the post-1991 period that it was more strengthened. For instance, a total of 77,563 improved stoves, i.e., '*three-stove*' model, were disseminated or build in rural Tigrai during the years 1991/92 - 1996/97 (BoANR, 1997a).[18] However, except for these attempts, it is not yet clear whether the stoves being disseminated actually have the desired level of efficiency in terms of fuel saving and whether there is a scope for further improvements in fuel efficiency, therefore, the need for empirical investigation.

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[16] This latest R&D effort is peculiar and sole initiative of the provincial government of Tigrai in collaboration with GTZ (German Technical Cooperation).

[17] Cooking efficiency and new fuels marketing project, under the Ethiopian Energy Study and Research Center in Addis Ababa, developed this stove.

[18] This job of improved stove dissemination was held under the Rural Women's Desk in the Bureau of Agriculture and Natural Resources (BoANR). Whereas the responsibility for technical design and stove development being under the Rural Technology Promotion Center (RTPC) within the BoANRs.

As could be clear from Table 2.10 (Chapter 2), the fact that the vast majority of biomass fuel is used for baking and cooking as opposed to lighting and heating justifies the R&D effort on *injera* cookers (stoves). It is also worth noting that in the diffusion process peasants does not purchase these stoves rather each person is taught how to build an improved stove based on information or advice provided by an extension agent. Moreover, adoption requires that households dismantle their old stoves, so that one type of stove is in use at any given time, as there is generally inadequate room in a household's living quarters for more than one stove.

4.3 Theoretical Model

To establish how the adoption of an improved stove is expected to affect household welfare, we postulate the following household utility function:

(4.1) $U_i = U(c_i, cf_i, tscw_i, tscd_i, an_i, \boldsymbol{h}_i)$,

where c_i denotes household *i*'s consumption during the period under consideration, cf_i is the frequency with which the household cooks (number of times per month), $tscw_i$ is the time spent by the household collecting woody biomass for fuel purposes, $tscd_i$ is the time spent collecting dung for fuel, and an_i is the number of farm animals the household owns. Finally, $\boldsymbol{h}_i$ is a vector of household characteristics that includes the number of household members, household income, and so on.

Consumption and number of farm animals are expected to contribute positively to household welfare (the latter also because cattle are a status symbol), whereas the amount of time spent collecting fuel (either woody biomass or dung) is expected to affect household utility negatively. We distinguish between times spent on the two types of fuels because the disutilities associated with collecting the two types of fuel may well differ. Finally, the effect on household welfare of cooking frequency is ambiguous. On the one hand, higher cooking frequency may reflect more flexibility (being able to prepare warm dishes whenever one desires), but, on the other, higher cooking frequencies may simply be the result of limited stove capacity. If the time spent cooking is valued negatively, an increase in cooking frequency may well be welfare decreasing.

When deciding whether or not to adopt an improved stove, the household will try to infer how the use of that technology is likely to affect family well being. The improved stove may affect the frequency with which the household cooks, and it may affect both the total time the household spends collecting fuel (both woody biomass and dung) (Barnes *et al*., 1993), and the relative amount of time spent collecting either fuel type. Let *I* be an indicator variable with value 1 if the household uses an improved stove, and 0 otherwise. Then, the probability of household *i* using an improved stove (I=1) is determined as follows:

(4.2) $P(I=1) = f(\Delta x_i, y_i, s_i, l_i)$, with $x_i = (cf_i, tscw_i, tscd_i, an_i)$,

where $\Delta x_i = x_i(I=0) - x_i(I=1)$ reflects the amount of variable *x saved* when household *i* replaces its old stove by an improved version. Further, y_i is household income, s_i denotes household size (number of household members), and l_i denotes other household characteristics including location (upper or middle highlands, or lowlands) (Barrett *et al*., 2004).

Unfortunately, we do not have any direct information about the changes in x_i at the household level– cooking frequency (Δcf_i), the time spent collecting dung ($\Delta tscd_i$) or woody biomass ($\Delta tscw_i$), and number of livestock (Δan_i). That means that we have to develop an estimation strategy that allows us to calculate the (expected) changes per household associated with the use of the new stove. The key assumption here is that there are no systematic differences between households that have adopted the new stove and those that have not; they are drawn from essentially the same distribution. That means that controlling for all (quantifiable) household characteristics, such as income, family size and composition, etc., adopting households are not inherently more prone to using larger quantities of wood and dung, for example, than non-adopting households. If that is the case, it is the *combination* of household characteristics that determines adoption behavior, and not so much one or two specific characteristics.

On the basis of this assumption, (expected) changes in cooking frequency, time spent collecting dung, time spent collecting woody biomass and livestock numbers can be inferred. We briefly explain the steps that are used to implement this in the current study. First, we consider the validity of the key assumption that all households are drawn from essentially the same distribution by testing whether adopter and non-adopters differ systematically with respect to any of the key characteristics for which we have information. We obtain support for our assumption if we are unable to reject the hypothesis that there are no systematic differences in the household characteristics of adopters and non-adopters.

Next, if our assumption is not violated, we proceed to estimate how the *levels* of cooking frequency (cf_i), the time spent collecting dung ($tscd_i$) or woody biomass ($tscw_i$), and the livestock (an_i) vary across households, using household characteristics as explanatory variables:

(4.3) $x_i = g^x(y_i, s_i, l_i, \boldsymbol{h}_i),\ \forall\, x_i = (cf_i, tscd_i, tscw_i, an_i),$

where $\boldsymbol{h}_i$ is again a vector of other regression-specific household characteristics and superscript x indicates that the specification may differ for each of the four variables of interest.

Endogeneity and simultaneity are clearly important issues that need to be addressed. Some variables such as household income are endogenous, while all dependent variables are explanatory variables in at least one other regression. Thus the system of regression equations in (4.3) must be estimated using a full two-stage least squares (2SLS) specification, with all truly exogenous variables (e.g., location, household characteristics) as instrumental variables.

We estimate (4.3) for the sample of households that have adopted the improved stove, as well as for the sample of households that have not adopted the improvement. Thus, we obtain two sets of coefficients on each of the (regression-specific) explanatory variables. The differences between these coefficients for each explanatory variable are then used to calculate the predicted *savings* on the dependent variables associated with the adoption of an improved stove. We denote these predicted savings by $\Delta\hat{x}_i$. In turn, these predicted savings are then used as regressors in equation (4.2), together with household characteristics such as income (y_i), family size (s_i) and location (l_i).

This two-step procedure considerably mitigates the endogeneity problem of determining a household's propensity to adopt a new stove, as well as the main factors affecting that propensity, and the household-specific benefits the stove is expected to provide, especially if the households of both samples are drawn from the same distribution. If the households in the two samples do not differ systematically with respect to essential household characteristics, we can infer that all households are potential adopters of new stoves. However, the household-specific combination of characteristics may be such that some households are observed to adopt a new stove, while others do not. Whether or not they discard their traditional stove depends on the household-specific savings a new stove provides, and these are calculated by multiplying the differences in the slope coefficients by the associated explanatory variables.

4.4 Estimation Results

Our data are from a survey of 200 households in Tigrai province, Ethiopia. Two-stage sampling was used to select the sample households. Four households were chosen at random from each of 50 *tabias* – the smallest administrative unit in the region – selected at random from a total of 600 *tabias* in the province. The (local) *tabai* administration is responsible for maintaining household lists from which the households targeted to interview were chosen.

Both quantitative and qualitative data were collected on the household's production (collection) and consumption of various biomass fuel types; demographic characteristics of the household include age, sex and literacy level of the household head and household size. Family resource endowments include total land area, cultivated area, number of trees, livestock holdings and type of stove used by the household. Also available from the survey are village level factors, including agro-ecological conditions or altitude range, and distance traveled (time spent) to collect different fuels.

Data on cooking/baking frequency of a household was weighted for respective end use share in the total household fuel using Table 2.10. Information on the different fuel types collected by the household was obtained in local units of measurement, but in a way that facilitated conversion to metric units and minimized errors. Considerations were also made to capture seasonal patterns of fuel availability and use. See Chapter 3 for details on instrument.

Before proceeding, it is necessary to check whether we can reject the hypothesis that the households in the two samples (those who have and those who have not adopted an improved stove) are drawn from the same distribution. Table 4.1 provides the mean values of the key household characteristics for the samples of households that have and have not adopted the improved stove. The table also provides the p-values of the two-sided Mann-Whitney U-tests with respect to whether the two samples differ in terms of these key characteristics.[19] The results do not allow us to reject the hypothesis that the two samples do

[19] The Mann-Whitney U-test is a non-parametric test. First, all observations in each of the adopters and non-adopters sub-samples are ranked from highest to lowest with respect to the variable of interest. The two series are then merged. Upon going down the merged series, if the observations roughly alternate between the two sub-samples, then the Mann-Whiney U-test fails to reject the assumption that observations are drawn from the same population. Alternatively, if observations from the top of the list all come from one sub-sample while those at the bottom from the other, the test rejects the null hypothesis of a common population (Harnett 1982).

not differ with respect to any of the individual household characteristics. Although this is not a definitive proof, it does give credence to our claim that it is the household-specific combination of characteristics that determines whether a household adopts a new stove.

Table 4.1 Means and standard deviations of 5 key household characteristics for households with and without an improved stove, and p-values of the two-sided Mann-Whitney U test

	Household income	Family size	Number of cattle	Land size	Middle highlands	Upper highlands
Traditional	145.954	5.395	3.370	3.423	0.538	0.193
stove	(105.578)	(2.210)	(2.864)	(2.095)	(0.501)	(0.396)
Improved	131.2821	5.432	3.765	3.207	0.444	0.160
stove	(74.259)	(2.127)	(2.481)	(1.809)	(0.500)	(0.369)
p-values	0.743	0.893	0.155	0.956	0.196	0.555

Before proceeding, it would also be worthwhile to provide the reader the insights as to how improved stove adoption is related to our variables of interest cooking frequency, time spent collecting wood, time spent collecting dung, and cattle holding. As it could be clear from Appendix Table 4A.2, adoption or use of improved stove is negatively related to cooking frequency, time spent collecting wood as well time spent collecting dung; whereas it is positively related to number of cattle or cattle holding of household.

4.4.1 The first-stage regression results

The impact of using an improved as opposed to a traditional stove is investigated by examining the four-equation regression model, equation (4.3), for the adopting and non-adopting households separately. We do not impose any restrictions that slope and/or intercept coefficients have to be identical across the two samples. Because of endogeneity and simultaneity considerations, the four equations are estimated as a system of equations using two-stage least squares (2SLS) regression[20] with the following instrumental variables: location (middle and upper highlands), family size and composition (i.e., number of adult females), land size, and the dummy variable 'use wood from own trees'. The regression results are provided in Table 4.2.

[20] Selection Bias is another important issue that needs to be taken care of besides endogeneity (simultaneity). Therefore, IMR (inverse Mill's ratio) was computed by running a *probit* regression of the standard stove adoption equation and then included as a regressor in the systems (2SLS estimation) to check for the Selection Bias. However, the IMR (inverse Mill's ratio) turned out insignificant in both cases, i.e., non-adopters and adopters, which proves there is nothing to worry about the Selection Bias. Hence, results of 2SLS estimation without IMR have been presented.

Table 4.2 2SLS regression results for households that have adopted (n=81) and have not adopted (n=119) improved stove [a]

Explanatory variable	Cooking frequency		Number of cattle		Time collecting wood		Time collecting dung	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Non adopter	Adopter	Non adopter	Adopter	Non adopter	Adopter	Non adopter	Adopter
Household income	0.032[b]	0.045[b]	0.007***	0.009***	0.199	-1.794	-0.033	1.271
	(0.020)	(0.028)	(0.003)	(0.004)	(1.923)	(2.979)	(0.734)	(1.136)
Family size	8.645**	8.931**			159.500*	105.793	13.760	-19.004
	(3.646)	(3.820)			(89.110)	(106.906)	(23.283)	(45.156)
Family size squared	-0.585*	-0.764**						
	(0.332)	(0.314)						
Number of adult females					640.906**	260.180	160.493**	224.481**
					(294.599)	(333.536)	(73.494)	(98.594)
Land size			1.479***	1.898***	-57.725	-680.773	-19.381	-64.241
			(0.508)	(0.632)	(391.651)	(494.877)	(158.236)	(257.873)
Number of cattle							16.139	6.338
							(90.968)	(129.570)
Time collecting wood and/or dung	-0.005**	-0.004						
	(0.003)	(0.003)						
Wood from own trees (=1; else 0)					707.369	-251.022		
					(498.363)	(488.509)		
Middle highland (=1; 0 otherwise)			-0.508	0.483	160.026	-934.825**	209.414*	229.598**
			(0.574)	(0.570)	(434.613)	(443.828)	(116.893)	(113.641)
Upper highland (=1; 0 otherwise)			-0.725	-0.509	-480.649	-1115.262**	144.842	83.074
			(0.740)	(0.731)	(550.395)	(567.849)	(151.095)	(164.182)
Constant	34.255***	29.066***	1.531**	0.876	-123.845	1838.313***	-120.192	-200.398
	(10.473)	(9.601)	(0.733)	(0.752)	(685.972)	(685.459)	(211.326)	(175.073)
R^2	0.0710	0.0603	0.2223	0.2723	0.1527	0.0974	0.0723	0.1959

[a] Standard errors in parentheses: ***, ** and * indicate significance at the 1%, 5% and 10% levels (or better), respectively.
[b] p≤0.11.

With the exception of time spent collecting fuel in the adopters' equation, all of the variables in the two cooking frequency equations are statistically significant at the 11% level or better. Households cook more often the larger household income, the larger the family (albeit at a decreasing rate), and the less time they allocate to fuel collection, which is probably indicative of a readily available (nearby) source of fuel.

Only household income and the area of land 'controlled' by the household are found to be statistically significant variables explaining cattle ownership in both the non-adopter and adopter equations (column 3 and 4, Table 4.2). As expected, both variables contribute positively to the number of cattle a household will own. It would appear that households own cattle as a form of wealth, especially because private landownership is not permitted. Somewhat surprisingly, the household's location is not found to affect the number of cattle it keeps.

The most important factors explaining the amount of time allocated to collecting wood in the non-adopters equation (column 5, Table 4.2) are family size (larger families need to collect more wood) and the number of adult females in the household (as adult females traditionally engage in fuel collection). Location is unimportant. In contrast, neither family size nor number of adult females is statistically significant in the adopters equation (column 6), but households located in the middle or upper highlands spend less time on wood collection, with coefficients for these location dummy variables statistically significant at the 5% level or better. Families that have adopted the improved stove spend less time collecting wood as such stoves are more efficient in their use of wood. Interestingly, household income, land area, and whether or not one uses wood from trees located on the homestead are not found to be important determinants of time spent collecting fuelwood.

Similar to the fuelwood equations, the number of adult females and the household's location (in the middle highlands) provide a statistically significant explanation of household time spent on dung collection (columns 7 and 8, Table 4.2). However, unlike the case for fuelwood, number of adult females is statistically significant in the adopters as well as non-adopters equation. And only the middle highlands dummy variable is statistically significant, but then in both equations. Surprisingly, while dung collection time would be expected to be inversely related to the number of cattle owned by the household, it turned out statistically insignificant and positive (both in the non-adopter and adopter equations). Household income has the expected positive sign, but is only statistically significant in the adopters' equation.

Family size and the size of the land area are found to be statistically insignificant determinants of time spent collecting dung.

Table 4.3 SUR regression results for derived demand functions for fuelwood and dung for non-adopters and adopting households (Double-logarithmic functional form) (n=200)[a]

	Fuelwood		Dung	
Explanatory variable	Non adopter	Adopter	Non adopter	Adopter
Household income	0.7707***	0.3172	-0.1926	0.4932
	(0.1859)	(0.2878)	(0.2261)	(0.5412)
Family size	0.2728	0.5344**	-0.0525	-0.2444
	(0.2761)	(0.2389)	(0.3363)	(0.4480)
Number of cattle	0.0377	-0.1985	0.5877***	-0.0646
	(0.1456)	(0.1997)	(0.1773)	(0.3728)
Price of wood (shadow)	-0.4747***	-0.2253**	0.2500***	0.2713
	(0.0742)	(0.1061)	(0.0914)	(0.2214)
Price of dung (shadow)	0.1792**	0.0540	-0.5773***	-0.6165***
	(0.0920)	(0.0689)	(0.1134)	(0.1292)
Use wood from own trees			0.1123	0.3273
(=1; 0 otherwise)			(0.2739)	(0.4298)
Middle highland (=1; 0	-0.4401*	-0.1328	1.6389***	1.1179***
otherwise)	(0.2321)	(0.2163)	(0.2817)	(0.4071)
Upper highland (=1; 0	-0.3301	-0.3367	1.8821***	1.6004***
otherwise)	(0.3257)	(0.3113)	(0.3952)	(0.5914)
Constant	-0.1791	2.0809	3.1435***	3.4904
	(0.8990)	(1.5088)	(1.0908)	(2.9052)
LR χ^2(df)	62.13(7)***	11.52(7)[b]	96.07(8)***	49.03(8)***

[a] Standard errors are provided in parenthesis: ***, ** and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.
[b] p-value=0.1175.

Derived demand equations for fuelwood and dung for both adopting and non-adopting households were also estimated using seemingly unrelated (SUR) regression with double-logarithmic functional forms. The double logarithmic function was preferred to a linear one as it provided a better fit to the data. Results are provided in Table 4.3. As expected, own (shadow) prices calculated from the survey (Gebreegziabher, Oskam and Woldehanna 2004) are statistically significant explanations of fuelwood and dung use and have the correct negative signs in each of the four equations. The prices of competing goods (e.g., shadow price of dung in the case of fuelwood) have the correct sign in all four equations, but are statistically significant only in the non-adopter equations. As in the time spent collecting dung equations, i.e., in Table 4.2, location variables are statistically significant in the dung demand function, while location is generally not important in determining the demand for fuelwood (with the possible exception of middle highlands in the case of non-adopters). Moreover, the estimated coefficients for income by non-adopting households and family size by adopting households have the expected signs and are statistically significant in the fuelwood demand equations, while the same is true for number of cattle in the dung demand equation for non adopters. These results were subsequently used, along with those of Table 4.2 to determine savings from adopting the new technology.

The predicted savings in cooking frequency, time spent collecting fuelwood, time spent collecting dung and livestock numbers are provided in Table 4.4. As indicated above, these are obtained by multiplying the differences in the estimated coefficients with the household-specific values of the explanatory variables. We find that the use of an improved stove is correlated with lower cooking frequencies, less time spent collecting fuel (both wood and dung), and increased cattle ownership. The latter result indicates that, at the margin, any change that affects the value of cattle to the household affects livestock holdings. Thus, even though cattle are kept because they provide dung for cooking and now less dung is required per household, each family will strive to increase their holding of cattle (by about 0.6 animals on average as indicated by the negative savings), probably because cattle are kept as a store of wealth and as a status symbol.

Table 4.4 Predicted time and other savings from adopting an improved stove, standard error (in parentheses) and t-tests of difference from zero

Item	Cooking frequency	Number of cattle	Time collecting wood	Time collecting dung	Fuelwood (kg/mo)[a]	Dung (kg/mo)[a]
Predicted savings ($\Delta\hat{x}_i$)	4.697 (0.708)	-0.599 (0.142)	472.665 (66.171)	40.840 (18.950)	68.278 (22.575)	19.899 (11.371)
t-values	6.63	-4.22	7.14	2.15	3.02	1.75

[a] Predicted saving obtained from derived demand functions estimated in Table 4.3

The savings in terms of woody biomass and dung are also given in Table 4.4. The estimated savings were obtained by comparing the predicted demands for adopters and non adopters of the improved stove technology. The results are interesting because they suggest that adoption of the new stove reduces harvesting pressure on local forest stands. Not only do the times spent collecting dung and wood go down, but, as a result, less wood and dung are used for cooking purposes. On a per household basis, we calculate adopters collect 68.278 kg less wood each month and 19.899 kg less dung each month. These results were found to be significant at the 1% and 10% levels, respectively. However, results also that adoption of an improved stove could have mixed environmental benefits. Grazing pressure on communal lands is likely to go up, as the number of cattle *increases* by an average of 0.6 per household.

4.4.2 The adoption of improved cooking stoves in Tigrai

We can now determine the factors that are likely to affect the adoption decision (equation 2). Apart from the predicted savings in cooking frequencies, cattle holdings and the amount of time allocated to collecting fuelwood or dung, we hypothesize that the decision to adopt an improved cooking stove also depends on other household characteristics, including household income, size and location. The results of the probit regression are presented in Table 4.5.

Table 4.5 Probit regression of the adoption of an improved cooking stove in Tigrai, Ethiopia (n=200)

Explanatory variable	Estimated coefficient[a]	Standard error
Saving in cooking frequency	0.0160*	0.0092
Saving in cattle numbers	1.5606**	0.7587
Saving in time collecting fuelwood	0.0009*	0.0005
Saving in time collecting dung	0.0057	0.0040
Household income	0.0167**	0.0076
Household income squared	-0.00002[b]	0.00001
Family size	-0.3482	0.2188
Middle highlands (=1; otherwise 0)	-1.2333***	0.4395
Upper highland (=1; otherwise 0)	-1.8988**	0.7852
Constant	-1.3884	0.9657
LR $\chi^2(9)$	17.59**	
Pseudo R^2	0.0652	

[a] * indicates statistically significant at the 10% level or better, ** at the 5% level or better.
[b] p-value = 0.108

The results are revealing. The savings in cooking frequency, time spent collecting wood and cattle numbers are all statistically significant factors explaining adoption. The time saved collecting dung is not found to be an important factor in the adoption decision, even though one would expect time spent collecting dung to decline as a result of adopting the new stove (since new stoves rely on wood only). We also find that, having controlled for the impact of household characteristics on the households' savings, their direct impact on the decision to build a new stove is negligible. Only households located in the upper highlands are found to be less likely to adopt new stoves.

4.5 Discussion

The results in this paper indicate that peasants in Tigrai province, Ethiopia, are willing to adopt new technologies if these result in economic savings. Barnes *et al*. (1993) found out that improved stove programs have been most successful when targeted to specific areas where fuelwood prices or collection time are high. In this study, we also found that the adoption of a more energy efficient or improved stove is proportional to the economic savings in fuel collection, cooking frequency and cattle required for everyday purposes. Our research also suggests that there may be a significant positive impact in slowing the degradation of agricultural and forested lands.

Based on our findings, improved stoves appear to reduce land degradation in three ways: (1) By switching to an improved stove as opposed to the traditional one, less dung is collected as fuel so more manure is available to benefit the soil. For example, for the households relying on dung collected from grazing lands and others' farmlands (see Appendix Table 4A.3), less dung being collected implies that the remaining amount, which would have been collected otherwise, will be left on the fields, which constitutes natural recycling and positive externality (Chapter 2). (2) Adoption of improved stoves results in less wood used as fuel, *ceteris paribus*, thus reducing deforestation pressure. As a result, more wood is available for others (non adopters and adopters), which implies less dung and crop residues will be used for fuel. (3) Finally, through its effect on time savings, stove adoption results in less time spent collecting fuelwood and dung, and in less time spent cooking. If labor markets also function fairly well, this would mean that more time is available for off-farm work (Woldehanna, 2000), leading to less time spent in agricultural and forestry activities. That, in turn, would imply reduced pressure on forests and agricultural land.

Lastly, the importance of new stoves can be determined from the results in this paper. There are some 600,000 rural households in Tigrai province. The probability that a household will adopt a new stove is 0.2884, implying that some 173,000 households are likely to adopt the more efficient technology. Given that each adopting household collects on average about 68.278 kg less fuelwood and 19.899 kg less dung per month, total potential savings could amount to approximately 141,745 tonnes of fuelwood and 41,289.564 tonnes of dung per year. Clearly, these estimates are based on potential, which assumes that all dung not collected would have been used in agriculture, and that all fuelwood savings come from forested areas, which is unlikely to be the case. In terms of wood alone, assuming an average of 120 t of biomass per ha (much higher than the current average), the potential reduction in deforestation amounts to nearly 1,200 ha per year, not an inconsequential savings. Given that there are almost 1 million ha of cropland in Tigrai, the dung saving translates into about two-thirds of an additional tonne of organic matter per hectare per year, again a substantial benefit.

Appendix 4A

Table 4A.1 Stove efficiency test results of '*Injera*' cookers

Energy Form	*Injera* Cooker Type	Cooking Time per Injera	Energy per Injera	Cooker Efficiency (PHV)[a]
		(Minutes)	(MJ)	(%)
Biomass Fuels				
Twigs, leaves: sticks (1:3)	Open fire with '*mitad*' on stones, height 13 cm	5.6	12.3	4.3
Twigs, leaves: sticks (1:4)	Filipini stove: molded clay design fully enclosed with '*mitad*' inlet and chimney, height 15 cm	13.1	11.1	4.8
Wood:	Tigrai stove: enclosed by clay walls with many small gaps in walls exhaust, height 14 cm	4.2	5.3	10.0
Twigs, leaves: sticks (1:3)	Experimental: like Tigrai with chimney, passive damper, height 12 cm	5.0	9.2	5.7
Electricity	Sample of models commonly marketed in Addis Ababa.	3.0-4.0	0.9	60
	Made-up of Aluminum *injera* cooker	not available		80

Note: [a] PHV= percentage of heat utilized

Source: UNDP/World Bank (1984).

Table 4A.2 OLS regression results for cooking frequency, cattle ownership and fuel collection, all households (n=200)[a]

Explanatory variable	(1) Cooking frequency	(2) Number of cattle	(3) Time collecting wood	(4) Time collecting dung
Household income	0.035**	0.007***	-0.038	0.486
	(0.014)	(0.002)	(1.558)	(0.369)
Use improved stove (=1; otherwise 0)	-5.010*	0.560[b]	-434.193*	-49.506
	(2.688)	(0.352)	(261.850)	(61.470)
Family size	8.616***		135.532**	8.763
	(2.424)		(67.028)	(15.722)
Family size squared	-0.700***			
	(0.209)			
Number of adult females			452.220**	174.567***
			(216.346)	(50.484)
Land size		1.594***	-309.073	19.807
		(0.391)	(298.642)	(70.761)
Number of cattle				-20.459*
				(12.284)
Time spent collecting wood and/or dung	-0.0019***			
	(0.0006)			
Use wood from own trees (=1; otherwise 0)			113.979	
			(341.379)	
Middle highlands (=1; otherwise 0)		-0.121	-238.408	206.415***
		(0.405)	(305.644)	(71.002)
Upper highland (=1; otherwise 0)		-0.567	-854.286**	101.077
		(524)	(390.763)	(91.284)
Constant	30.786***	1.097**	888.781*	-87.624
	(6.674)	(0.561)	(497.884)	(116.691)
R^2	0.138***	0.235***	0.096***	0.141***

[a] Standard errors are provided in parentheses: *** indicates statistical significance at the 1% level, ** at the 5% level, and * significant at the 10% level.
[b] Statistically significant at 11.3%.

Table 4A.3 Distribution of sample households by source of freely collected fuels by type (in % of households involved) (n=200)

Source	Fuel type		
	Wood	Dung	Crop residues
Own farmland/backyard	15.0	33.0	62.5
Others' farmland	-	5.0	35.5
Grazing land	33.0	50.5	-
Forest land	52.0	-	-
Total	100.0	88.5[a]	98.0

[a] The remaining are households not using dung at all.

Chapter 5 Afforestation in Ethiopia: Would Community and Household Tree Planting Imply More Wood Being Available for Fuel?♣♣

5.1 Background

Deforestation is a major problem in Ethiopia. Only 4.2 percent of the country's surface (or 13 million ha of 110.3 million ha) is forested (10% or more canopy cover), compared to 40 percent about a century ago (Hawando, 2004). Standing timber amounts to some 285 million m^3, or about 22 m^3 per ha, indicating a preponderance of dry rather than wet tropical forest ecosystem. Total biomass in forest ecosystems amounts to 573 million metric tonne (t) or 44 t per ha. Wood fuel dominates biomass use. In 2005, for example, 108.879 million m^3 of timber were harvested for fuel wood (nearly 25% more than in 2000) while 2.982 m^3 was harvested for industrial round wood, all of which were consumed domestically; harvests of timber for other uses were insignificant in comparison (FAO 2006). Between 1990 and 2005, the average annual rate of deforestation was nearly one percent, one of the highest in the world.

As forests are mined, peasants switch from fuelwood to dung and crop residues for cooking and heating purposes, thereby damaging the agricultural productivity of cropland. Household fuel consumption over the past several decades indicates a rapid growth in the share of animal dung. In Tigrai province, for instance, the share of dung increased from about 10 percent of total household fuel in the 1980s to about 50 percent by 1999 (see Tables 5.1 & 5.2). Already in the 1980s Newcombe (1989) estimated that, by burning some 7.9 million metric tons of dung per year, the reduction in agricultural productivity from lost nutrients associated with manure amounted to some 6 to 9 percent of the country's GNP. Moreover, the use of animal dung for fuel rather than for soil conditioning has a bearing on the country's balance of payments as considerable quantities of chemical fertilizers have to be imported to remedy the soil fertility.

The Ethiopian government has identified a two-pronged strategy to stem deforestation and the degradation of agricultural lands – afforestation at both the community and household levels, and dissemination of more efficient stove technologies. The assumption underlying the tree growing strategy is that at least a significant part of whatever is planted will be used as fuelwood. An interesting question is whether tree planting will indeed fully or partially make

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available more biomass as fuel? Or, do farmers have other purposes for which they grow trees?

Table 5.1 Average domestic fuel consumption of a rural household, Tigrai in 1999

Fuel type	Consumption (mega joules)	%
Woody biomass	38,267.2	48.65
Animal dung	37,469.6	47.63
Crop residues	2,047.5	2.6
Charcoal	858.0	1.1
Oil products	17.3	0.02
Total	78,659.6	100.0

Source: Gebreegziabher (2001)

Table 5.2 Share of fuel types in total household consumption, Tigrai (in%) [a]

	ENEC & CESEN (1986)	EESRC (1995)	
Source of Fuel	All Tigrai	Urban	Rural
Fuel wood and tree residues	82.40	49.0	65.8
Animal Dung	10.60	2.6	18.1
Agri Residues	6.00	2.2	8.6
Charcoal	0.90	40.9	6.6
Oil products	0.05	4.4	0.9
Electricity	0.05	0.8	0.0
Total	100.0	99.9	100.0

[a] Numbers may not add to 100% due to rounding.
Source: ENEC & CESEN (1986) and EESRC (1995)

The history of afforestation in Ethiopia is over a century old, but there has been no systematic research into the effectiveness of the afforestation strategy in terms of resolving the fuelwood problem in the country. Tree cutting for fuelwood is the major cause of deforestation in the country. The purpose of the current study is to examine the potential of the tree growing strategy as a remedy to the fuel problem. To do so, we use a unique data set covering 500 farm households and 100 communities in the highlands of Tigrai, northern Ethiopia. More specifically, the objectives of the current research are, first, to describe household tree planting and identify its behavioral determinants - what factor(s) enhance the likelihood of involvement in tree planting? Second, we evaluate whether household tree planting translates into more biomass available for fuel. Third, we assess the role that community forestry has in resolving the fuelwood problem. We approach the problem for aggregate tree planting as well as on a species-by-species basis. Finally, we draw some lessons or implications for policy from the analysis.

In the next section, we briefly review afforestation in Ethiopia while tree planting in the study region is discussed in greater detail in section 5.3. Our model of the tree planting decision is provided in section 5.4. A description of the dataset used for the study is provided in section 5.5, followed by results and discussion in section 5.6. The conclusions follow.

5.2 Afforestation in Ethiopia: A Review

Government's attempt to intervene in the forestry sector in Ethiopia has its origins in the reign of Emperor Menelik II (1889-1909). Trees were regarded as state property and a royalty payment was imposed on timber harvest. Moreover, during that time there was a scarcity of wood in and around Addis Ababa. The strategy adopted by the Emperor was to alleviate the fuel wood crisis through normal market operations, encouraging individual farmers to grow Eucalyptus and bring it to market. Two important policy instruments were pursued: delivering Eucalyptus seedlings to farmers at subsidized prices and exempting land planted to Eucalyptus trees from tax (Godoy, 1992). These two policy instruments combined with the rapid growth (high volume production) and coppicing ability of the genus have contributed to the popularity and rapid spread of Eucalyptus among smallholder cultivators in Ethiopia. Various studies have witnessed the outstanding performance of Eucalyptus even under harsh environmental conditions including drought (Jagger and Pender, 2003; Gindaba, 2006).

Official forestry legislation began, however, in the 1940s, that is, after Ethiopia’s liberation from Italian occupation. Although the first forestry legislation concerned forest harvesting revenue, it also focused on controlling rapid and on-going clearing of forests, which was already a problem at that time. Conservation of natural resources gained constitutional status in 1955, with land not owned by any physical or legal person declared to be the property of the state (Laike, 1990). The protective forest proclamation in the forest acts of 1965 was another pre - 1975 initiative.

The establishment of Peasant Associations (PAs) for the implementation of radical land reform was an important undertaking during the period between 1975 and 1991. PAs were established within an area of 800 ha and were mandated to administer all the land (including natural resources) falling within their jurisdiction (Nickola, 1988). The Forests and Wildlife Conservation Proclamation (Proclamation 192) of September 5, 1980 was another undertaking. Before 1980, most issues of forestry conservation and development were the responsibility of the Ministry of Agriculture, although an agency which specifically catered to forest conservation in larger state forests had already been established in the 1970s. Proclamation No. 192 created a separate Forestry and Wildlife Conservation and Development Authority (FaWCDA) to address broader issues of forestry, and establish specific regulations. The former responsibilities of the Ministry of Agriculture were transferred to FaWCDA, but a reorganization in 1985/86 merged it into the Ministry of

Agriculture (Laike, 1990). According to Proclamation 192, each PA shall develop its own forest by planting trees within its local areas as designated by FaWCDA.

Farm forestry has a long tradition in Ethiopia, with silviculture based entirely on indigenous knowledge. It was already there before government intervention. Three farm forestry technologies often practiced in Ethiopia constituted homestead tree planting, field tree planting and farm woodlots. Nevertheless, information on the types of indigenous practices in the various agro-ecological zones is limited, while the extent of private or household tree planting is not well documented. In the last few years household tree planting has been encouraged mainly through the distribution of seedlings from government nurseries. Seedlings have been distributed for free or at subsidized prices in order to encourage tree planting by farmers.

Community forestry activities started in 1976 with assistance from Swedish International Development Agency (SIDA). A team of socio-economists was given the task of collecting information about forestry activities carried out by the PAs, but this group became a department within FaWCDA in 1980, and later community forestry and soil and water conservation were merged into the Ministry of Agriculture as Community Forests and Soil Conservation Development Department (CFDD). Again the main emphasis was the mobilization of peasants to establish their own woodlots. Task forces composed of representatives from PAs, Urban Development Associations (UDAs) and government organizations were established at provincial, sub-provincial and district levels for the purpose of promoting and coordinating CFDD activities. By 1983/84, 12 provincial, 77 sub-provincial and 212 district task forces were already in operation. Moreover, a total of 312 demonstration nurseries had been established at the sub-province and district levels for training of PA representatives and, by the end of 1984, over 42,000 farmers were trained. The total number of seedlings raised in four years, including the 1983/84 season, was 104.5 million on 70,400 ha, an average of 1480 trees/ha (Booth, 1985).

Community forestry was undertaken to provide fuelwood and construction material for the community, and to reclaim degraded areas, particularly hillsides. There were 19,228 PAs by 1984 and about 10 percent of their land was assumed to be allotted for woodlot or wood production (Booth, 1985). In actual practice, community woodlots ranged between 10 ha and 80 ha in size, but totaled only 20,000 ha with an average yield of $8m^3$/ha per annum and were estimated to result in a total MAI of 160,000 m^3 (EFAP, 1994). Nonetheless, the contribution of these community forests is largely unexplored.

5.3 Tree Planting and Tree Resources in Tigrai

Government afforestation effort in Tigrai began in 1970 under the auspices of a USAID "Food for Work Programme", which also included road building and dam construction projects in four areas: Mekelle, Maychew, Adigrat and Wukro (Hunting, 1976). In 1971 a request was submitted to the UN/FAO World Food Programme (WFP) to obtain additional supplies of grain to enable the afforestation project to be expanded. About three years elapsed between the submission of this request for WFP support and the arrival of the first shipments of grain. Thus, between 1971 and 1974 the project was supported by USAID. During 1974, both USAID and WFP grain shipments were received in Tigrai, after which USAID withdrew from the project leaving WFP as a sole supporter.

The project was administered by the Forestry Department until mid-1975 when the State Forest Development Authority (SFoDA) was given responsibility for all forestry-related activities in Ethiopia. Due to a shortage of Forestry Department staff, however, the implementation of terracing, afforestation and the distribution of grain payments was undertaken by the Extension and Project Implementation Department (EPID) of the Ministry of Agriculture. One expatriate forestry advisor based in Mekelle was given overall responsibility for the project but, due to a lack of both transport and operating expenses, was rarely able to visit afforestation sites. The work was, therefore, left almost entirely to EPID staff, none of whom had any formal training in forestry. As a result some of the project sites suffered from poor nursery organization, incorrect spacing during planting and wrong choice of tree species. While tree planting in Tigrai was not promoted by government prior to 1970, between 1970 and 1974 nearly 1,500 ha were planted and terraced at 11 sites (Hunting, 1976), again an insignificant area considering ongoing level of degradation. A survey in 2000/01 showed that there are about 9 woodlots or plantation sites per *tabia*, most of which were established in the post 1991 period. The average size or area of the woodlots also varied between 5 and 18.5 hectares (Gebremedhin *et al*., 2003; Jagger *et al*., 2003).

Three distinctions can be made regarding property rights and tree resources in Tigrai: private or household tree holdings, community woodlots, and state forests. The private or household tree holdings include trees privately grown around homesteads and cultivated land for various purposes that often fall under the category technically referred to as agro-forestry. The diversity of tree species grown by private households can be aggregated into indigenous trees, *Eucalyptus* species, other exotic species (e.g., *Shinus molle*, *Acacia decurrens*, etc), cash crop trees (coffee, etc), fruit trees (lemon, orange, papaya), and multi-purpose trees (i.e., leguminous and for fodder almost entirely *Sesbania* species). The proportion of tree growing farmers by agro-ecology and type of trees is provided in Table 5.3. Indigenous trees and Eucalyptus are the two most important. Overwhelmingly farmers in the lowlands plant indigenous rather than Eucalyptus species, while the opposite happen to be the case for the midland and highland regions. Clearly, government nurseries constitute major sources of seed/seedlings in all regions for all species, with the exception of cash crop and fruit trees (Table 5.4). Property rights are vested in the individual holder, and the provincial government's current land use policy also gives the ownership of natural trees found on the cultivated land to the user or the farmer to whom the holding belongs. The individual holder is free to make use of, sell or rent the yield, berries or resins, from such trees found on her land (CNRST, 1997). The land use policy provides protection of economically important endangered indigenous trees such as *Boswellia papyrifera*, *Acacia senegal*, *Ficus vasta*, *Diospyros mespiliformis*, *Faidherbia albida (Acacia albida)*, *Ficus sycomorus*, and *Podocarpus gracilor* found on cultivated land.

Table 5.3 Distribution of tree growing farmers (households) by agro-ecology and tree type, Tigrai in 2000 (in %)

Tree type	Agro-ecology			
	Lowland (East)	Lowland (West)	Midland	Highland
Indigenous	74	69	70	58
Eucalyptus	13	14	65	89
Other exotics	6	31	11	11
Cash crop trees	8	0	7	6
Fruit trees	6	0	7	6
Multi-purpose trees	6	0	2	0
No trees	19	22	7	6

Source: WBISPP (2002)

Table 5.4 Distribution of tree growing farmers (households) by seed (seedlings) sources and tree type, Tigrai in 2000 (in %)

Tree type	Seed (seedling) source							
	Gov't nursery	Other farmer	Own nursery	Market	NGO	School	Church	Community plantation
Indigenous	60	6	17	8	3	1	2	0
Eucalyptus	72	4	9	12	0	1	1	1
Other exotic	85	0	12	3	0	0	0	0
Cash crop	28	26	16	4	0	0	0	0
Fruit trees	8	0	12	29	0	0	0	0
Multi-purpose	91	0	0	5	0	0	0	0
All trees	66	6	12	11	1	0	1	1

Source: WBISPP (2002)

Table 5.5 Distribution of tree growing farmers (households) by methods of planting and tree type, Tigrai in 2000 (in %)

Tree type	Method of planting				
	Direct seeding	Bare root	Container	Cutting	Natural regeneration
Indigenous	2	9	22	2	66
Eucalyptus	9	25	63	0	3
Other exotic	0	9	83	0	7
Cash crop	19	51	31	0	0
Fruit trees	33	8	8	0	0
Multi-purpose	0	12	65	0	0
All trees	6	14	23	1	47

Source: WBISPP (2002)

Table 5.6 Location of trees on the farm landscape by tree type for Tigrai in 2000 (in %),

Tree type	Location				
	Homestead	Field boundary	Crop fields	Stream banks	Other places
Indigenous	58	15	24	0	3
Eucalyptus	50	26	5	9	8
Other exotic	99	0	0	0	0
Cash crop trees	58	0	24	18	0
Fruit trees	50	0	0	50	0
Multi-purpose trees	94	0	3	3	0
All trees	50	15	21	4	4

Source: WBISPP (2002)

Area enclosures and community plantations were initiated in Tigrai primarily for ecological regeneration as part of the environmental reclamation program. However, also include economic objectives as reducing fuelwood shortage. Community woodlots are regulated through the bylaws of local governments; these most often emphasize input contributions and protection against human and livestock interference. Community woodlots and collective action are frequently viewed as viable resource management arrangements in more remote areas or ones with intermediate population density. However, it needs to be verified that community woodlots do indeed contribute to reducing fuelwood shortage, as it is often thought.

State forests constitute natural high forests preserved for biodiversity conservation and other purposes, with property rights vested in the state. It could be either national forest priority areas (NFPAs) or regional forest priority areas (RFPAs). Cross-boundary forest areas also fall within the category of state forests. The first priority within the context of these high forests is protection and conservation. Of the 58 most important high forest areas classified or designated as national forest priority areas (NFPAs), two are found in Tigrai (EFAP, 1994).

5.4 Theoretical Model

There are two approaches to analyzing the tree growing (planting) decision of households: one is to choose investments that maximize net expected returns (Patel *et al*., 1995); the other is based on utility maximization, analyzing the behavioral factors that underlie the tree growing decision (Thacher *et al*., 1997). The former regards tree planting to be worthwhile if tree planting yields higher net expected returns compared to major crops such as maize and coffee, or enhances the output of agricultural crops so that costs of tree planting are more than covered. Under the behavioral approach an individual farm household is assumed to be involved in tree planting so long as the utility attained from planting or investing in trees is larger than what would be attained otherwise. We follow the latter approach.

Consider a farm household's or community's decision to plant trees. Suppose the decision maker can choose whether or not to plant or invest in trees. Denote the decision to plant trees by index *t*, with *t*=1 if it is decided to plant or invest in trees, and 0 otherwise. Then, the utility function for the *i*th household's decision be specified as $U(z_i^t,\mathbf{h}_i)$ (Chambers and Foster, 1983), where z_i^t is a vector of attributes related to tree planting and $\mathbf{h}_i$, is a vector of household or community-specific socio-economic characteristics.

Given that behavior is consistent with a well-defined utility function; then, the utility for i^{th} household of not planting or investing in trees can be written as:

(5.1) $U_i^0=V(z_i^0,\mathbf{h}_i) + \eta(z_i^0,\mathbf{h}_i,e_i^0)$,

where V and η are real valued functions with V the certain component of the utility and η the random component, and e_i^0 is unobserved vector containing all unmeasured attributes and characteristics. Similarly the utility of planting or investing in trees can be written as:

(5.2) $U_i^1=V(z_i^1,\mathbf{h}_i) + \eta(z_i^1,\mathbf{h}_i,e_i^1)$,

where e_i^1 is a vector representing unmeasured attributes or characteristics.

The utility maximizing condition implies that the household will plant or invest on trees when

(5.3) $V(z_i^1,\mathbf{h}_i) + \eta(z_i^1,\mathbf{h}_i,e_i^1) > V(z_i^0,\mathbf{h}_i) + \eta(z_i^0,\mathbf{h}_i,e_i^0)$.

From the above formulation, it is quite apparent that two sets of arguments (variables) explain the tree planting decision: those constituting **z** and those constituting **h**. Among the latter household income, labor, land area cultivated and number of cattle are some of the variables expected to influence the tree planting decision of farm households. Land holding is expected to have a positive influence on the number of trees grown. Greater land availability would be expected to permit tree planting without the sacrifice of agricultural production necessary to meet food and income needs of the household. We distinguish between land area cultivated and homestead area. Cattle may be either a substitute or a complement to tree planting.

Regarding the tree attributes, one can envisage trees having multiple roles in the rural livelihood. One attribute could be that they provide the households with wood products that can be used as firewood or converted into cash as timber (Thacher *et al*., 1997). Moreover, trees provide wood for various local uses, such as housing construction, fencing, farm tools (implements), furniture, and household utensils. Trees also provide products such as fodder, berries for food and serve as bee forage. In addition to fulfilling such material needs of the farm households, trees play an important ecological function in agricultural systems. They play a role in maintaining and enhancing the physical environment needed to sustain crop production (Filius, 1982). Hence, it could be the case that the farm household plants certain species on the basis of specific attributes, as many of the attributes are species-specific and vary across species. Because these variables are unobserved or unavailable we concentrate on the vector of observed household-specific (socioeconomic) characteristics underlying the tree planting decision.

To capture the effect of household tree planting on fuel wood consumption, we postulate the i^{th} household fuel wood consumption function as (Sadoulet and de Janvry, 1995):

(5.4) $q_i=q(p_i,y_i,\mathbf{h}_i)$,

where q_i is quantity of fuel wood consumed by household i, p is price of fuel wood, y is household income and **h** is defined as previously. As in standard consumption theory, price is expected to affect fuel wood consumption negatively, whereas income is expected to contribute positively to consumption. Finally, the effect of the vector household characteristics and resource endowments cannot be determined a priori.

5.5 Empirical Model

5.5.1 Household tree planting decision

Consider a random sample of n observations, and distinguish between two important aspects of tree planting; i.e., the extent of tree planting (growing) of a household and the household's decision whether or not to be involved in tree planting (growing). Let Y_{1i} and Y_{2i} respectively denote the extent of tree planting by a household and the household's decision whether or not to involve in tree planting, and let Y_{1i}^* and Y_{2i}^* be the corresponding latent variables underlying tree planting measures. The Heckman selection model equations for household i are specified as (Verbeek, 2004):

(5.5a) $Y_{1i}^* = X_{1i}\beta_1+u_{1i}$,

(5.5b) $Y_{2i}^* = X_{2i}\beta_2+u_{2i}$ (i=1, …,n),

where X_{ji} is a $1\times K_j$ vector of exogenous regressors, β_j is a $K_j\times 1$ vector of parameters, and $u_1 \sim N(0, \sigma)$, $u_2 \sim N(0,1)$, and $corr(u_1, u_2)=\rho$.

Note that Y_{1i}^* is not observed for households not involved in tree planting. As in Heckman (1979) the first equation, equation (5a) is the regression equation and the second equation, equation (5b) is the selection equation. The second equation is of binary choice type specified to describe whether or not i^{th} household is involved in tree planting. Then, we have the following observation rule:

(5.6) $Y_{1i} = Y_{1i}^*$, $Y_{2i}=1$ if $Y_{2i}^* > 0$

(5.7) Y_{1i} not observed, $Y_{2i}=0$ if $Y_{2i}^* \leq 0$.

where Y_{1i} is household i's actual number of trees grown. The binary variable Y_{2i} simply indicates growing or not growing trees.

The Heckman selection model is preferred over the standard tobit model or even ordered logit model as in Patel *et al*. (1995), because besides correcting for selection bias such a specification would enable us to discern whether or not the same factors underlie the decision to plant trees and the extent of tree planting.

5.5.2 Household tree planting and fuelwood availability

In order to determine the impact of household tree growing on the household's fuelwood consumption function we specified the empirical model as:

(5.8) $q_i = g\,(y_i, fs_i, p_i, nt_i, l_i, \mathbf{h}_i)$

where the dependent variable q_i is the quantity of *i*th household's fuelwood consumption (as in above), y_i is household income, fs_i family size, p_i price of fuelwood for household *i*, nt_i is the number of mature trees household *i* holds, l_i refers to location and $\boldsymbol{h}_i$ is a vector of other household characteristics and resource endowments. We used the opportunity cost in agriculture of time spent collecting fuelwood as a proxy for fuelwood price. To capture the impact of household tree planting on fuelwood availability, we included the variable number of valuable mature trees the household owns (for all trees and for trees of species *s*), as an explanatory variable. Agro-ecological conditions and altitude range (lower, middle and upper highland) identify location. We focus on these variables of interest for data limitation.

We estimate separate OLS regression of equation (5.8) with inclusion of a disturbance term ε, that is, all trees regression and species regression. In the all trees regression number of all trees in the aggregate was included as explanatory variable. In the separate species regression, plantings of individual tree species are included as explanatory variables. We preferred such empirical approach mainly because it would enable us to tackle important questions this paper would like to address. For example, question as to whether tree planting in the aggregate has any association with fuelwood consumption of household? That is, the question of whether household tree planting fully or partially make available more biomass as fuel? Moreover, we expect that the species differ in quality in terms of their usefulness as fuel, be it exotic or indigenous, hence, considered species regression so as to enquire a step further for any species specific role.

5.5.3 Community tree planting and fuelwood availability

In order to determine the effect of community tree planting on the household's fuelwood consumption function we specified the following empirical model:

(5.9) $q_i = g\,(y_i, fs_i, p_i, D^w, l_i, \mathbf{h}_i)$

where D^w is an indicator variable characterizing community woodlot w. Equation (5.9) is different from equation (5.8) with respect to the indicator (dummy) variable D^w. The reason for using an indicator variable is that harvest quantities of fuelwood from community woodlots were not included in the community dataset, nor was the inventory of biomass stock. Because of this data limitation we capture the effect of community tree planting (woodlots) on fuelwood consumption through the indicator variable. We distinguish four categories of woodlots as relatively high, medium, low and very low based on volume of biomass using BoANR (1997b).

5.5.4 Data

The data we used in this chapter come from a survey of 500 households and 100 communities collected in Tigrai province, northern Ethiopia, during the year 2000. The data was collected by the International Livestock Research Institute, International Food Policy Research Institute, and Mekelle University as part of the broader initiative on 'strategies for sustainable land management in the East African Highlands' (Chapter 3). The household dataset include demographic characteristics of the household, such as age, sex and literacy level of the household head and family size, through to household resource endowments that include total land holding, cultivated land area, and livestock (cattle) holdings of household. Also available are household income and quantitative and qualitative data on household's consumption of fuelwood, various biomass fuel types, and number of mature wood trees grown by households. The data also cover information on location. A summary description of the data used in the household analysis is presented in Tables 5.7.

Table 5.7 Summary statistics of variables used in regression (n=500)

Variable	Mean	Std. Dev.	Min	Max
Family size	5	2	1	11
Adult males	1	1	0	6
Adult females	1	1	0	5
Household income (Eth Birr)	1356.30	1218.19	157.75	9270
Number of cattle	3	3	0	17
Cultivated land (*tsmdi*[a])	2.54	2.98	0	19
Homestead area (*tsmdi*)	1.32	1.23	0	7
Involvement in tree planting				
Households involved (in percent)	81			
Households not involved (in percent)	19			
Number of mature wood trees/household				
All trees	22	45	0	531
Olea europaea	1	3	0	50
Eucalyptus camaldulensis	8	31	0	500
Eucalyptus globulus	6	17	0	140
Acacia ethbaica	5	24	0	300
Faidherbia albida (Acacia albida)	1	5	0	70
Fuel wood(kg)	290.71	278.14	0	1785

[a] *tsimdi* is local unit (1 *tsimdi* = 0.25 hectare)

In rural settings, it is not uncommon to find diversity of tree species grown by farm households. In our dataset, for example, we found a total of 149 tree species grown by sample households, of which five species dominated - *O. europaea, E. camaldulensis, E. globulus, A. ethbaica*, and *F. albida (A. albida)*. The first two are exotic species, while the remainder are indigenous. In light of the country's fuel problem and due to high yield and coppicing ability, Eucalyptus has been the favorite wood tree as it has been encouraged by government for over a century. Data on community woodlots covered characteristics of respondents, woodlot management, and labour contributions (such as uncompensated compulsory labour, uncompensated voluntary labour, rotation of community members, etc), material input contributions, harvest information (such as harvest of grasses, poles, tree fodder, etc) from community woodlots by community members for various purposes; investments by the community (soil and water conservation structures, fences, etc.). Most of the woodlots were established since 1991. However, there were also woodlots as old as 1971. Size of woodlots ranged from 0.25 to 50 ha with the mean area being about 9 ha.

5.6 Results and Discussion

5.6.1 Household tree planting decision

Arnold *et al*. (2006) argue that, in selected situations, there appears to be the scope for supply-side interventions that could increase the spectrum of low cost, multi-purpose woody species and husbandry options available to farmers, to enable them to increase supplies of fuelwood as a co- or bi-product of managing trees and shrubs on-farm for other benefits. However, although the history of afforestation in Ethiopia is over a century old, there has been no systematic research into the effectiveness of the afforestation strategy in terms of resolving the fuelwood problem in the country. In here we explore what factor(s) enhance the likelihood of involvement in tree planting as well as the extent of tree growing? The Heckman selection model estimates of the determinants of household tree planting decision and the extent of tree growing are presented in Table 5.8. We see a clear pattern in terms of which underlying factors are more important in the decision to grow trees vis-à-vis the extent of tree growing. Most of the variables considered turned out to be significant at 10 percent level or better.

From the selection equation results, availability of male labor positively and significantly influenced the household's decision to grow trees, whereas female labor was found to have no any significant effect. Land area cultivated was important and significantly influenced tree growing decision albeit with unexpected negative sign, indicating that households with less land are more likely to be involved in tree planting compared to households with more land. In the empirical work we distinguish between cultivated land and homestead areas. Homestead area positively and significantly influenced households' tree planting decisions. This implies that households with relatively larger homestead areas are more likely to be involved in tree planting compared to those with smaller homestead areas. Number of cattle also significantly and positively influenced the household tree growing decision. However, household income turned out to have no significant effect on households' decisions to plant trees. Among the location factors considered, only middle highland positively and significantly influenced household's tree planting decision.

Table 5.8 Heckman selection model results of extent of tree planting (dependent variable total number of tree planted) and of the decision to plant trees

Explanatory Variable	Estimation results	
	Coefficient[a]	t-statistic
Regression equation		
Male labor	7.096*	1.68
Female labor	7.248	1.15
Land area cultivated	-0.222	-0.23
Number of cattle	0.019	0.02
Household income	0.007*	1.92
Homestead area	-4.466**	-2.14
Middle highland	10.139**	2.22
Upper highland	2.107	0.29
Selection equation		
Male labor	0.444***	4.04
Female labor	0.040	0.45
Land area cultivated	-0.104***	-3.61
Number of cattle	0.084***	2.69
Household income	-0.000	0.50
Homestead area	0.147*	1.83
Middle highland	0.506***	3.62
Upper highland	0.261	1.20
Statistic		
ρ	-0.139	0.057[b]
σ	46.032	6.965[b]
λ	-6.385	3.197[b]
N	484	
F(8, 474)	17.73	
Prob>F	0.000	

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.
[b] standard error rather than t-statistic

With respect to the extent or amount of tree planting, the availability of male labor still positively and significantly influenced the number of tree grown by a household, albeit at lower level of significance. This suggests that households with relatively more male labor will grow more trees than households with less male labor. As it was the case on household's tree planting decision, female labor availability also turned out to have no significant effect on extent of tree growing of household, probably because planting wood trees is essentially male activity. Surprisingly, cultivated land area was found to have no significant effect on number of tree grown by household, still with unexpected negative sign. Yet more surprisingly and contrary to what was found with respect to its effect on household's tree planting decision, homestead area significantly and negatively influenced extent of tree growing of household.

This implies that households with smaller homestead areas grow more trees compared to those with relatively larger homestead areas. The possible explanation for this could be because trees might not compete with other land options, i.e., with activities such as crop cultivation and home gardening. It could be that farmers grow the trees as farm boundaries that it may not compete with other crop activities (Kidanu, 2004). Number of cattle was found to have no significant effect on extent of tree growing of households, contrary to what was found with respect to its effect on households' tree planting decisions. Household income, which was found to have no any significant effect on tree planting decisions, positively and significantly influenced extent of tree planting. Among the location factors middle highland positively and significantly influenced the extent of tree planting whereas upper highland turned out to be insignificant. The fact that the variable upper highland turned out to have no significance suggests that households located in the upper highland do not differ from those in the lower highland in terms of extent of tree growing. It also implies that households located in middle highland plant more trees compared to those in the lower and upper highlands. Such results depict the diverse nature of the agro-ecological specificity of the activities like tree planting.

As regards to goodness-of-fit of the model, as could be clear from the result in Table 5.8, F statistic (test) turned out significant at far better than 1 percent level. Therefore, we reject the null hypothesis in favor of the alternative that all of the explanatory variables included help explain the variation in extent of tree growing among households.

5.6.2 Household tree planting and fuelwood availability

The impact of household tree planting on fuelwood availability was investigated by regressing households' fuelwood consumption on household and farm characteristics, and the number of mature total trees (model 1) and the total mature trees of each particular species (model 2). From these results, we obtain insights as to whether household fuelwood consumption is affected by the availability of mature trees and their type.

Most of the variables considered in the investigation turned out to be significant at the 10 percent level of significance or better. Family size and wood price were found to be significant, with expected positive and negative signs, respectively, in both regression models. Household income positively influenced fuelwood consumption; the estimated coefficient was significant at the 10 percent level in the case of model 1 but insignificant when individual species were considered. The positive sign for the income coefficient indicates that wood is a normal good and that wood consumption increases as income increases. As expected we found household resources endowment (number of cattle) to have a highly significant influence on household fuelwood consumption. It was positively and significantly related to fuelwood consumption everywhere, i.e., in both all trees and the species regressions. Among the location factors the variable upper highland turned out to be negatively and significantly related to fuelwood consumption particularly in the all trees regression (column 2, Table 5.9); indicating that less wood is consumed as one goes from lower to the middle and upper highlands. Except for the negative signs all location variables turned out insignificant in the species regression (see column 3, Table 5.9). The intercept terms were also statistically very significant and positive everywhere.

Table 5.9 OLS estimates (standard error in parenthesis) of effect of household tree planting (number of trees) on household fuelwood consumption

Variable	Dependent variable (fuelwood consumption)[a]	
	Model 1 (All trees)	Model 2 (Species)
Family size	13.775**	16.077**
	(7.166)	(6.961)
Ln(Wood price)	-0.062***	-0.049**
	(0.024)	(0.024)
Household income	0.036*	0.031
	(0.020)	(0.021)
Number of cattle	22.631***	18.832***
	(4.674)	(4.610)
All trees (species)	0.737***	
	(0.285)	
Tree species:		
Olea europaea		1.444
		(3.768)
Eucalyptus camaldulensis		-0.475
		(0.389)
Eucalyptus globulus		-0.212
		(0.734)
Acacia ethbaica		2.677***
		(0.498)
Faidherbia albida (Acacia albida)		4.528
		(2.951)
Middle highland	-37.1198	-13.988
	(28.925)	(28.740)
Upper highland	-94.058**	-58.150
	(41.553)	(42.862)
Constant	175.428***	153.069***
	(45.239)	(44.348)
n	415	415
F-value	10.44***	9.90***
R-squared	0.1522	0.2127

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

As regards to the relationship of household tree planting with fuelwood consumption, i.e., the issue of whether it transpires into being used as fuel, model 1 results of all trees regression reveal quite clear positive relationship between number of mature trees and fuelwood consumption of household. Therefore, a claim could be made 'yes tree planting in the aggregate contributes to household fuelwood consumption'. Nonetheless, such a generalization based on aggregate variable might lead to the conclusion that whatever species planted translates into being used as fuel. Hence, this calls for investigating a step further how important the various species are in terms of their contribution to household's fuelwood consumption? This is an interesting question pertaining to the species regression. Among all the species considered the species *A. ethbaica* was found positively and significantly related to fuelwood consumption of household. For example, the species *O. europaea*, *F. albida* (*A. albida)* and both *Eucalyptus* species turned out to be insignificant. It appears that indigenous tree species such as *A. ethbaica* are important in terms of household fuelwood use. Despite that Eucalyptus was the favorite tree species that has been widely promoted it turned out to be not significantly related with household fuel consumption. One possible explanation for this to happen could be because there are other ends or purposes that are competing in such a way that whatever planted may not, even partially, translate into being used as fuelwood. For instance, if we consider the typical exotic species *Eucalyptus*, often widely promoted for fuelwood purpose, the construction market is one possible outlet. It might be that it out compete and likely undermine the purpose of being used as fuelwood. Whereas in the case of the species *Olea europaea*, that it is an indigenous species typically preferred for preparing traditional farm implements like ox-traction tools and others might be the reason.

Therefore, precisely speaking, it turns out that the strategy of household tree growing as a remedy to the fuel problem should take account of the multiplicity of purposes involved in tree growing. We see our findings might also help as to which species to pick up (i.e., which species might be more important to focus) in line with the policy of addressing the fuel problem and the attendant land degradation.

5.6.3 Community tree planting and fuelwood availability

OLS regression was run to assess the effect of community woodlots on household fuelwood consumption. Results are presented Table 5.10. Most of the variables considered in the regression turned out to be significant at 10 percent level of significance (or better). Needless to discuss about results for variables family size, household income, number of cattle, wood price and location variables middle and upper highland as have already been discussed in the preceding section.

Table 5.10 OLS estimates (standard error in parenthesis) of effect of community woodlots on household fuelwood consumption function

Variable	Dependent variable (fuelwood consumption)[a]
Family size	14.247**
	(6.913)
Household income	0.038**
	(0.02)
Number of cattle	20.120***
	(4.701)
Ln(Wood price)	-0.056**
	(0.024)
Middle highland	-70.418**
	(31.369)
Upper highland	-124.682***
	(45.116)
Woodlot characteristics	
High (=1, if total volume >1948m^3; 0, otherwise)	-113.783***
	(45.307)
Medium (=1, if 1098m^3 < total volume ≤ 1948m^3; 0, otherwise)	18.638
	(43.303)
Low (=1, if 560m^3 < total volume ≤ 1098m^3; 0, otherwise)	88.797*
	(50.341)
Constant	215.045***
	(52.783)
N	425
F-value	11.15***
R-squared	0.1948

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively

Community woodlots have been encouraged as a remedy to the fuel problem in the country. The basic economic question was whether indeed they have an effect or contribute to addressing the fuel problem? Our findings reveal that they hardly have any significant effect on household fuelwood consumption. For example, the variable for relatively high total stock biomass turned out to be highly significant but with unexpected negative sign. It suggests that, *ceteris paribus*, households with or around community woodlots with relatively high biomass volume consume significantly less wood. Reported results for variables on woodlot characteristics are in contrast to woodlots with very low biomass volume. It could be that the households depend on other fuel sources such as dung and crop residues and consume less of fuel wood so that it turned out negative. Among the possible explanations for community tree planting (woodlots) to have no significant effect on household fuelwood consumption could be: one, that there are institutional setbacks as regards to the utilization of fuelwood, poles, and other timber products by members (households), particularly in the case of woodlots with better biomass volume; two, the available biomass stock of the woodlot is not enough that members (households) can depend on. Arnold et al. (2006) argue that devolution of control (power) over forest and other public lands to the local level could be envisaged to improve the property rights and to improve the efficiency in resources management. They also argue that the devolution has the potential to reverse (ameliorate) some of the factors contributing to reduced access to gatherable fuelwood supplies. Therefore, it could be seen an option in circumstances where institutional setbacks are the main problem.

5.7 Conclusions

This paper evaluates the effectiveness of the afforestation strategy of Ethiopia as a remedy to the country's fuel problem using datasets from sample cross-sections of 500 households and 100 communities in the highlands of Tigrai, northern Ethiopia. Key questions were: What factor(s) enhance the likelihood of involvement in tree planting as well as the extent of tree growing? Does household tree planting translate into more biomass available for fuel? What role does community forestry have in resolving the fuelwood problem? The following lessons or conclusions could be drawn.

As regards to factors underlying the households' decisions to plant trees and the extent of tree planting, our findings reveal a clear pattern, that exactly the same factors do not necessarily underlie the two aspects of tree growing. That which factor is most important and the direction of causality varies from one to the other. Results also suggest that tree planting may not necessarily compete with other land use option. Our findings also point to intra-household patterns of resource endowments or allocation such as male versus female labor availability in the household's decision to grow trees as well as the extent of tree growing.

As regards to whether household tree planting (growing) transpires into being used as fuel, results reveal that it differs from species to species. Findings suggests that there is no any relationship between household tree growing and fuelwood use (consumption) of the household, particularly in the case of Eucalyptus, typical exotic species widely promoted for this purpose. It appears that indigenous tree species such as *A. ethbaica* are important in terms of household's fuelwood use. It might be that there are other competing ends in such a way that whatever planted may not fully translate into fuelwood. Therefore, it is worthwhile that the strategy of household tree growing as a remedy to the fuel problem should take account of the multiplicity of purposes involved in tree growing. In this respect, the findings of this study might also help as to which species to pick up (i.e., which species might be more important to focus) in line with the policy of alleviating the fuel problem and the attendant land degradation.

With respect the question of whether indeed community tree planting (woodlots) have an effect on or contribute to addressing the fuel problem, it appears that they hardly have any significant effect on household fuelwood consumption, implying that they have no significant contribution to addressing the fuel problem.

Generally, the novelty in here is that, besides testing whether or not household and community tree planting (growing) transpire into being used as fuel, we provide species specific finding, which are of help in sharpening forestry policy.

Chapter 6 Fuel-augmenting Technical Change for Reversing Land Degradation: the Case of Biogas Innovation in Ethiopia[♣♣♣]

6.1 Background

Land degradation is the major cause for agricultural stagnation and rural poverty in Ethiopia (Wood, 1990; Hagos *et al*., 1999; Hengsdijk *et al*., 2005). Land degradation has various forms including soil erosion.[21] The aspect of land degradation being considered in here is nutrient loss (depletion) because of removal or burning of dung for fuel purposes. Because of the deforestation that has occurred over many years scarcity of fuel wood is a critical problem in Ethiopia. As a result peasants have switched to burning animal dung and crop residues for fuel. Such burning of dung which was source of soil humus and fertility is the one that has brought about a progressive decline in land quality and agricultural productivity[22]. This use of animal dung for fuel has reached its extreme especially in the northern parts of the country (Gebreegziabher, 2001). The growing shortage of fuel wood for household consumption in these areas has led to the dung produced burnt as principal cooking fuel.

Strictly speaking, N (nitrogen) and P (phosphorus) deficiencies is believed to be the major biophysical constraints affecting African agriculture and reversing this nutrient (soil-fertility) depletion is vital to poverty alleviation (Sanches *et al*., 1997). Nonetheless, the issue has been ill-treated and research until very recently concentrated primarily on other biophysical constraints such as erosion. Indeed earlier modeling attempts to capture the impact of soil/land quality on productivity have emphasized on soil loss due to erosion (McConnell, 1983; Byiringiro and Reardon, 1996; Kruseman and van Keulen, 2001). Likewise, the focus of most Ethiopian studies has been on water erosion; for example, such as conservation practices (Holden *et al*., 1998; Sonneveld and Keyzer, 2003; Hengsdijk *et al*., 2005). But there is hardly any attempt to address the problem of nutrient depletion (Abegas, 2005).

Due to relative high cattle number per capita in rural areas Ethiopia is among the attractive countries for biogas generation. Owing to its potential, it is argued that the country

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♣♣♣ Earlier version of this chapter was presented at the International Conference on 'Economics of Poverty, Environment and Natural Resource Use', 17-19 May 2006, Wageningen, the Netherlands.

[21] For a further account of the various forms of land degradation better refer the reader see Bojö (1996) pp163-164.

[22] As explained elsewhere in the thesis economic and financial accounts of the reduction in agricultural productivity from lost nutrients associated with use of animal dung for household fuel in Ethiopia can be found in Newcombe (1989), Sutcliffe (1993), and Bojö and Cassells (1995).

could provide more than the subsistence level rural fuel requirements from biogas generation (Parikh, 1983). The recent per capita and average livestock holding (for selected animal types) in Ethiopia has be provided in Appendix Table 6A.4. It also makes much more sense given the areas with severely degraded soils are the ones which support over four-fifth of the country's human population (Shiferaw and Holden, 2000; Gebreegziabher, 2001). In this respect, improvement in resource-use efficiency through technological alternatives like biogas is vital. Still application of biogas production and use in Ethiopia is in an infant (demonstration) stage. Empirical evidence of the role of innovative biogas application is lacking. The fact biogas was largely seen as replacement to fuel wood and kerosene (AFREPREN, 2001) and its role in redressing land degradation was not realized might have resulted in the very limited attention for this subject.

In this chapter we examine the potential of the biogas innovation for redressing the problem of land degradation in Ethiopia. We postulate that with fuel-augmenting technological change farmers will be operating on a higher production frontier than would be the case applying the conventional practice. Taking current output level or production function (in agriculture) in relation to patterns explaining fuel uses as a benchmark, we insert biogas technology to simulate the consequences of such technologies in productivity improvement. We also provide a more pragmatic test for viability of biogas innovation in economic terms by applying the to all sample farm households in the dataset. Farm dataset referring to 2001 and 2002 production years from a stratified sample of 200 farm households in Tigrai region, northern Ethiopia was used for analysis. Results are based on simulations.

Two fundamental questions involved in assessing or evaluating the potential of biogas innovation in reversing land degradation are: one, how and to what extent does the biogas innovation contribute to improvement soil (land) quality and productivity? Therefore, the immediate logical step would be assessing its impact in terms of enhancing agricultural productivity. Nonetheless, use of biogas innovation involves investment costs on the biogas digester (plant). Therefore, the second fundamental question is how economically viable is investing on the biogas innovation? The second question would lead us to valuation and analysis of economic returns to investment on biogas innovation. Therefore, we need to develop a framework that allows us to tackle these two issues. By doing so this chapter shades light on the role of biogas innovation in redressing land degradation. To our knowledge there has been no any attempt that examined this role in the scientific literature. Moreover, this chapter also develops a conceptual framework to capture this role.

The remaining of the chapter is organized as follows. In the next section we present the state of biogas technology: a review of experiences; biogas in the rural livelihoods in section 6.3; in section 6.4 model framework of farm production function with biogas innovation; simulation setup and data in section 6.5, results and discussion in section 6.6; conclusions will follow.

6.2 State of Biogas Technologies: A Review of Experiences

6.2.1 Global overview

The early history of methane gas produced by fermentation goes to the beginning of 1st century A.D. The appearance of flickering lights emerging from below the surface of swamps was noted by Plinius (van Brakel, 1980). However, a more recognizable scientific works in this respect started in the 17th century.

Generally, technological options for the use of biogas as energy source in rural areas are two: one at household or family level and another at village or community level (Parikh, 1983). Meaning, there are village size or community biogas plants and family size or household plants. Nevertheless, it should also be noted that there are large-scale and intermediate scale digesters used for agro-industrial applications such as in food factories, wineries, etc and for urban applications such as electric power generation (Daxiong *et al*., 1990; Heavner and Churchill, 2002).

Biogas in China

There are about five million biogas digesters in China (Table 6.1). Biogas in China is used by about 25 million people, for cooking and lighting for 8-10 months a year. Many rural households are equipped with both biogas stoves and improved cooking stoves. With the latter type, the peasants burn straw and wood as usual during the winter months, for cooking and heating. Besides to household heating and cooking, biogas in China is used for poultry hatching, tea roasting, and grain and fruit storage. Moreover, the slurry is also used as fertilizer for fish farming and for pig feed which showed good results in semi-intensive production systems (Steinfeld *et al*., 1998). Aggregate gas production of all household digesters in China totals about 2,000 million m^3 biogas per year. In southern China, the total gas yield of family size digesters averages 300 m^3 per year (over 8 months); whereas in the north, production is 200 m^3 biogas per year or less depending on ambient temperatures.

Table 6.1 Biogas digesters in Asian countries

Country	Number ('000)
China	4,700
India	1,000
Nepal	49

Source: AFREPREN (2001)

Improved and cheap biogas stoves and lamps have been developed and are distributed to every biogas owner. The cost of one biogas lamp varies between 6-12 Yuan[23]. Lamps and burners are adapted to low pressures of about 2 cm at which family sized digesters with capacity of about $10m^3$ operate. Furthermore, the use of biogas in China is manifold, besides to the family sized digesters. There are about 400 biogas motive power stations with a total installed capacity of about 4,300 kW (kilowatts) and 800 biogas electrical power stations with a total capacity of about 7,800 kW providing electricity to about 20,000 households. China also has sound experience in running diesel and gasoline engines with biogas. (Daxiong et al, 1990; Marchaim, 1992)

Based on Fritz (1983) three typical factors, not operative in "*western*" oriented developing countries, could be identified to have contributed to the successful spread of biogas technologies in China. These include the basic principle of social equality, organization at village level and the use of local materials and methods for local conditions. Especially the latter factor, the use of local materials and methods has resulted in a reduced price of the '*brick-built Chinese*' digester to a quarter of the Indian built/model steel tank. Moreover, existence of institutional arrangements or organizational structure for village administration has also enhanced the success in village biogas plants in the early phase of biogas development in China (Parikh, 1983).

Biogas in India

As it could be clear from Table 6.1, India stands next to China in terms of dissemination of biogas technologies in rural areas. Biogas is commonly used for cooking and lighting. There are a number of enterprises in each state that produce stoves and lamps. At some community and institutional biogas plants, biogas operates engines or agricultural equipment. Some enterprises in India manufacture or adapt diesel engines with optional operation in biogas (Marchaim, 1992). Activities in using biogas in India gained momentum since the 'National Project of Non-conventional Energy Sources' in 1982. These days, however, biogas plant is

[23] Currently 1 YUA =0.131 USD.

generally regarded or accepted as a desirable technology among richer farmers. The early dissemination of biogas in India involved such activities as convincing bankers to give loans for biogas installations and setting up the organizational structure, subsidy system, etc.

Further technological improvements and financial help were realized to be essential for successful introduction and operation of biogas technology in the rural areas of India. Three lines of technological improvements already recognized were: nullifying the effect of low temperature on gas production; devising simple, economical and labor-saving equipment for dung collection; and effective techniques for drying and transporting the effluent. Intensive efforts were made to upgrade technology to produce more gas with less sophistication (Marchaim, 1992).

6.2.2 Biogas in Ethiopia

Biogas was first introduced to Ethiopia in the 1970s (Appendix Table 6A.2). Appendix Table 6A.1 provides biogas dissemination in Ethiopia to date. Most of the biogas plants were installed at demonstration centers (Kebede, 1995). Various institutions/agencies were involved in biogas dissemination of which the Ministry of Agriculture (MoA) through its Rural Technology Promotion Centers (RTPC) over the country was one (Appendix Table 6A.3). The different types (brands) of biogas technologies introduced in the country included the Indian, Chinese and other less known models . Amongst which, for the same amount of biogas generated per day, the fixed dome Chinese model was regarded to be less costly than the floating dome Indian model (EESRC, 1995; AFREPREN, 2001). The high initial investment cost was seen as serious impediment to the dissemination or adoption of biogas technology during that time.

In Tigrai too the history of biogas introduction goes to 1970s. During this time four family sized biogas plants were introduced for demonstration purposes. Later on ten others were disseminated of which three of them were successful. Some of these biogas plants were used both for lighting and other cooking with small stoves fitted to them. *Injera* baking is an essential end use in the context of Ethiopia as far as household fuel consumption is considered and accounts for over half of the household’s fuel consumption, both in urban and rural areas. However, little attention was given to include i*njera* baking in the biogas plants so far demonstrated. In fact, research work in this respect has shown that there exists the potential for use of biogas for *injera* baking, which in turn reinforces the possibility for integrating the various fuel end uses of household lighting, other cooking and *injera* baking into one biogas plant.

6.3 Biogas in the Rural Livelihoods

6.3.1 Biogas as an alternative energy source

Biogas could primarily be used for domestic fuel purposes. The most important domestic uses of biogas are cooking and lighting. Biogas is a clear burning fuel free of indoor pollution. Because biogas has different properties from other commonly used gases such as propane and butane and is only available at low pressures, specially designed stove capable of burning biogas efficiently are used.

6.3.2 Use of the effluent/ digested slurry: the profit of biogas

The slurry discharged as byproduct from a digester contains 1-12 percent solids and consists of refractory organics, new cells formed during digestion, and ash (Marchaim, 1992). These components of the slurry constitute soluble nutrients and trace elements, insoluble nutrients, and the organics present in the solids (humic materials), which provide fertilizer and soil conditioner properties. Despite some differences, the components of the specific digested material are similar in content to the feedstock material used for the digestion process. Therefore, this would allow us to examine and compare the various uses and values of the original material feedstock such as dung without anaerobic digestion (ex-ante/ ex-post) vis-a-vis the digested slurry.

There are many possible ways in which the feedstock biomass (dung) resources could be used in many of the developing country settings like Ethiopia. For example, a given quantity of cattle dung biomass, which is the issue at hand, might be used as manure to provide fertilizer and soil conditioning or for fuel. In all cases nitrogen content is most important element both in quantity and effect on crops. In general, four alternative practices could be identified as regards to traditional uses of dung resource:

- I burning for fuel
- II. applying to the field surface without under-ploughing
- III. applying to the field with under-ploughing
- IV composting and applying to the field

Therefore, understanding the pros and cons associated with each of the alternative practices would help us better visualize the significance of biogas.

Practice I

Burning dung for fuel to meet domestic energy needs is the conventional practice in many developing countries. But, it results in a complete loss of nitrogen. Only phosphorus, potassium and the trace elements remain in the ash. Three important limitations might be quite apparent from such practice: firstly, burning leaves virtually no nitrogen. Secondly; the 'traditional fuel efficiency' is considerably lower than it would be for biogas produced from the same amount of dung biomass. For example, with conventional burning only about 9-12% of the total fuel value of dung can be used efficiently while the rest is lost (Hailu and Tesfay, 1994). Thirdly, such conventional burning of dung results in indoor pollution and exposure to smoke which is detrimental to family health. Nonetheless, we see it practiced in countries like Ethiopia as it meets acute energy needs of people or households in myopic[24] sense.

Practice II

Applying dung directly by spreading it to the field surface is conventionally practiced in Ethiopia, and the fate of the nitrogen depends on the composition of the biomass. Nitrogen is present in animal manures in two forms: organic and ammonia. In most other sources of biomass it exists in smaller quantities, and as organic matter. Most organic nitrogen is the form of proteins and nucleic acids, while the ammonia nitrogen is present as either ion, NH_4, or free ammonia, NH_3. For fresh cattle manures ammonia nitrogen can vary from a low of 3% to 20% or even as high as almost 40%. Cattle manure, equivalent figures are between 24 and 37.6%, around 18% for pigs, and 8% for fresh chicken manure (Marchaim, 1992).

Practice III

Applying into the field with under-plowing is another alternative to use of manure. It might be expected prevent loss of ammonia through volatilization, and might help that most of the nitrogen is conserved if this under-plowing into the field is done while manure is fresh. However, these ions are relatively soluble and can be leached from the soil. Practicing this option is relatively time consuming especially in the case when manure is produced daily while the application is infrequent. Storage might be necessary once all the land has been

[24] The term myopic is used in here to mean near- or short-sightedness in time-horizon. The decision maker values immediate needs (benefits) more regardless of future detrimental consequences it might entail.

planted or planting season is over and a large percentage of the nitrogen can be lost to the atmosphere in the event of inappropriate storage conditions.

Practice IV

Composting and drying is a common way of recycling manure resources in Ethiopia. In this case mixture of crop residues, farm trashes and dung biomass are piled in a heap and left to decompose aerobically it is a practice often advised by extension agents. In this case compost might stay or be stored for a long period of time before or without being applied to the field. Although usually inoffensive to handle, has reduced volume, and does not attract flies or other insects, the composted biomass has few degradable organics. In addition, under such a practice the loss of nitrogen during composting and storing might be quite substantial.

Therefore, two conclusions can be drawn in light of the four alternative practices. One, the conventional practice of burning dung for fuel to meet domestic energy needs is too inefficient and most of its fuel value is wasted. Two, all the alternative land applications of animal manure involve substantial amount of loss in nitrogen. Nitrogen losses under alternative manure management practices are provided in Table 6.2.

Table 6.2 Nitrogen losses under alternative practices of manure management

Field practice	Nitrogen effectiveness index (%)
Manure spread and ploughed in immediately	100
Effluent from digester introduced immediately into irrigation water	100
Dried digester effluent spread and ploughed in	85
Manure piled 2 days before spreading and ploughed in	80
Manure piled for 14 days	55
Manure piled for 30 days	50

Source: Marchaim (1992)

6.3.3 Biomass uses following anaerobic digestion

Whereas alternatives I-IV illustrated above provide one service or output, i.e., fuel or manure/fertilizer, biogas technology (anaerobic digestion) fulfills both fuel and fertilizer purposes of the household. Nitrogen can be lost during digestion only by reduction of nitrates to nitrogen gas and volatilization of ammonia into biogas. Since there is very little nitrate present in manure, such loss through reduction is insignificant. Loss of nitrogen through volatilization of ammonia can occur from the slurry if not handled correctly. Since organic matter is degraded during digestion to produce biogas the percentage of nitrogen in the slurry rises as compared to its solid content. Nitrogen is conserved during anaerobic digestion. For instance, a 23% reduction in total solids concentration is accompanied by a corresponding increase in the nitrogen content of the remaining solids. With animal manures, the ammonia nitrogen concentration increases during digestion. Some evidences show from 24.0-49% ammonia nitrogen increase in dairy cow manure during digestion (Marchaim, 1992).

6.3.4 Land application of effluent

The direct application to the land is the most common technique of disposal and use of manure in most parts of the world. Advantages of manure are that it improves tilt; increases water-holding capacity; lessens wind and water erosion, improves aeration, promotes the growth of beneficial organisms and maintains soil fertility. The economic value of manure as a fertilizer is derived from its available nitrogen, phosphorus and potassium content, and as a soil conditioner. Hence, the same logic can be applied to the effluent generated by biogas digester.

In most countries where biogas plants were constructed, the effluent was used as a fertilizer. Institutes extensively studied the use of the effluent in the Republic of China, and they found chemical changes in the organic substances during fermentation. Studies in Sichuan Province of China and elsewhere found out that use of effluent increased yield regardless of soil type. Indeed long-term experiments have shown that the chemical and physical properties of the soil improved markedly few years after applying digester effluent with 11-20% increase in total yield of various crops (Marchaim, 1992). There is clear evidence that the slurry did not increase the salinity of the soil; rather it reduced residual effects in the long term. The application of digested slurry over a period of years has led to a continuous increase in crop production. This may be due to the effect of slow release of nitrogen compounds and improved soil structure.

6.3.5 Pollution control and improving rural environmental health

Biogas technology is both clean and an environmental friendly biotechnology, with considerable positive environmental externalities. In the treatment of animal manure, it produces biogas as an energy source, while the digested slurry is used as a fertilizer. Because it decomposes organic material it reduces environmental pollution and also destroys pathogenic microorganisms, protecting humans and animals from point of view of environmental health. The multiple benefits of the system have been demonstrated on the basis of diverse waste digesters, both at North Carolina State University and Kibbutzim in Israel. Success stories of the technologies triggered the concept of holistic farming. This concept of 'holistic farming' as a new concept of 'agricultural ecosystem' integrating the multiple benefits has its origin around this technology. (Marchaim, 1992; US EPA, 2003)

6.4 Model Framework

As could be clear from the earlier section we postulate 'fuel-augmenting technical change for reversing land degradation'. Under the conventional practice, i.e., without fuel-augmenting technical change, fuel and soil fertility maintenance compete for dung as resource. Nutrients loss because of using dung for fuel rather than for soil fertility maintenance implies clear opportunity costs. The argument for fuel-augmenting technical change, therefore, lies on the premise that the fuel problem or crisis resulting from diminishing fuel wood sources is the major factor underlying this nutrient depletion (land degradation). With fuel-augmenting technical change farmers will be operating on a higher production frontier than would be the case applying the conventional practice. In what follows, we conceptualize the model framework to tackle the issue at hand and explain the mechanisms involved.

Let the farmer's crop-specific production function for crop j be specified (Woldehanna, 2000) as:

(6.1) $q_j = f(L_j, A_j, K_j, X_j, s)\ \forall\ j$=B,T,W.

where q_j stands for farmer's quantity output of crop j; L_j, A_j, K_j and X_j, respectively, represent farmer's labor, land, capital and farm variable input to crop j; s is soil quality attribute; and the subscripts B, T and W stand for crops barley, teff and wheat, respectively.

The soil quality attribute s as specified in here stands for nutrient loss or change in land quality resulting from use of dung for fuel rather than for soil fertility maintenance. Because fuel problem is the underlying factor, we can examine change in land quality in relation to patterns of fuel use or fuel consumption function of the household.

Hence, let the farm household's fuel use (consumption) function for kth fuel be specified as:

(6.2) $c_k = c(fs, y, p_k, l, \mathbf{h})\ \forall\ k$=d,f

where the explanatory variables fs, y, p_k and l stand for family size, household income, price of kth fuel, and location, respectively, and $\mathbf{h}$ is a vector of other household characteristics; the subscripts d and f represent dung and fuel wood, respectively.

As it could be clear from the fuel consumption function, equation (6.2), two fuel types (sources), that is, dung and fuel wood could be envisaged as far as fuel use of the farm household in question is considered. In situations of increasing fuelwood scarcity the household's fuel consumption will be dominated by dung with an increasing amount of dung being substituted for fuel wood. Note that the amount of nutrient loss or depletion is proportional to the quantity of dung used or burned as fuel. Therefore, the dynamics of soil quality s for farmer i can be derived from the behavior of the farmer's fuel use c_d and technology considerations. Denote initial soil quality $s(0) = s_0$. Hence, change in soil quality

(6.3) $\dot{s} = s_0 - c_d$

where $\dot{s}$ is change in soil quality; and c_d the quantity of dung consumed as household fuel as in above. The idea is that soil quality will remain the same (constant) without burning (removal) of dung. Bear in mind that $\dot{s}$ in equation (6.3) stands for time rate of change in soil quality with time subscripts suppressed and, hence, can be represented as s_t when c_d is c_{dt}, without loss of generality. That is, say for t=1, rewrite equation (6.3) as:

(6.4) $s_1 = s_0 - c_{d1}$

Note that under the conventional practice, i.e., without fuel-augmenting technical change, the quantity of dung consumed as household fuel c_d is directly put into conventional furnaces (stoves) and burned for household cooking purposes which results in nutrient depletion particularly all the nitrogen will be lost in this process. Note also that soil quality is being evaluated at the end of the period in question, t=1. Hence, say for c_d quantity of dung consumed as fuel in time t=1, c_{d1}, as in equation (6.4), there will be lower or reduced soil quality s available for crop growth next year, which eventually results in lower agricultural productivity. The idea is that because most nutrients particularly all the nitrogen will be lost with conventional burning, eventually, there will be lesser nutrients available for crop growth which leads to reduced output or productivity. This reduced output because of lower soil quality is what is meant by the farmer operating on a lower production frontier.

Now suppose that the farmer installs a biogas digester technology or innovation. This innovation uses wet dung as feedstock or input and upon anaerobic fermentation process generates (produces) biogas as principal output and digester slurry (effluent) as a byproduct. Let the production of biogas be specified as

(6.5) $g = g(D, L_g)$

where g is quantity or volume of biogas output such as in cubic meter, D quantity of dung (fresh) used as feedstock and L_g labor input in biogas production. Labor input is required for operations such as water fetching, mixing of dung with water to be fed to the digester plant, and day-to-day plant maintenance. Therefore, to keep the model simple we can specify the biogas production function as in equation (6.5). Note that the feedstock input D need not be only dung crop residues such as wheat straw, rice straw and corn stalk can also be used. We assume that the quantity of biogas output g is determined by the capacity (size) of the digester plant and D and L_g are combined in fixed proportions.

Biogas production also depends on factors such as the feedstock or raw material type and its freshness, temperature, and pH besides the essential inputs as specified in equation (6.5). For example, the fresher the dung, the better will be the yield in most cases. However, the setting of the study area provides ideal temperature and appropriate practices can be followed by the farmer to regulate or maintain the desired pH level. We consider there is sufficient supply of fresh cattle dung. For simplicity, assume that the net quantity of dung used as input in biogas production D is equal to the quantity of dung that would have been used as fuel with conventional burning, i.e., c_d=D.

Now the biogas output is used for household fuel consumption and replaces both dung and wood. The slurry (effluent) is used for soil fertility maintenance. This implies that with fuel-augmenting technical change, i.e., with biogas innovation the household will now be able to simultaneously recycling nutrients while fuel need is met. At least in theory it is plausible to assume that the amount of nitrogen that would have been lost by conventional burning can be replenished or recycled through land application of the slurry. Technically speaking this is an efficient use of the resource dung. It contributes to resource use efficiency in the sense that; firstly, two services, fuel and soil fertility maintenance are generated from the same quantity of dung resource. Secondly, output or production from the same unit of resources will be enhanced by mitigating the nutrient loss (depletion) that would have occurred if it were for conventional burning.

Studies that tried to capture or model the role of biogas innovation in enhancing productivity are almost non-existent. For example, studies on effect of use of slurry on yield are extremely scanty. Besides, it is not obvious the mechanism or channels through which it affects production. The technical change considered in here is different from the one in the standard technical change literature, for example, as in Chambers (1988) in two important respects: firstly, it takes a slightly different form because it is factor neutral technical change. Secondly, what is being augmented is not the farm production input(s) but fuel use or consumption of household. Nonetheless, an equivalent interpretation applies because more output can be produced with the same unit of resource; this way too farmer’s resource use efficiency of has increased. Therefore, the issue at hand can be viewed as the case where more output can be produced with the same unit of resources.

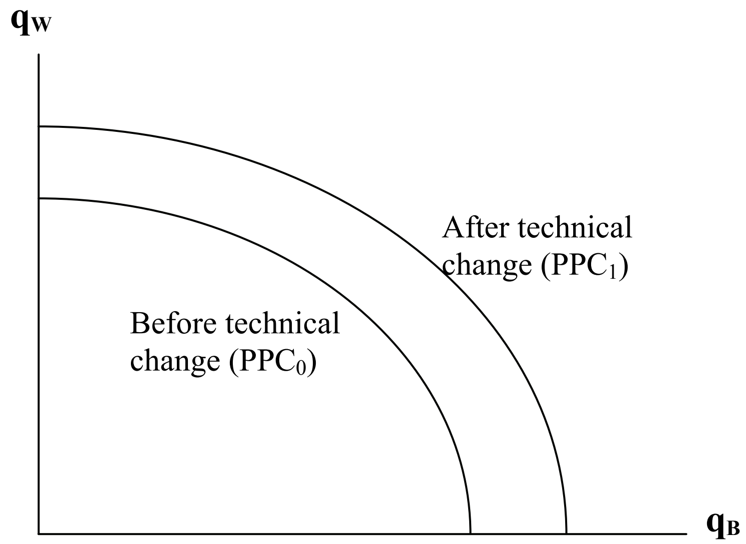

Figure 6.1 *Fuel-augmenting technical change in two outputs space*

Fuel-augmenting technical change can be illustrate in two dimensional (outputs) space like in Figure 6.1 above. If we let q_B on the *x-axis* and q_W on the *y-axis* are two outputs the farmers produces, with the subscripts B and W standing for barley and wheat as in above. The combination of the two outputs the farmer produces using the same amount of inputs under the two technology regimes can be represented by production possibility curves PPC_0 and PPC_1. For example, under the conventional practice, i.e., before the technical change, because most of the dung is burned for fuel in conventional furnaces and nutrient loss or depletion takes place, the farmer will be operating on the lower production possibility curve or frontier PPC_0. After the technical change, i.e., with fuel-augmenting technical change, however, because nutrient depletion is countervailed more output will be produced from the same amount of inputs which implies an outward shift of the production possibility curve from PPC_0 to PPC_1.

Note that biogas involves lump sum initial investment costs to the farm household. The farmer has to buy the digester (plant) and accessories needed to use biogas for fuel. Therefore, determining viability of the technology requires numerical computation of costs and benefits. Letting economic returns be

(6.6) $$R = \sum_{t=0}^{T} \delta^t (B_t - C_t)$$

where R is present value of net returns from investment in biogas innovation; *t=0* is the current year (period), *t=T* is the last year (or terminal period) and *t*=0,1, . . ., T, the time horizon; $\delta=1/(1+r)$ is the discount factor and *r* the governing interest rate; B_t stands for benefits at time *t* from biogas innovation and C_t is cost at time *t*, with C_0 standing for initial investment cost.

In situations of zero running costs[25] it turns out one of determining the payback[26] period or length of time (years) it requires to recoup the initial investment costs of biogas innovation.

6.5 Simulation Setup and Data

6.5.1 Simulation setup

In the presence of longitudinal field or plot level monitoring data on the dynamics of soil quality, it turns out to including the soil quality attribute into the regression model to see how output changes over time with changes in soil quality. Nonetheless, one can hardly find such type of data in developing country settings. Nor do we have observations on biogas innovation. Therefore, we simulate the relevant biogas technology from experiences elsewhere. However, as explained earlier, studies on effect of use of slurry on yield are extremely scanty. In addition, it is not obvious the mechanism or channels through which it affects production. To our knowledge Marchaim (1992) is the only one that tried to documents evidences on the effect of use of slurry (effluent) on yield. Evidences are that use of effluent for soil fertility maintenance increases yields of various crops by 11 to 20% (Section 6.3.4). Hence, this level of yield increase experienced elsewhere was assumed to hold in our case. Three alternative levels of productivity improvements, i.e., 11, 16 and 20 percent yield increase resulting from biogas innovation were considered in the simulation.

[25] The idea underlying the zero running costs is that labor costs incurred by household maintaining the biogas plant will be offset by the fuel benefits generated from the biogas plant for household cooking and baking.
[26] Payback period (years), defined as the number of years required to recover or recoup the initial investment cost of the innovation, in our case turns out one of determining the terminal period T for which $\sum_{t=0}^{T} \delta^t B_t = C_0$.
For given interest rate and constant stream of annual benefits, this can be determined using the table of present value of annuity or determine the time period for which R≥0.

Table 6.3 Relationship between digester size, cattle requirement and end uses equivalent of fuel/gas output

Digester size/capacity (m^3 gas production/day)	Number of cattle required	Daily requirement of fresh dung (kg)	End use equivalent (Cooking of number of persons)
2	4 to 5	35 to 50	5 - 8
3	6 to 8	50 to 75	8 - 12
4	7 to 9	80 to 90	12 - 16
6	10 to 12	95 to 120	16 - 20
8	12 to 15	115 to 150	22 - 26
10	16 to 20	150 to 200	28 - 32

Source: Krishna (1988) and Hailu and Tesfay (1994)

To begin with two heads of cattle is taken as the minimum requirement for a family size-biogas plant (AFREPREN, 2001). However, the cattle requirement shouldn't be restrictive given that dung can be collected and straw can also be used as feed stock for biogas generation. Table 6.3 provides the relationship between digester size, cattle requirement and end uses equivalent of gas output. Economic viability of buying a biogas installation was analyzed/ simulated on the basis of individual farm (household) data. This way we can determine for how many of them it would be viable or suitable. Financial benefits of biogas innovation envisaged were two: benefit from use of slurry (effluent) for soil fertility maintenance and benefit from savings on kerosene expenditure. Benefit from use of slurry (effluent) for soil fertility maintenance was numerically computed for each of the sample farm (household). The difference between predicted yield and simulated yield with respect to the crops considered was regarded as productivity gains from using or adopting biogas innovation and used in the benefit computation. Crop output prices during the survey period/ in the dataset were used in the computation of benefit. Moreover, the annual cash outlay on kerosene by respective sample farm households was taken as savings on kerosene expenditure and added to the benefit stream in the analysis applied to all the sample.

Biogas digester types (brands) important for Ethiopia are floating dome (Indian model) and the fixed Chinese (or *Deenbandhu*) model. Initial investment cost of biogas plant varies between Birr 4,600 to 6100 (BTSDT, 2001) depending on the size (capacity) of the digester. An initial investment cost of Birr 5350 for the *Deenbandhu* model of an optimal size, i.e., $4m^3$ gas per day capacity was used in our analysis. Alternative levels of interest rate on loans can be considered to determine the payback period (in years) required to recoup the initial investment once the benefit streams are known. Numerical computation of the present value of net returns as in equation (6.6) also requires choice of an appropriate interest/ discount rate. We consider the farmer can borrow the money to buy a biogas installation at competitive interest rate. The prevailing interest rate for loans varies between 7.5 and 9.25 percent. Publicly owned commercial banks provide loans at 7.5 percent interest rate, which is the minimum rate set by the central bank. Other private banks provide loans with an interest rate of 7.5 to 9.25 percent. DECSI (Dedebit Savings and Credit Institution), the main lending institution in rural Tigrai, also provides package loan to rural households with an interest rate of 9 percent (Woldehanna, 2005)

Continuous loading fermentation process is assumed. Under the continuous loading fermentation process the normal digestion and gas production begin after a certain period of time from the initial feeding. Feed stock is then fed continuously into the digester every day and effluent is discharged in the same amount of influent, simultaneously. By such process constant fermentation and uniform gas productions could be achieved. Moreover, the control is also easy. Then the household uses the biogas output to meet its fuel needs and the byproduct or slurry to be applied to crop fields for soil fertility maintenance. We assume that the biogas output will be sufficient to meet the household's fuel needs including *injera* baking, other cooking and lighting. We consider the biogas digester plant is centrally located near the stable/homestead at about 15 m distance from the housing unit and farmer's plots are located with in certain radius from stable (homestead).

6.5.2 Data

The dataset used in this paper come from a stratified sample of peasant farmers in northern Ethiopia. A two period (two production year) data from 200 cross-sections of peasant households was obtained. The data set refers to 2001 and 2002 production years and farmers in the sample are located particularly in *Enderta* and *Hintalo-Wajerat* districts of Tigrai, northern Ethiopia.

Mixed crop-livestock farming is the dominant system in the area. Crops grown by peasant farmers include lentils, vetch, linseed, and vegetables with barley, wheat, teff, and sorghum. Barely, wheat and teff are the most important crops in the area in order of importance both from point of view of area of land allotted to each crop and the number of farmers involved (See Tables 6.4 and 6.5). Most of this peasant agriculture or crop production is practiced under rain-fed condition. Table 6.6 provides summary statistics of variables considered in the estimation of current production technology.

Table 6.4 Cropping pattern: percent of farm households growing crops

Crop type	Enderta	Adigudem	Total
Teff	63.5	65.4	64.4
Wheat	71.0	64.4	67.7
Barley	78.5	82.7	80.6
Sorghum and finger millet	6.0	22.3	14.2
Legumes	42.5	39.1	40.8
Oil crops	7.5	10.9	9.2
Vegetables	9.5	4.9	7.2

Source: Woldehanna (2000)

Table 6.5 Share of land and inputs allocation per *tsimdi* by crop type of an average farm household (1 *tsimdis*=one-fourth hectare)

Crop type	Share of land	Labor hour/ tsimdi	Var. inputs Birr/tsimdi
Teff	0.197	167.94	34.70
Wheat	0.250	76.42	87.46
Barley	0.364	71.05	77.13
Sorghum and finger millet	0.049	83.26	11.49
Legumes	0.110	70.64	48.24
Oil crops	0.018	69.76	29.46
Vegetables	0.010	185.24	61.89

Source: Woldehanna (2000)

Table 6.6 Summary statistics of farm dataset used in the simulation (n=398)

Variable name	Mean	Std. Dev.	Min	Max
Total yield in kg (barley)	436.03	510.97	50	3900
Total yield in kg (*teff*)	276.88	307.88	50	2100
Total yield in kg (wheat)	574.42	637.17	50	3800
Labor input in hours (barley)	174.49	166.44	24	1196
Labor input in hours (*teff*)	306.59	283.48	92	1608
Labor input in hours (wheat)	194.29	201.60	32	1920
Land in *tsmdi* (barley)	2.492	2.05	1	13
Land in *tsmdi* (*teff*)	1.909	1.83	1	8
Land in *tsmdi* (wheat)	2.517	2.51	1	20
Variable farm inputs in birr (barley)	234.23	282.56	30	2080
Variable farm inputs in birr (*teff*)	46.60	59.77	6	375
Variable farm inputs in birr (wheat)	219.61	281.56	24	2989
Capital farm input in birr (total)	1696.18	1528.25	0	9700
Number of cattle	5.421	4.98	0	32

Source: Own calculations from the dataset.

Table 6.7 Descriptive statistics quantity consumed, expenditure and time spent collecting fuel of sample households (n=199)

Variable name	Mean	Std. Dev.	Min	Max
Quantity consumed dung in kg per year	1364.59	790.71	0	3951.36
Quantity consumed wood in kg per year	624.26	743.99	0	4129.92
Quantity consumed kerosene in lit per year	13.30	5.87	0	48
Kerosene expenditure in birr per year	51.57	25.94	0	216
Time spent collecting dung in hours per year	109.11	180.95	0	973
Time spent collecting wood in hour per year	157.08	240.07	0	1498

Concerning to the fuel use, wood and dung are the prominent fuel sources in the study area. A closer look at the quantity consumed of two fuels shows that dung is the main fuel source both in volume and number of households involved (Table 6.7); nearly all of the sampled households used dung whereas lesser proportion of the sample households', that is, about 80 percent used wood. This was mainly due to the growing scarcity of wood resources in the area. We also found that crop residues are not used for fuel in the study area.

Table 6.8 Distribution of sample households by mode of fuel acquisition by fuel type (in %) (n=199)

Mode of acquisition	Fuel type	
	Fuel wood	Dung
Free collection	61.4	30.9
Buying	13.2	0.0
Own source (tree/cattle manure)	3.6	51.3
Free collection + own source		17.8
Do not use fuel wood	17.8	
Total	100.0	100.0

With respect to the mode of acquisition of the different fuels, most of the wood was found to be self-collected. About 60 percent of the households were found to be free collectors. About 13 percent of the households were also found involved in buying fuel wood. Own source accounted for major part of the dung used as fuel. Distribution of sample households by mode of fuel acquisition is presented in Table 6.8.

6.6 Results and Discussion

Dung was found to be the dominant fuel source for households in the study area. Moreover, no evidence of manure use of dung was found in the dataset which is an indication that most of the dung resource in the area being burned for fuel, with nearly nothing left for soil fertility maintenance. Hence, it can safely be argued that the current production technology (output level) is representative of the conventional practice. As could be evident, with biogas innovation, i.e., with fuel-augmenting technical change, farmers will be operating on a higher production frontier. Farmers will be able to replenish most of the nutrients that would otherwise be lost applying the conventional practice. Simulation results showed that, on average, biogas innovation results in crop-specific potential gain of between 30 and 87 kg in yield terms depending on the crop type and level of yield increase being considered (Table 6.9).

Besides the productivity gains it was quite essential to determine economic viability of the biogas innovation. Therefore, we provide a more convenient test for economic viability of the innovation. Determination of economic viability of biogas innovation for a farm household in question was carried out by numerical computation of costs and benefits involved. Benefit streams considered were benefit from use of slurry (effluent) for soil fertility maintenance and benefit from savings on kerosene expenditure. Benefits from use of slurry (effluent) for soil fertility maintenance were computed on the basis of individual farm household data. The simulation could be applied to all crops that needed nitrogen. However, it was simplified to Teff, Wheat and Barley, which cover about 80 percent of the arable land. Simulated increase in total yield on the basis of actual yield for each of these three different crops was considered as productivity gain from using or adopting a biogas innovation. Then, these results were used in the determination of benefit streams for respective farms (households). Simulated yield increases on the basis of actual yield showed that, on average, biogas innovation results in crop-specific potential gain of between 46 and 114 Birr per farm (household), in value terms (Table 6.9).

Table 6.9 Summary of simulated yield increase in kg and in Birr for alternative levels of productivity improvement by crop

	Mean simulated yield increase by crop		
	Barley	Teff	Wheat
Simulated yield increase in kg			
(a) 11% increase in yield	48	30	42
(b) 16% increase in yield	70	44	61
(c) 20% increase in yield	87	55	76
Simulated yield increase in Birr			
(a) 11% increase in yield	60	46	63
(b) 16% increase in yield	87	66	91
(c) 20% increase in yield	109	83	114

The essential cost element in a biogas installation is its initial investment cost. Once benefits from use of slurry (effluent) for soil fertility maintenance for the three different crops considered was determined savings on kerosene expenditure was added to it to arrive at the annualized benefit of biogas innovation (installation) for respective sample farm household.

Assuming zero running cost the question reduces to one of determining how long will it take to recoup the initial investment cost of the biogas innovation? This in turn is also contingent up on the choice of interest rate. Table 6.10 presents distribution of sample farms (households) by payback period (years) to recoup the initial investment cost of a biogas installation for the three levels of yield increase under alternative rates of interest. Given 11% yield increase, results are that about 1 percent of the sample farms (households) can recoup their initial investment costs in 10 years or less, regardless of the discount rate, and about 2 percent of farms (households) required between 10 to 15 years to payback their initial investment. Rather, the level of discount rate was found to matter for farms (households) in the payback period categories of between 10 to 30 years. For example, 2% decrease in interest from 8% to 6% either doubled or tripled the farms (households) that recoup their initial investment costs in 10 to 30 years (see column 3). Most of the farms households considered, however, required more than 40 years recouping their initial investment.

Alternative interest or discount rates were found relatively more important in the case of 16 percent and 20 percent yield increases. Given the 16% yield increase, whereas a marginal decrease in interest rate by 1%, say from 9% to 8%, didn't change the number or proportion of farm households that recoup their initial investment costs in 10 years or less, a further 2% decrease in interest, say from 8% to 6%, more than doubled the number or proportion of sample farm households that recoup their initial investment in 10 years time (column 4, 5 and 6, Table 6.10). It also meant doubling of the number or proportion of farms/households that recoup their initial investment between 10 to 15 years time. With the 20% yield increase and at 9% interest rate about 4 percent of the sample farm households recoup their initial investment in 10 years or less and about 8 percent at 6% discount rate (see columns 7 to 9, Table 6.10). Not surprisingly and perhaps needless to mention, higher levels of yield increase resulted in relatively considerably more farm households being able to recoup the initial investment in 10 to 15 years time or less, regardless of interest rate. About 11 percent of sample farms/households recouped their initial investment in 15 years time or less with the 20% yield increase compared to 1 percent with the 11% yield increase at 9% interest rate. Given the level of yield increase, decreasing interest rate also increased the number or proportion of farm households that recoup their initial investment in the categories of shorter payback period. Nonetheless, still most of the farm households required more than 40 years to recoup the initial investment, even with the highest level of yield and lowest interest rate.

Table 6.10 Distribution of sample farms/households by payback period to recoup the initial investment on a biogas installation for alternative/ three levels of yield increase and discount rate (n=199)

Payback period (PBP)	Alternative levels of simulated yield increase and discount rate [a]								
	11% yield increase			16% yield increase			20% yield increase		
	9%	8%	6%	9%	8%	6%	9%	8%	6%
≤ 10 years	1.0 (2)	1.0 (2)	1.0 (2)	1.5 (3)	1.5 (3)	4.0(8)	4.5 (9)	5.5(11)	8.5(17)
10 < PBP ≤ 15 years	0.0(0)	0.0(0)	2.0 (4)	3.5(7)	4.5 (9)	6.0(12)	6.0(12)	7.0(14)	7.5(15)
15< PBP ≤ 20 years	0.5(1)	2.0 (4)	2.0(4)	3.5 (7)	4.0 (8)	5.5(11)	3.5 (7)	4.5(9)	4.5(9)
20< PBP ≤ 30 years	2.0 (4)	2.0 (4)	5.5(11)	3.0 (6)	4.0(8)	5.5(11)	4.0(8)	3.0(6)	14.0(28)
30< PBP ≤ 40 years	1.0(2)	2.0 (4)	2.5 (5)	1.0 (2)	2.0(4)	4.5 (9)	0.5 (1)	3.5 (7)	3.5(7)
> 40 years	95.5(190)	93.0(185)	87.0(173)	87.5(174)	84.0(167)	74.4(148)	81.4(162)	76.4(152)	61.8(123)

[a] Number of households involved in parenthesis

Table 6.11 Distribution of sample farms/households by payback period to recoup the initial investment on a biogas installation for alternative policy combinations (n=199)

Payback period (PBP)	Alternative policy combinations [a, b]											
	11% yield increase				16% yield increase				20% yield increase			
	i	ii	iii	iv	i	ii	iii	iv	i	ii	iii	iv
≤ 10 years	1.0 (2)	1.0 (2)	9.0(18)	9.5(19)	5.0 (10)	6.0(12)	18.0(36)	19.0(38)	10.5(21)	11.5(23)	29.5(59)	34.0(68)
10 < PBP ≤ 15 years	2.0 (4)	3.0(6)	6.5(13)	8.5(17)	6.0(12)	6.5(13)	16.0(32)	18.5(37)	7.5(15)	7.0(14)	16.5(33)	14.0(28)
15< PBP ≤ 20 years	2.5 (5)	4.0(8)	4.5(9)	5.5(11)	4.0(8)	5.5(11)	6.0(12)	8.5(17)	3.0(6)	7.0(14)	6.0(12)	7.0(14)
20< PBP ≤ 30 years	3.5(7)	3.0(6)	6.0(12)	11.0(22)	3.0(6)	4.0(8)	8.0(16)	7.5(15)	7.5(15)	11.5(23)	4.0(8)	8.0(16)
30< PBP ≤ 40 years	0.5(1)	1.5(3)	4.5(9)	3.5(7)	1.0(2)	3.0 (6)	4.0 (8)	2.0(4)	6.0 (12)	2.0 (4)	1.5 (3)	4.5 (9)
> 40 years	90.4(180)	87.4(174)	69.3(138)	62.0(123)	81.0(161)	74.0(149)	48.0(95)	44.2(88)	65.3(130)	61.0(121)	42.2(84)	32.2(64)

[a] Number of households involved in parenthesis.
[b] Alternative policy combination i = 9% interest rate + 20% reduction in initial investment cost; ii = 8% interest rate +20% reductions in initial investment cost; iii = 9% discount rate + 50% reduction in initial investment cost; iv = 8% interest rate + 50% reduction in initial investment cost.

In general, cost-benefit analysis results suggest that a biogas installation is still feasible for some (few) of the farm households even at the prevailing interest rate on loans and initial investment cost. It also highlights that there exists opportunities for economic viability of the innovation. However, it should also be noted that considering only interest rate, it turns out that the majority of the farm households might not recoup their initial investment cost in the foreseeable future. This has to do with the high initial investment cost. That the initial investment cost still stands to be a challenge to the wide spread adoption of biogas innovation among smallholder farms.

The fact that the majority of the farms (households) considered could not recoup in the foreseeable future triggers the question 'how could the viability of the biogas installation be improved particularly to those farm households that could not recoup their initial investment in the foreseeable future? Another instrument for policy other than or besides to interest rate that could be envisaged to improve viability and enhance wide spread adoption of biogas innovation is to influence the initial investment cost. That is, lowering or reducing the initial investment cost by certain proportion, say 20% or 50%. This could result from a much higher demand for biogas installation. For example, concerted R&D effort to identify and encourage local production of biogas installation using local materials, as experienced elsewhere, could considerably reduce the initial investment cost. Therefore, a further analysis of the effect of combination of policies was undertaken. Four alternative policy combinations were considered for each of the three levels of yield increase: i) 9% interest rate + 20% reduction in initial investment cost; ii) 8% interest rate + 20% reduction in initial investment cost; iii) 9% interest rate + 50% reduction in initial investment cost; iv) 8% interest rate + 50% reduction in initial investment cost. Results are presented in Table 6.11.

Given 11% yield increase, a policy of reducing initial investment cost by 20% was found to have no effect particularly on the category of sample farms (households) that recoup their initial investment in 10 years or less while it either doubled or more than doubled those that recouped their initial investment in the categories of 10 to 20 years (column 1 & 2, Table 6.11). This was in contrast to above results for same level of yield increase and interest rate but without any reduction in initial investment cost. However, with higher levels yield increase, a policy of reducing initial investment cost by 20% was found to have significant effect particularly on the category of sample farms (households) that recoup their initial investment in 10 years or less. It resulted in either doubling or more than doubling of the farm households that can recoup their initial investment in 10 years or less, compared to corresponding above results for same level of yield increase and interest rate but no reduction in initial investment cost (see columns 5, 6, 9, & 10). It also improved the proportion of farms/households that recoup their initial investment in 10 to 15 years time. However, its effect on farms/households with payback period categories in the range of 15 to 40 years was mixed. The proportion of farms/households with payback period of greater than 40 years also decreased by about 5 to 15 percent compared to corresponding results for same level of yield increase and interest rate but with no change in initial investment cost.

A policy of reducing the initial investment cost by 50% very significantly improved the viability of the biogas installation compared to corresponding results but 20% reduction in initial investment cost (columns 3, 4, 7, 8, 11 & 12, Table 6.11). For example, gien the 11% yield increase, the number of farm households that recoup their investment in 10 years or less increased by more than eightfold, in contrast to results for 20% reduction in initial investment cost. The magnitude of increase, however, declined as one moves up from 11% yield increase through to 16% and 20% yield increase. Specifically, about 18 percent of sample farm households recoup their investment in 10 years or less with 16% yield increase at the 9% interest rate and 19 percent at the 8% interest rate. Whereas about 30 percent and 34 percent of farms (households) recoup their investment in 10 years or less at the 9% and 8% interest rate, respectively, under the 20% yield increase. In this respect, a marginal decrease in interest rate by 1%, say from 9% to 8%, also meant about 1 to 4 percent increase in number farm households that can recoup their initial investment in 10 years or less, with in the various levels of yield increase. A policy of reducing the initial investment cost by 50% also either doubled or more than doubled the farm households that can recoup their initial investment in 10 to 15 years or less. In fact, at the highest level yield increase, i.e., at the 20% yield increase, neither the 30% further reduction in initial investment cost nor the marginal decrease in interest rate by 1% was found to have any effect particularly on the number farm households falling in the payback period categories of 15 to 30 years. However, the proportion of the farm households in the payback period category greater than 40 years reduced considerably to about 30 to 90 percent across the different levels of yield increase.

In general, the above analysis of four alternative policy combinations for each of the three levels of yield increase reveal a policy instrument that influences or acts on the initial investment cost could considerably improves the viability or suitability of biogas installation (innovation). The proportion of farms (households) that recoup their initial investment in 10 years or less was more that twofold greater with the policy of 20% reduction in initial investment cost particularly at the higher levels of yield increase, as compared to results for same interest rate with no reduction in initial investment cost. It also considerably improved the magnitude or proportion of farms (households) that recoup their initial investment in 10 to 15 years time compared to corresponding results with initial investment cost unchanged. Moreover, more importantly, a policy of 50% reduction or a further 30 reduction in initial investment cost considerably improved the viability of the biogas installation. The number of farm households that can recoup their investment in 10 years or less increased by more than eightfold in contrast to results for 20% reduction in initial investment cost, at the 11% yield increase. Indeed, it turns out that such a significant reduction in initial investment cost results in quite significant proportion, i.e., nearly up to 15 to 48 percent of the farm households being able to recoup their initial investment in 15 years or less, depending on the level of yield increase considered.

From the above analyses, two issues come into light particularly with respect to dissemination of biogas innovation and redressing land degradation: the first one, disseminating the biogas innovation among farm households for which it is still viable even at the prevailing interest rate and initial investment cost. This could be looked into or considered as a short-run option. However, if considerable gains are to be made in redressing land degradation, the second issue, i.e., a along run alternative, a concerted R&D effort to identify and encourage local production of biogas installation using local materials for wide spread adoption of the innovation appears to be vital.

6.7 Conclusions

By way of reviewing the state of biogas technologies and role of biogas in rural livelihoods; this chapter developed a conceptual framework to assess the potential of biogas innovation in redressing land degradation. In fact it is the first of its kind both in terms of shading light on the role of biogas innovation in redressing land degradation and conceptualizing the model framework to capture this role. By simulating the relevant technology from experiences elsewhere we examined productivity improvements resulting from biogas innovation. Moreover, we provide a more pragmatic test for economic viability to determine or infer for how many of the individual farms (households) considered a biogas installation would be feasible. The following conclusions can be drawn from the foregoing discussion.

Biogas innovation appears to be an appropriate technology, both from sustainability and technical or resource use efficiency considerations, for countries with problem of land degradation like Ethiopia. It meets fuel demand of farm households. It enables farmers to replenish most of the nutrients that would otherwise be lost applying the conventional practice. Indeed biogas innovation has considerable potential in reversing land degradation. It also makes much more sense given the high cattle number in rural areas of Ethiopia, both in terms of per capita and average holdings. Despite such potentialities biogas dissemination in the country is at its infant (demonstration) stage.

Cost-benefit analysis results reveal that the majority of the farms (households) might not recoup their initial investment cost in the foreseeable future. Considering only interest rate, it turns out that 1 to 8 percent could recoup their initial investment in 10 years or less at the various level of yield increase. clear opportunities for economic viability of the innovation. However, it should also be noted that a biogas installation was still feasible for some of the farms (households) at the prevailing interest rate on loans and initial investment cost, even at a more stringent test for viability. The fact that the majority of the farms (households) could not recoup their initial investment cost in the foreseeable future has to do with the high initial investment cost. Indeed the initial investment cost still stands to be a challenge to the wide spread adoption of biogas innovation among smallholder farms. Results also showed that a policy instrument that influences or acts on the initial investment cost could considerably improves the viability or suitability of biogas installation (innovation). The proportion of farms (households) that recoup their initial investment in 10 years or less was more that twofold greater with the policy of 20% reduction in initial investment cost particularly at the higher levels of yield increase, as compared to results for same interest rate with no reduction in initial investment cost. Moreover, a policy of 50% reduction or a further 30 reduction in initial investment cost considerably improved the viability of the biogas installation. Indeed, it turns out that such a significant reduction in initial investment cost results in quite significant proportion, i.e., nearly up to 15 to 48 percent of the farms (households) being able to recoup their initial investment in 15 years or less, depending on the level of yield increase considered.

Besides efficiency and economic gains biogas has considerable unaccounted benefits. Biogas is both clean and an environmental friendly biotechnology with considerable positive environmental externalities. Because it decomposes organic material it reduces environmental pollution and also destroys pathogenic microorganisms, protecting humans and animals from point of view of environmental health. Biogas is also a clear burning fuel free of indoor pollution. It mitigates family health hazards from indoor pollution and exposure to smoke of conventional burning. Biogas technology also provides considerable gains in ‘fuel or energy efficiency’ compared to direct burning of dung in conventional furnaces (stoves). It is quite obvious that all these unaccounted benefits of the biogas technology would also contribute considerably to its viability.

In general, two issues emerge or come into light particularly with respect to dissemination of biogas innovation and redressing land degradation: the first one, disseminating the biogas innovation among farms (households) for which it is still viable even at the prevailing interest rate and initial investment cost. This could be looked into or considered as a short-run option. However, if considerable gains are to be made in redressing land degradation, the second issue, i.e., a along run alternative, a concerted R&D effort to identify and encourage local production of biogas installation using local materials for wide spread adoption of the innovation appears to be vital.

Appendix 6A

Table 6A.1 Biogas dissemination in Ethiopia by region and type (brand) of digester

Region	Number of digesters	Type of digester				
		Indian floating	Chinese	Camaratec	Deenhandhu	Others
Tigrai	16	13		3		
Afar	1	1				
Amhara	70	64		1	3	2
Oromiya	165	92	5	24	7	37
Somale	3	3				
Benishangul	3	1				2
SNNP*	72	67	1	2	2	
Gambela	1	1				
Harari	5	4		1		
Addis ababa	18	12		1	2	3
Dire Dawa	4	3			1	
Country total	358	261	6	32	15	44

*SNNP is Southern Nations Nationalities Peoples' region
Source: BTSDT (2001)

Table 6A.2 Biogas digesters in Ethiopia by region and year of construction

Region	Number of digesters	Year of construction				
		1970-4	1975-9	1980-4	1985-9	1990-3
Tigrai	16	4			10	2
Afar	1					
Amhara	70		5	7	51	7
Oromiya	165	13	44	18	48	42
Somale	3				3	
Benishangul	3				1	2
SNNP*	72	2	15	21	32	2
Gambela	1				1	
Harari	5				5	
Addis ababa	18	2	2	5	2	7
Dire Dawa	4					4
Country total	358	21	66	51	154	66

Source: BTSDT (2001)

Table 6A.3 Biogas dissemination in Ethiopia by region and institutions involved

Region	Number of digesters	Institutions involved				
		EREDPC	MoA (RTPC)	R.E. Bureau	NGOs	Others
Tigrai	16	2	8	1	5	
Afar	1			1		
Amhara	70	5	54	1	10	
Oromiya	165	39	48		43	35
Somale	3			3		
Benishangul	3			1		2
SNNP*	72	8	60		4	
Gambela	1			1		
Harari	5	2	1	2		
Addis ababa	18	12			4	2
Dire Dawa	4	1		3		
Country total	358	69	171	13	66	39

*SNNP is Southern Nations Nationalities Peoples' region

Source: BTSDT (2001)

Table 6A.4 Per capita and average holdings of selected livestock in Ethiopia in 2001/02 by region

Region	Per capita holding				Average holding			
	Cattle	Sheep	Goats	Poultry	Cattle	Sheep	Goats	Poultry
Tigrai	0.78	0.20	0.52	1.20	3.66	0.94	2.44	5.66
Afar	2.71	1.22	2.35	0.41	12.65	5.72	10.96	1.90
Amhara	0.72	0.36	0.26	0.91	3.25	1.64	1.19	4.13
Oromiya	0.83	0.22	0.19	0.68	4.13	1.07	0.96	3.37
Somali	0.88	0.77	0.96	0.22	4.80	4.18	5.25	1.21
Ben Gumuz	0.49	0.09	0.34	1.54	2.21	0.41	1.52	6.99
SNNP	0.72	0.26	0.22	0.66	3.29	1.18	0.99	3.00
Gambella	0.83	0.31	0.33	1.58	3.54	1.30	1.43	6.73
Hareri	0.49	0.07	0.27	0.43	2.35	0.35	1.27	2.05
Addis Abeba	0.84	0.16	0.00	0.84	4.06	0.76	0.00	4.07
Dire Dawa	0.63	0.36	1.06	0.52	3.27	1.87	5.45	2.65
Country overall	0.77	0.27	0.26	0.78	3.65	1.29	1.21	3.67

Source: CACC (2003a, b)

Table 6A.5 Empirical counterpart of model framework in Section 6.4

Table 6A.5a Estimation results (standard error in parenthesis) of current production technology[a,b]

Explanatory variable	Dependent variable (crop)[b]		
	Barley (n=152)	*Teff* (n=135)	Wheat (n=136)
Land	0.582***	0.651***	0.653***
	(0.127)	(0.121)	(0.138)
Labor	0.119	0.350***	0.291**
	(0.116)	(0.136)	(0.1410
Variable farm input	0.343***	0.014	0.020
	(0.094)	(0.059)	(0.096)
Capital farm input	0.011	0.050	0.061*
	(0.038)	(0.043)	(0.036)
Constant	3.147***	3.501***	3.836***
	(0.370)	(0.418)	(0.424)
F-statistic	56.85	45.19	50.16
Prob>F	0.000	0.000	0.000
R-square	0.607	0.582	0.605

[a] The current (conventional) production technology was estimated using Cobb-Douglas functional form of equation (6.1) in the text, for the three different crops.
[b] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

Among the various inputs considered in the estimation of the current production technology land was found indispensably essential input for all three crops considered. The relative importance of labor varied from one crop to the other and variable farm input was significant only in the case of barley.

Table 6A.5b Mean predicted and mean simulated yield (total) for alternative levels of productivity growth by crop type (standard error in parenthesis)[a,b]

	Crop		
	Barley	Teff	Wheat
Predicted yield (total) in kg	485.409	364.367	424.109
	(30.020)	(17.697)	(28.251)
Simulated yield (total) in kg			
(a) 5% growth in TFP	567.558	429.897	514.409
	(34.903)	(20.657)	(34.113)
(b) 10% growth in TFP	662.493	519.088	623.993
	(40.529)	(25.232)	(41.745)
(c) 15% growth in TFP	757.522	611.992	745.814
	(49.514)	(29.501)	(50.932)
(d) 20% growth in TFP	923.862	742.071	930.072
	(57.390)	(35.829)	(62.078)

[a] The estimated current production technology (Cobb-Douglas production function) was used for prediction and simulation. Note that in the Cobb-Douglas production function, $Q = cL^{\alpha} K^{\beta} R^{\gamma} V^{1-\alpha-\beta-\gamma}$ the constant term c is an index for technology and is interpreted as total factor productivity. Details can be found in Verspagen (2005).
[b] Model simulations were run for four alternative levels (assumptions) of TFP growth; 5%, 10%, 15%, and 20% for the three different crops considered, assuming biogas innovation is factor neutral technology and raises productivity of all factor inputs.

Chapter 7 Urban Fuel Demand and the Implication for Rural Hinterlands: the Case of Ethiopia

7.1 Background

Deforestation in Ethiopia has resulted in growing fuel scarcity and higher firewood prices in urban centers (Gebreegziabher, 2004). Urban centers have long been dependent on rural hinterlands for their fuel. Wright and Yeshinigus (1984) report that woodlands around Axum were cut down to supply fuel for the growing population of city dwellers, at the time of Axumite civilization. Spanning from around 1000 B.C. to 1st millennium A.D. the Axumite civilization paralleled ancient civilizations in the Middle East and Greece (Butzer, 1981; Phillipson, 2000). This dependence of urban centers on their rural hinterlands has also aggravated the devastation. The environmental impact of urban fuel demand in general and that the reliance on biofuels in particular results in or contributes to forest degradation is well established fact (Heltberg, 2004; Edwards and Langpap, 2005). Especially in the environments with very limited wood resources such as the African Sahel, the increasing dependence of the urban centers on their rural hinterlands has a much more serious environmental impact than if it were only for rural fuel demand (Morgan, 1983; Kramer, 2002; FAO, 2004). Even with lower levels of per capita consumption of fuel wood the concentration of a large number of people in smaller areas like cities and towns coupled with the preference of urban households for charcoal over wood intensify the pressure on the existing local forest resources.

The fundamental economic question in here is 'How could the pressure of urban centers on the rural hinterlands be reduced (or, in general, how should the urban fuel issue be addressed)?' The answer to this question is one of two or a combination of two. i) Through substitutions between or switching from one fuel to another. For example, through substituting away or switching from fuelwood to electricity. Electricity as cooking fuel is cleaner and do not cause deforestation. Hence, switching from fuelwood to electricity leads to reduced pressure on the forest resources. ii) Through technological alternatives such as through use of fuel efficient or fuel saving cooking appliance or stove technologies. For example, two types of fuel efficient or fuel saving cooking appliance or stove technologies could be envisaged in this respect; improved wood stoves (cooking appliances) (Chapter 4) and electric cooking appliance (stove) technologies. Nevertheless, it appears that two things should hold for the stove technologies to have a real effect on the rehabilitation of local forests. First, the technology must be widely used in the economy beyond minimum threshold level. That is, it requires that the majority of the households adopt the innovation. Second, stove technologies particularly the improved wood stoves should be significant in terms of fuel saving. However, the later one is outside the intention of this chapter.

Given this pressure of urban centers, it appears to be clear that rurally conceived and rurally focused solutions will be insufficient to reduce the environmental damage and address the problem which calls for the need for a broader rural-urban approach to the problem. But, previous studies (cf. Amacher et al 1993 and 1996; Heltberg, Arndt and Sekhar, 2000; Kohlin and Parks, 2001) have emphasized on the rural-side and little has been done with respect urban dimension of the problem. The contribution of this paper, therefore, is that it gives insights in urban fuel demand using four fuel goods and draws consequences in terms of the problem of deforestation. In addition, Pitt (1985), Kebede *et al*. (2002), Chambwera (2004), Heltberg (2004) and Edwards and Langpap (2005) are among the few previous studies in this respect. Nonetheless, firstly, the focus of these studies has been whether the poor can afford modern fuel (Kebede *et al*., 2002), instead of broader policy questions and the diverse potentialities there in to tackle the problem. Secondly, some of these studies (Edwards and Langpap, 2005) have looked at only specific fuel good in isolation from its related fuel good which might make the findings incomprehensive. Thirdly, and more importantly, those that considered more than one fuel good (Pitt, 1985; Chambwera, 2004) applied empirical procedure that considered each fuel good individually or separately and fail to take into account the interdependencies. Therefore, to provide better insights into the problem, this chapter adopts a system of demand approach, thus including the whole set of fuel goods consumed by urban households.

In this chapter we investigate the possible means of reducing the pressure of urban centers on the rural hinterlands using a dataset of 350 urban households from stratified samples of seven urban centers in Tigrai, northern Ethiopia, referring to the year 2003. More specifically; the intentions of this chapter are twofold: One, to analyze the urban households' demand for various fuels. In doing so we seek to determine substitution or complementarities between fuels and draw insights that might be useful in the endeavor of reducing the pressure on local forest resources. Two, assess the scope for promoting modern cooking appliance or stove technologies that could play a significant role in reducing the pressure on local forests. Finally, we draw consequences or implications of findings in terms of broader policy issues.

The remaining of the chapter is organized as follows. In section 7.2 we briefly review urban fuel demand and deforestation in Ethiopia. Section 7.3 presents the model for fuel demand and the implication using comparative statics. Section 7.4 presents empirical model and data description; in section 7.5 we present results and discussions. Section 7.6 concludes.

7.2 Urban Fuel Demand and Deforestation in Ethiopia

Traditional biofuels are the sole or dominant sources of fuel for the great majority of the urban population. Appendix Table 7A.1 presents energy consumption pattern of urban households in Ethiopia, both for the country overall and Tigrai in particular. In Tigrai, in 1995, biofuels accounted for over 90 of fuel consumption by urban households. However, in 2003 the share of traditional fuels declined by about 6 percent (see the columns for urban Tigrai (2003) of Appendix). Electricity consumption in urban Tigrai increased from 0.8 percent in 1995 to 5.8 percent in 2003.

Of the various end uses, *injera* baking and normal cooking are two most important ones as far as urban domestic fuel consumption is considered. Included in normal cooking is preparing or cooking sauce, soup or stew (*wet*) dishes from meat, vegetables or others to eat with *injera.* Boiling water, making coffee and the likes, which involve lighting a fire several times a day, as well are considered normal cooking. In all settlement typologies i*njera* baking is the major consumer of fuel wood and accounts for over 50 percent of the total household fuel consumption (Gebreegziabher, 2004).

Electricity and petroleum products are the two modern fuel sources used in Ethiopia. With regards to electricity the public utility EEPCo (Ethiopian Electric Power Corporation) is the major supplier. There are also few community and privately owned systems. There are two power supply systems in the country, the interconnected system (ICS), which has grid connections and is mainly supplied form hydropower plants, and the self contained system (SCS), which constitutes isolated power generating units operating with diesel. Table 7A.2 in the Appendices, shows the role of these two systems in the overall electricity/power supply of the country. Electricity supply has considerably improved during the past few years. For example, overall electricity supply increased by 37 percent in the last five years (Appendix 7A.2) with the main growth coming from the expansion of hydro power supply. But there is a long way to go. EEPCo has about 800 thousand customers throughout the country, ranging from domestic users to high voltage large industries. Electricity constitutes less that 4 percent in the total domestic consumption of urban households and the current level of electrification is only about 14 percent (ACD, 2003). By and large, lighting is the dominant end use in the domestic sector and the use of electricity for baking is limited to larger towns and to a very limited number of households, which also implies an increased pressure on local forests.[27]

Among the petroleum products, kerosene and LPG are the important ones mainly in urban areas but also in rural areas. In cities and large towns, kerosene is used for normal cooking by some households. However, in medium to small towns with no electricity supply kerosene is most often used for lighting and in rare cases for cooking.

7.3 Consumer Demand Theory: Comparative Static Analysis

Consider a consumer who derives utility from consumption of a vector of n commodities denoted by q. Furthermore, assume that the vector q includes broader categories of consumption goods such as food, fuel and non-fuel non-food. Let u denote the utility the consumer derives from consuming these goods. Following the standard formulation of utility function (see Deaton and Muellbauer, 1980; Sadoulet and de Janvry, 1995), the household's utility function can be written as:

(7.1) $u(q;\mathbf{h})$

where **h** stands for individual characteristics of the household. And the budget constraint

(7.2) $p'q = y$

where p' is an n-dimensional row vector of prices; y is the amount of income which can be spent on the different commodities. The objective of the household is to maximize utility by choosing q, subject to her budget constraint given in (2). Therefore, the Lagrangean of the consumer's maximization problem can be rewritten as

(7.3) $L = u(q,h) + \lambda(y - p'q)$

where λ is a Lagrange multiplier. Solving for the Lagrangean function (3), we get a set of i=1,…,n observed demand equations:

(7.4) $q_i = q_i(p,y;\mathbf{h})$

Upon partially differentiating (4) with respect to income y, and prices p_j, we get n income and n^2 price slopes. Then multiplying the income slopes and price slopes by their respective income/quantity and price/quantity ratios we get n income elasticities and n^2 price elasticities useful for comparative statics.

[27] The growing demand for forest products could be viewed as source of growth, forest growth (Foster and Rosenzweig, 2003), particularly in situations where the supply of forest products such as firewood is organized by firms (farm households) engaged in production of firewood from allocation of own resources. The reason demand is seen as a pressure is because the supply of biofuels in not organized in such a way that farmers (firms) produce fuelwood from own resources allocation. Rather it is collected from communal and natural forests creating a pressure on existing already scarce forest resources.

(7.5) $\frac{\partial q_i}{\partial y}\frac{y}{q_i} = \eta_i$, and

(7.6) $\frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i} = \varepsilon_{ij}$

In comparative-static analysis the objective is to determine how an economic variable of interest, for example, quantity demand in our case, responds to changes in the value of some parameter or exogenous variables. Or put simply how the optimal choice changes as a parameter changes.

Deaton (1990) assumes that geographically clustered households face the 'same prices'. For the case of Tigrai, we depart from this assumption and allow for households to face different prices. This also makes sense since the markets for fuels are fragmented and dispersed along the wood route. In addition, the possibility for fuelwood trade to takes place on one-on-one basis is very high. While the sign of the cross-price variables might not be predicted beforehand, own-price variables are expected to have negative signs.

Note that if preferences are separable the n vector of commodities q in equation (7.1) can be partitioned into groups, say three, and that the utility function can be represented as

(7.7) $u = v(q_A, q_F, q_O) = f[v_A(q_A,),v_F(q_F),v_O(q_O)]$

where $f(\ )$ is an increasing function and v_A, v_F and v_O are the sub-utility functions associated with food, fuel goods and other goods or services, respectively. The idea is that due to complexity for consumers in making choices among very large array of alternatives, income is allocated to broad groups of goods such as food, fuel, and other goods in the first stage. In the second stage, the budget for fuel is then allocated to specific items such as electricity, kerosene and wood. The implication of this stepwise budgeting process is that decisions made at each stage can be regarded as corresponding to a utility maximization problem of its own. (Deaton and Muellbauer, 1980 pp127-128; Sadoulet and de Janvry, 1995 pp36-37)

7.4 Empirical Model and Data

7.4.1 Empirical Model

The empirical framework outlined here proceeds with demand equations, budget shares of specific fuel goods as electricity, kerosene, charcoal and wood in relation to household's total expenditure. In general, fuel expenditure accounts for 19 percent of household's total budget.

For the empirical demand analysis we use the Almost Ideal Demand System (AIDS). This demand system derives from a utility function specified as a second-order approximation to any utility function (Sadoulet and de Janvry, 1995 pp43-44). The demand functions are specified in budget share as follows:

$$(7.8) \quad w_{Fi} = a_F + \sum_J b_{FJ} \ln p_J + c_{Fi} \ln \frac{y_i}{P},$$

where w_{Fi} in equation (8) defined as $w_{Fi} \equiv \frac{y_{Fi}}{y_i}$ is fuel F's budget share in household i's budget; with y_{Fi} household i's expenditure on fuel F for F=W, C, K, and E standing for wood, charcoal, kerosene and electricity respectively consumed by the household, p_J is price of Jth good; y_i is households total expenditure on all goods; and P is consumer price index. This share is assumed to be a linear approximation of the logarithm of the price of Jth good and the logarithm of the ratio of total expenditure to price index.

However, some of the households were observed to have not consumed some of the fuel goods at least during the period considered, implying zero values for corresponding observations of budget shares in Equation (7.8). The dependent variable is thus censored, rendering OLS estimates to be biased. With censoring or zero observations it fails to comply with the standard assumptions with respect to the disturbance term. This problem is solved by using a two-step estimation procedure that combines a probit analysis with standard seemingly unrelated (SUR) regression. Therefore, rewrite the system of demand equations to be estimated as (Sadoulet and de Janvry, 1995):

$$(7.9) \quad w_{Fi} = a_F + \sum_J b_{FJ} \ln p_J + c_{Fi} \ln \frac{y_i}{P} + \mu_F \xi_{Fi} + \upsilon_{Fi},$$

where the additional terms ξ_{Fi} and υ_{Fi} on RHS of equation (7.9) respectively stand for inverse Mill's ratio and for residual term of fuel F for household i, and μ_F is the coefficient corresponding to the inverse Mill's ratio. Coefficients or parameters are subject to standard restrictions in neo-classical theory.[28]

Once we estimate the coefficients then the price and income elasticities could be calculated from the coefficient estimates as (see Sadoulet and de Janvry, 1995):

$$\varepsilon_{FF} = -1 + \frac{b_{FF}}{w_F} - c_F, \; \varepsilon_{FJ} = \frac{b_{FJ}}{w_F} - \frac{c_F}{w_F} w_J, \; \eta_F = 1 + \frac{c_F}{w_F};$$

[28] Coefficients/parameters are subject to restrictions, $\sum_F a_F = 1$, $\sum_F b_{FJ} = 0$, $\sum_F c_F = 0$, $\sum_J b_{FJ} = 0$, $b_{FJ} = b_{JF}$. Note that the first three are adding up restrictions whereas the last two are referred to as homogeneity and symmetry, respectively.

where ε_{FF} and ε_{FJ} respectively stand for own-price and cross-price elasticity and η_F is income elasticity of demand for fuel *F*. The income elasticity enables us to characterize whether specific fuel good is normal, inferior or a luxury good depending on the value and sign of the coefficient.

Note that the inverse Mill's ratio ξ_{Fi} comes from the first step estimation of household *i*'s decision to consume a specific fuel good *F*. For exposition, consider a decision involving a choice between consume and not consume. That is, the decision whether or not to consume a specific fuel good *F*, say wood, by household *i* essentially involves a choice between yes or no. Such dichotomous choices are best modeled as probit. Hence, specify the probit model as:

(7.10) $\text{Prob}(q^*_{Fi}=1)=\text{Prob}(f_{Fi}(p_F,y_i,\boldsymbol{h}_i)+e_{Fi} >0)$,

where q^*_{Fi} is equal to one if household *i*' consumes fuel good *F* and zero otherwise; p_F, y_i, and $\mathbf{h}_i$ respectively are the prices of related fuel goods, income, and characteristics that apply to the household; and e_{Fi} a residual term. Then the inverse Mill's ratio is generated from the probit estimation as:

(7.11) $\xi_{Fi} = \varphi(f_{Fi})/\psi(f_{Fi})$,

where φ is the probability density function and ψ the cumulative density function of the standard normal distribution of the residual term.

The demand functions for the different fuel types considered were estimated using seemingly unrelated (SUR) regression. Estimation of almost ideal fuel demand system like in equation (7.9) presupposes the use of price index often calculated from the dataset. In our case, the general consumer price index for the study region (CSA, 2006) corresponding to the year in consideration was used as price index.

Another issue of concern in this chapter is the adoption of fuel efficient or fuel saving cooking appliance or stove technologies in particular the electric *mitad* stove and the behavioral factors that underlie the adoption. Let *S* be an indicator variable indexing whether the household owns an electric *mitad* cooking appliance (stove) ($S=1$) or not ($S=0$). Hence, the probit model of the adoption of electric *mitad* stove can be specified as:

(7.12) $\text{prob}\,(S_i=1) = \Phi(x_i'\beta)$

where Φ is the standard normal distribution function, x_i a vector of regressors and β is a vector of parameters to be estimated. Note that $\text{prob}\,(S_i = 0) = 1 - \Phi(x_i'\beta)$.

7.4.2 Data description and sampling

A one period data was collected from stratified sample of three hundred fifty urban households. Urban centers in the study area were categorized into four settlement typologies as city, large, medium, and small towns, based on their population. According to ENEC & CESEN (1986) and EESRC (1995) urban centers could be categorized into four settlement typologies as city, large, medium, and small towns, depending on whether their inhabitants are >$100x10^3$, 25-$100x10^3$, 5-$25x10^3$, and <$5x10^3$, respectively. The 1994 Population and Housing Census (CSA, 1995), identifies a total number of 74 towns in Tigrai. Focal towns were identified given the time and budget limitations.

To have an idea of the current population and to base the sampling on this figure of the current population, the population of the focal towns was projected to 2000 and 2003. Then, proportionate sampling by importance of town sizes in the population share was applied on this estimate of the current population.

Table 7.1 Summary statistics of variables considered in the analysis (n=350), year 2003

Variable	mean	Std. Dev.	Min	Max
Family size	4.925	2.196	1	10
Age of head	49	14	18	95
Education of head/ highest grade completed				
Illiterate (in percent)	39			
Grade 1-3	15			
Grade 4-6	18			
Grade 7-8	11			
Grade 9-11	5			
Grade 12 and above	12			
Employment type/occupation of head				
Self employed (in percent)	69			
Public employee	16			
Private employee	15			
Wood price (Birr/kg)	0.47	0.259	0.05	3.00
Charcoal price (Birr/kg)	0.64	0.299	0.08	1.67
Kerosene price (Birr/lit)	2.36	0.389	1.00	5.00
Electricity price (Birr/kWh)	0.28	0.206	0.01	3.66
Total expenditure (in Birr)	6,910	5,087	1,045	46,398
Budget share of fuel	0.206	0.080	0.018	0.469
Budget share of food	0.620	0.112	0.085	0.875
Budget share of other goods and services	0.174	0.117	0	0.878
Budget share of wood	0.105	0.075	0	0.403
Budget share of charcoal	0.035	0.033	0	0.193
Budget share of kerosene	0.021	0.020	0	0.128
Budget share of electricity	0.030	0.030	0	0.196

Questionnaire was prepared and used for data collection. Data pertaining to food and non-food non-fuel expenditure, expenditure on the different fuels consumed (firewood, charcoal, kerosene, electricity, etc), income, and types of cooking appliance (stove) technologies used were collected. In addition, responses on fuel preferences, reason for not using specific cooking appliance or stove type, etc was also collected. Five enumerators were trained and used for the data collection. Summary statistics of the variables considered in the analysis is provided in Table 7.1. Although the study, i.e., the data collection considered all possible fuel types and categories, none of the sample households were found using LPG and crop residues. In addition, smaller proportions of the households, about 20 percent, were found using dung which was mainly freely collected. Therefore, the empirical analysis focused on the four fuel goods firewood, charcoal, kerosene, and electricity.

Table 7.2 Description of cooking appliance/ *injera* baking stoves used by sample households (n=350)

Stove type	Households involved	Percent
Tigrai-type (traditional clay enclosed)	324	92.57
Open hearth (three-stone stove)	2	0.57
Tehesh	4	1.14
Mirte	1	0.29
Electric *mitad*	71	20.29

7.5 Results and Discussion

7.5.1 Demand system

At first a probit model of the decision to consume fuel *F* was estimated, to explain whether or not particular fuels are used. That gives insights about how the fuel goods considered are related to each other. Moreover, the probit model was used as an intermediate input to calculate the inverse Mills ratio. Results are presented in Table 7.3. Normally probit command (estimation) drops variables that perfectly predict (completely determine) the outcome in the dependent variable. Therefore, results have been presented for coefficient estimates of the remaining variables. Overall validity of model regressions in all cases turned out quite significant. Considering likelihood ratio (LR) test, for example, computed value chi-square was greater than the critical value at far better than 1 percent level of significance, particularly in the case of charcoal, kerosene and electricity. This implies that the restrictions do not apply. Or put differently, this was in favor of the alternative hypothesis that all of the explanatory variables included help explain the variation. Overall fit of model regressions also performed well in all cases, despite some variations from one to the other.[29] For example, the model explained about 37 percent of the variations in the decision to consume electricity, but only 12 percent for charcoal. Also the predicted probabilities were found quite substantial.

Table 7.3 Probit estimates (standard error in parenthesis) of the decision to consume fuel *F*

Explanatory variable	Dependent variable consume fuel *F* (q_{Fi} *=1, if yes; 0, otherwise)[a]			
	Wood	Charcoal	Kerosene	Electricity
Price of wood				0.719**
				(0.365)
Price of charcoal	-0.421		1.563***	3.194***
	(0.490)		(0.382)	(0.558)
Price of kerosene	0.134	0.551**		
	(0.275)	(0.235)		
Price of electricity		0.185	1.803	
		(1.635)	(2.991)	
Household income/expenditure	-0.014	0.122***	0.139***	0.020
('000 Birr)	(0.026)	(0.044)	(0.035)	(0.029)
Family size	-0.018	-0.137**	-0.045	0.028
	(0.074)	(0.060)	(0.052)	(0.061)
Age of head	0.004	0.023**	-0.018**	0.023**
	(0.014)	(0.011)	(0.008)	(0.010)
Education of head[b]	-0.165***	-0.024	-0.064	0.172**
	(0.065)	(0.056)	(0.046)	(0.071)
Employment type/ occupation	0.065	0.007	0.032	-0.084
(=1, if self employed; 0, otherwise)	(0.078)	(0.058)	(0.046)	(0.056)
Constant	1.816*	-1.343	-0.666	-2.626***
	(1.058)	(0.904)	(0.991)	(0.623)
n	350	350	350	350
Share of zeros (in percent)	22.57	24.86	25.71	20.31
Predicted prob at (mean)	0.951	0.862	0.770	0.921
Pseudo-R^2	0.130	0.123	0.141	0.369
LR $\chi^2(7)$	13.18	22.37	35.75	83.87
Prob>χ^2	0.068	0.002	0.000	0.000

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.
[b] Education of head (highest grade completed) was captured on a 0, …, 11 scale; defined as 0=Illiterate, 1=Grade 1-3, . .. , and 11=Post graduate, respectively.

As could be clear from Table 7.3, price of related good, household income (expenditure) and other household characteristics were the explanatory variables considered

[29] Pseudo/ McFadden's R^2 defined as McFadden's $R^2 = 1 - \frac{\log \hat{L}_1}{\log \hat{L}_0}$ was used to assess the overall fit of model; where $\log \hat{L}_1$ is the maximised likelihood when both the constant term and the explanatory variables are in the model, and $\log \hat{L}_0$ is the maximised likelihood when only the constant term is in the model.

in the empirical analysis. Among the other household characteristics considered was employment type or occupation, to see whether or not it makes a difference being self employed or public/private employee. Whereas the rest of the variables turned out insignificant education of head significantly and negatively influenced the decision to consume wood (column 2, Table 7.3). Price of kerosene positively and significantly influenced the decision to consume charcoal (column 3, Table 7.3). Moreover, household income, family size and age significantly influenced the decision to consume charcoal. The fact that education of head significantly and negatively influenced the decision to consume wood implies the less likely will the household consume wood the higher her level of education. The fact that price of kerosene positively influenced the decision to consume charcoal also suggests that charcoal and kerosene are substitutes. Similarly, price of charcoal positively and significantly influenced the decision to consume kerosene (column 4, Table 7.3). In addition, household income and age were found to be statistically significant. Price of wood, price of charcoal, age and education of head turned out to be significant and positive as far as the decision to consume electricity in concerned (column 5, Table 7.3). The fact that price of wood positively influenced household's decision to consume electricity indicates that wood and electricity are substitutes.

System of demand equations were estimated to explain the demand for the different fuel goods considered. An Almost Ideal Fuel Demand System was specified and seemingly unrelated (SUR) regression was used in the estimation. Results have been presented in Table 7.4. Main explanatory variables considered were own-price, price of related good and household income/expenditure. In addition, the inverse Mills ratio was included as explanatory variable to correct for the problem of censoring or zero observations. In the wood demand equation (column 2, Table 7.4), own-price, price of electricity and household income turned out to be highly significant and negative, whereas charcoal price and price of electricity were found to have no significant effect on demand for wood. The inverse Mill's ratio was also found to be highly significant. In the case of charcoal (column 3, Table 7.4) only the income variable turned out to be statistically significant, whereas all the price variables turned out to be insignificant. The inverse Mill's ratio was also found to be significant in this case. Own-price and income was found highly significant in the kerosene demand function and all the cross-price variables turned out to be insignificant (column 4, Table 7.4). Price of wood and household income were found to have statistically significant effect on electricity demand with negative and positive signs, respectively, while the rest of the price variables turned out to be insignificant. However, care need to be taken in the interpretation of these results.

Table 7.4 Seemingly unrelated (SUR) regression results (standard error in parenthesis) of Almost Ideal Fuel Demand System (AIFDS)

Explanatory variable	Dependent variable share in total expenditure of fuel F (w_F)[a]			
	Wood	Charcoal	Kerosene	Electricity
Ln (Price of wood)	0.020***	-0.005	-0.004	-0.011**
	(0.008)	(0.005)	(0.003)	(0.006)
Ln (Price of charcoal)	-0.005	0.004	-0.001	0.008
	(0.005)	(0.005)	(0.003)	(0.007)
Ln (Price of kerosene)	-0.004	-0.001	0.007***	-0.007
	(0.003)	(0.003)	(0.003)	(0.005)
Ln (Price of electricity)	-0.011**	0.008	-0.007	0.011
	(0.006)	(0.007)	(0.005)	(0.008)
Ln (Total expenditure/P)	-0.022***	-0.016***	-0.008***	0.007*
	(0.007)	(0.005)	(0.003)	(0.004)
Inverse Mill's ratio (ξ)	-0.086***	-0.107**	-0.020	-0.002
	(0.032)	(0.055)	(0.022)	(0.049)
Constant	0. 191***	0.151***	0.062***	0.024
	(0.031)	(0.036)	(0.019)	(0.031)
R^2	0.215	0.076	0.067	0.078
χ^2	46.95	17.60	12.78	11.47
P-value	0.000	0.007	0.047	0.075

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

For a more straight forward interpretation of results, we calculated price and income elasticities of demand, which are provided in Table 7.5 below. All own-price elasticities showed the expected negative sign. Specifically, the demands for firewood, charcoal and kerosene were found to be price inelastic with own-price elasticity of less than one. Arnold *et al*. (2006) found out that, with the exception of evidences from India, most estimates of own-price elasticity reflect the demand for fuelwood and charcoal particularly in urban areas are price inelastic. The fact that the demands for firewood and charcoal, our case, turned out price inelastic was consistent with their findings. Nonetheless, the magnitude is substantially larger, i.e., -0.83 in the case of firewood, than what is suggested by them, which implies that urban households in Ethiopia are relatively more price responsive than might be the case for other African countries or South Asia. The cross-price elasticities related to firewood and electricity were found statistically significant at 5% level or less. However, most cross-price elasticities were not significantly different from zero. Elasticity of electricity demand with respect to price of wood turned out to be significant and negative. Apparently, wood and electricity could be expected to be substitutes particularly with respect to *injera* baking. It might not be that the rise in wood price directly affects the quantity demand of electricity. Typically one stove technology can be used only for one particular fuel good. The two fuel goods involve use of entirely different cooking appliance (stove) technology. Therefore, it could be that a rise in price of wood induces household's decision to consume electricity and hence invest in or adopt electric *mitad* that its sign turned out to be negative. Or, alternatively, it could be that in areas where electricity is available and intensively used there are good working markets and the price of wood is relatively low that its sign turned out to be negative.

Table 7.5 Price and income elasticities of demand for fuel *F*

Parameter	Elasticity (ε_{FF}, ε_{FJ}, η_F)			
	Wood	Charcoal	Kerosene	Electricity
Price of wood	-0.831	-0.095	-0.150	-0.391
Price of charcoal	-0.041	-0.870	-0.035	0.159
Price of kerosene	-0.034	-0.019	-0.659	-0.238
Price of electricity	-0.099	0.243	-0.322	-0.642
Income/expenditure	0.791	0.543	0.619	1.233

Arnold *et al*. (2006) argue that, in most studies, the effect of income on fuelwood consumption turns out to be small, irrespective of how income is measured. That they are in the range of -0.31 to 0.06 and that relatively few of these observed income elasticities are significantly different from zero. Whereas, in our case, income elasticities for all the fuel goods were found to be positive and significantly different from zero, implying that none of fuels considered are inferior goods. In fact, there is no support for the *energy ladder* hypothesis[30] contrary to what is suggested by Arnold *et al*. It could be because Ethiopia is at the bottom of the energy ladder. The magnitude of the income elasticities, however, varied for the different fuels. For example, while the demand for electricity was found to be income elastic (>1), the demand for wood, charcoal, and kerosene were found to be income inelastic. Moreover, the magnitude of the income elasticities of demand for both firewood and charcoal was found to be substantially larger than what is suggested by Arnold *et al*. Technically speaking, while electricity can be characterized to be a luxury fuel good, the latter three appear to be necessities.

The fact that the price variables in Table 7.4 tuned out significant also support that households face different prices. Indeed if it were not for the sufficient variations in our sample, i.e., among sample households with respect to the variables of interest fuel prices, it would have turned out otherwise or meaningless including these variables in the econometric

[30] The *energy ladder* hypothesis postulates a progression to modern fuels as a household's economic well-being, i.e., income, rises, implying that fuelwood is an 'inferior good' (Arnold et al., (2006).

analysis. In fact this suggests that it is how the market for the good in question is organized what matters instead of geographic clustering of households.

7.5.2 Cooking appliances or stove technologies

It has been clear from the earlier section that most of the stove technologies currently in use have a very low efficiency and about 85 to 90 percent of potential energy is wasted, which implies an increased demand for traditional or biofuels and hence an increased pressure on local forests. It has also been emphasized that one way that could be envisaged to tackle the urban fuel problem is through technological alternatives such as through use of fuel efficient or fuel saving cooking appliances or stove technologies. Two types of fuel efficient or fuel saving cooking appliances (stove) technologies envisaged were improved wood stoves and electric cooking appliance (stove) technologies. Others constant, adoption of fuel efficient or fuel saving improved wood stove with conversion efficiency of say 20 to 30 percent could reduce fuel wood consumption of the household by 50 percent as compared to the traditional one. On the other hand, other things constant, adoption of electric *mitad* stove or substituting away from fuel wood to electricity results in the entire full amount (100%) of fuel wood that would have been consumed by the household being saved. However, for their real effect to be sensed the cooking appliances or stove technologies should be adopted by majority of the households. Therefore, data on types of cooking appliance (stove) technologies used was analyzed, with emphasis on dissemination of these technologies. A description of the different cooking appliances or stove technologies used by sample households is provided in Table 7.2.

The clay enclosed traditional *Tigrai* type stove was found to be the predominant stove used in urban areas. Open hearth (three-stone stove), *Tehesh*, *Mirte* and the electric *mitad injera* baking stoves were also found to be used by sample households (Table 7.2). These cooking appliances or stove technologies used in urban areas particularly that of *injera* baking could be categorized into two as wood stoves and electric *mitad* stove. With the exception of the electric *mitad* all the rest are essentially wood stoves. Both *Tehesh* and *Mirte* are improved stoves recently introduced in light the growing fuel problem. *Tehesh* is different from the traditional *Tigrai* type stove in that it is a double-walled stove with a baffle that permits smoke (and heat) to recycle before it escapes out of the chimney – essentially a combined-heat stove. It also has an insulation from the bottom. It was believed that by promoting *Tehesh* stove a further fuel savings of 22 percent could be realized compared to the *Tigrai* variants that have only a single wall. The *Mirte* stove is a more recent development in stove R&D. It is a pumice-cement stove and has the advantage of easy assembly and portability. The open hearth (three-stone stove) was found to be rarely used except in some local beer breweries. In addition, the *Tehesh* and *Mirte* stoves were found in the hands of limited number of households. But about 20 percent of the sample households were found to have adopted the electric *mitad*. It might appear paradoxical that fewer households adopted the electric *mitad* despite that most of the households, about 80 percent were found using electricity. That it is too expensive was the main reason identified for non-adoption. For example, two-thirds of the non-adopters responded that it is too expensive. In fact, it turns out that electricity is mainly used for lighting.

Table 7.6 Probit model estimates (standard error in parenthesis) of electric *mitad* use/adoption[a]

Variable	Coefficient	Marginal effect
Price of wood	0.208	0.052
	(0.430)	(0.107)
Price of charcoal	-0.028	-0.007
	(0.399)	(0.010)
Price of kerosene	0.034	0.008
	(0.117)	(0.029)
Household income/expenditure (‘000 Birr)	0.061***	0.014***
	(0.019)	(0.00)
Family size	0.115**	0.028**
	(0.053)	(0.013)
Age of head	0.041***	0.010***
	(0.011)	(0.002)
Education of head	0.124**	0.031**
	(0.055)	(0.014)
Employment type/ occupation	0.043	0.011
	(0.051)	(0.013)
constant	-4.548***	
	(0.837)	
Pseudo-R^2	0.256	
LR $\chi^2(8)$	51.06	
Prob>χ^2	0.000	

[a] ***, and ** indicate statistically significant at 1%, and 5% level (or better), respectively.

Probit model was estimated to determine the factors underlying the adoption of electric *mitad*. Price of related goods, household income (expenditure), and other household characteristics including family size, age and education of head were the explanatory variables considered. Results are presented in Table 7.6. All price variables turned out to be insignificant. This was contrary to what would be expected. Instead family size, age and education positively and significantly influenced electric *mitad* adoption. It appears that price of related good affects household’s decision to consume electricity. However, characteristics of household such as household income (expenditure), family size, age and education matter or are more essential in terms of determining whether or not household adopts the electric *mitad*. As could be clear from the table, the overall fit of model also turned out to be quite good. The model explains about 26 percent of the variations in electric *mitad* adoption. Also provided in the table are marginal effects (at mean) of the variables on the probability of electric *mitad* adoption (see last column of table). Obviously increased household income increased the likelihood that the household adopts the electric *mitad*. One year of extra schooling of household head *ceteris paribus* increased the probability of adoption by 0.031. Similarly, holding all others constant, a unit change in family size and age also implied an increase in probability of adoption by 0.028 and 0.010 respectively.

Wood and tree resource still constitute major sources of fuel for urban households and that electricity is mainly used for lighting.

7.6 Conclusions

This paper investigated the potentialities for reducing the pressure of urban centers on the rural hinterlands. At first, probit model of the household's decision to consume specific fuel good was specified and estimated. Then, an Almost Ideal Demand System for fuel goods was estimated using SUR seemingly unrelated regression. Moreover, probit model was estimated to determine the factor underlying the adoption of electric *mitad*. The following important conclusions can be drawn from the foregoing discussion.

Besides prices of related goods household income (expenditure) and other household characteristics such as family size age and education of head are important variables as regards to explaining household's decision to consume a particular fuel. Nonetheless, the relative importance of each of the factors varied from one fuel good to the other. It doesn't make a difference whether the household is self employed or a public or private employee. While it increases the likelihood that the household will consume electricity, improvement in income and education decreases the probability that the household will consume wood. This is quite interesting in the sense that it means reduced pressure on wood resources. Moreover, probit regression results of household's decision to consume fuel suggest that charcoal and kerosene are substitutes and that wood and electricity are substitutes.

Estimation results of fuel demand system was used to calculated price and income elasticities of demand and characterize respective fuel goods. Concerning price elasticities, the demands for firewood, charcoal and kerosene were found to be price inelastic with own-price elasticity of less than one. The cross-price elasticities related to firewood and electricity were also important in terms of explaining quantity demanded of the respective fuel good. Elasticity of electricity demand with respect to price of wood turned out to have unexpected negative sign. One reason for the unexpected negative sign could be because the substitution is not immediate. Or, alternatively, it could be that in areas where electricity is available and intensively used there are good working markets and the price of wood is relatively low that its sign turned out to be negative. Income elasticities for all the fuel goods were found to be positive, suggesting that none of fuels considered are inferior goods. The magnitude of the income elasticities, however, varied for the different fuels. For example, while the demand for electricity was found to be income elastic (>1) the demand for wood, charcoal, and kerosene were found to be income inelastic. Technically speaking, while electricity can be characterized to be a luxury fuel good, the latter three appear to be necessities.

The results in this chapter also draw considerable implications in terms of how pressure of urban centers on their rural hinterlands could be reduced. Findings of this research indicate significant positive impact in slowing down the pressure of urban centers on their rural hinterlands through raising the level of education and income of public. In this respect, at least three things appear quite discernible from the findings. One, income and education were found negatively related to household's decision to consume fuel wood. For example, results suggest a policy that raises the level of education of public by one unit., i.e., a policy that raises the level of education, say from lower primary (grade 1-3) to higher primary (grade 4-6) schooling would ceteris paribus reduce the probability an average household consumes wood by 0.02. Two, we found household income and education positively associated with household's decision to consume electricity. That is, it increased the likelihood that the household will consume electricity. Three, income and education also enhanced the probability that the household adopts the electric stove. For instance, a policy that raises the level of education, say from lower primary (grade 1-3) to higher primary (grade 4-6) schooling would ceteris paribus enhance the probability an average household adopts the electric *mitad* by 0.03. In addition, findings this research also reveal considerable potentialities for reducing the pressure on local forest resources through substituting away or switching from fuel wood to electricity and through wide spread use of more efficient or fuel saving cooking appliances (stoves). By switching or substituting away from fuelwood to electricity, the entire full amount (100%) of fuelwood that would have been consumed by the household can now be saved.

Wood and tree resource still constitute major sources of fuel for urban households and that electricity is mainly used for lighting. Yet a lot need to be done disseminating improved wood stoves such as *Tehesh* and *Mirte*. It appears quite important distinguishing between short- and long- run options as regards to redressing the pressure of urban centers on rural hinterlands. In the short-run could be envisaged widespread dissemination of wood stoves such as *Tehesh* and *Mirte,* and tackling bottlenecks to dissemination of these stoves. In the long-run substituting away or switching from fuelwood to electricity could be envisaged. However, it should be noted that such fuel switching is conditioned by widespread use of the cooking appliance electric *mitad* stove. Therefore, tackling bottlenecks to dissemination of this stove is of paramount importance. It is important to note that results in this chapter essentially different as compared to those in chapter 4 in two important aspects: firstly, those of chapter two pertain to rural areas (households) whereas this chapter refers to urban areas. Secondly, the cooking appliances or stove technologies in question are different; i.e., stove technology considered in chapter 4 is the '*three stove model*' whereas in this chapter it is electric *mitad* stove.

Data in this study also support our claim that it is how the market for the good in question is organized what matters instead of geographic clustering of households. Hence challenge the idea that clustered households face the 'same prices'.

Appendix 7A

Table 7A.1 Final energy consumption of urban households in Ethiopia: Country overall and Tigrai

Fuel type	Country overall (1998/99)		Urban Tigrai (1995) Share (%)	Urban Tigrai (2003)[a]	
	Qty (in Tera Joules)	Share (%)		Qty (in Mega Joules)	Share (%)
Wood and tree residues	34,969.38	66.1	49.0	29,187.80	53.2
Crop residues	2,823.65	5.3	2.2	0.00	0.0
Dung	3,262.90	6.2	2.6	3,526.11	6.4
Briquette & biogas	0.00	0.0	0.0	0.00	0.0
Charcoal	5,855.81	11.1	40.9	15,666.16	28.5
Electricity	1,832.05	3.5	0.8	3,176.03	5.8
Petroleum fuels	4,161.24	7.8	4.4	3,325.77	6.1
Total	52,905.03	100.0	99.9	54,881.87	100.0

[a] Own survey results for representative household and RWEDP (1997) was used for conversion into energy units.
Source: ADC (2003) and EESRC (1995)

Table 7A.2 Energy/electricity production (country overall) by system/ source and year (in Giga Watt hour/GWh)

System/source		Year				
		99/2000	2000/01	2001/02	2002/03	2003/04
ICS						
	Hydro	1631.5	1774.3	1975.2	2007.1	2262.5
	Diesel	4.0	2.1	0.1	21.1	16.1
	Geothermal	20.0	5.1	1.0	0.0	0.0
	Total	1655.5	1781.5	1976.3	2028.2	2278.6
SCS						
	Hydro	14.3	15.5	16.6	16.5	16.5
	Diesel	19.0	14.8	16.5	19.0	22.7
	Total	33.3	30.3	33.1	35.5	39.2
ICS+SCS						
	Hydro	1645.8	1789.8	1991.8	2023.6	2279.0
	Diesel	23.0	16.9	16.6	40.1	38.8
	Geothermal	20.0	5.1	1.0	0.0	0.0
	Total	1688.8	1811.8	2009.4	2063.7	2317.8

Source: http://www.eepco.gov.et/ (Accessed 07 August 2006)

Chapter 8 Discussion of Results, Conclusions and Policy Implications

8.1 Brief Introduction

Environmental degradation resulting from unsustainable use of forests and failure to replenish (recycle) the soil nutrients removed in the production cycle are widespread in Africa (Sanches *et al*., 1997). The same applies for Ethiopia where many years of deforestation have significantly depleted the country's forest resources, which previously covered a major proportion of its total land mass. The deforestation has resulted in among others, a shortage of fuelwood, or a fuel problem. As the supply decreases fuelwood has increasingly been replaced by animal dung and crop residues, which in turn brought about a progressive decline in land quality and agricultural productivity (Arnold *et al*., 2006). This in turn has led to increased farmers' vulnerability to shocks, food insecurity and poverty (Amsalu, 2006). The links between environmental degradation and poverty in developing countries, in its broadest sense, has been well established (Reardon and Vosti, 1995; Scherr, 2000).

This thesis embarked on looking for options to ameliorate or address the fuel problem and land degradation. Moreover, it placed the emphasis on soliciting or identifying the dimensions that need to be envisaged in tackling the problem especially in the context of Ethiopia.

The foregoing four chapters focused on dealing with or answering specific issues and research questions that arose with respect to redressing the fuel problem and land degradation, as discussed in the introductory chapter. However, some of the questions raised in the introductory chapter were beyond the scope of the foregoing individual chapters. In addition, results of the individual chapters need to be summarized and integrated.

The purpose of this chapter is therefore, a dual one: to summarize and integrate the findings in foregoing chapters; and, to address some of the broader issues that were beyond the scope of these chapters.

The remainder of the chapter is organized as follows. The next section contains a discussion of the findings, and this will be followed by an outline of implications for policy, and a description of issues for further research.

8.2 Discussion of Findings

8.2.1 Land degradation and stoves

The concept of energy efficiency - and hence the development of new and energy efficient stove technologies - has its origin in the 'oil price shocks' of the 1970s (Dunkerley *et al*., 1981). Since then improved stoves have been regarded as a technological substitute for fuelwood (Amacher *et al*., 1992 and 1993). However, knowledge about the characteristics of stove adoption is sparse. While a substantial growing literature characterizes the important features of adopting agricultural production technologies (Dadi *et al*., 2004; Barrett *et al*., 2004), empirical evidences on the adoption of improved stove technologies are almost non-existent. Amacher *et al*. (1992) and Barnes *et al*. (1993) appear to be the only two in this respect. Amacher *et al*. (1992) empirically analyzed the adoption of improved stove using data from Nepal. Their work focused on the adoption of improved stoves under uncertainty. Whereas Barnes *et al*. (1993) provides a general review of the conditions for success and failure as instructive for the design of stove programs. Moreover, empirical evidences on the effectiveness or fuel saving efficiency of the improved stoves, particularly wood stoves, are also extremely scanty and mixed. For example, based on data from three villages in the rural Jiangxi Province of China, Chen *et al*., (2006) found out that improved stove have a positive effect on fuelwood consumption which turns out to be contrary to the rationales behind the promotion of improved stoves. Despite the fact that improved stoves has been introduced in many developing countries including Kenya, Uganda and Ethiopia (www.itdg.org) (Bess and Mazzoni, 2001) since the late 1980s, much of the literature (evidences) has focused on a description of the benefits in the area of health and added convenience of the improved cooking stoves (Hulscher, 1998; Arnold and Persson, 2003). Barnes *et al*. (1993) found out that improved stove programs have been most successful when targeted to specific areas where fuelwood prices or collection time are high. By and large, none of these earlier - or previous - studies dealt with the link or role of improved stove in redressing land degradation.

This thesis investigated the role of using an improved stove in redressing land degradation, as well as determining the factors that affect the stove adoption decision. Results showed that expected savings in cooking frequency, time spent collecting wood, and cattle numbers are all statistically significant factors explaining adoption. The fact that savings in time spent collecting wood turned out significant was in line with Barnes *et al*. (1993). The time saved collecting dung is not found to be an important factor in the adoption decision, even though one would expect this to decline as a result of adopting the new stove. We also found that, having controlled for the impact of household characteristics on the households' savings, their direct impact on the decision to build a new stove is negligible. Only households located in the upper highlands were found to be less likely to adopt new stoves. Results in this thesis also revealed that by using the improved stove instead of the traditional one, not only are the times spent collecting dung and wood reduced, but also less wood and dung were used for cooking purposes. On a per household basis, adopters collected about 70 kg less wood and about 20 kg less dung each month, which clearly indicates that adoption of the new stove reduces harvesting pressure on local forest stands. However, findings also showed that the adoption of an improved stove might have mixed environmental benefits as grazing pressure on communal lands is likely to rise, owing to the subsequent increases in the number of cattle per household.

The thesis went a step further and attempted to illustrate the importance of improved stoves, and to determine the possible implications of the findings by scaling them up to the province or region level. Let us take as given that there are some 600,000 rural households in Tigrai. The probability that a household will adopt a new stove was 0.3 (see Chapter 4), implying that some 173,000 households are likely to adopt the improved stove technology. Let us also assume that all dung not collected would have been used in agriculture, and that all fuelwood savings come from forested areas. And assume too that each adopting household collects on average about 70 kg less fuelwood and 20 kg less dung per month, then the total potential savings would amount to of approximately 141,745 tonnes of fuelwood and 41,290 tonnes of dung. In terms of wood alone, assuming an average of 120 tonnes of biomass per ha (much higher than the current average), the potential reduction in deforestation amounts to nearly 1,200 ha per year – hardly an inconsequential saving. Nonetheless, it should be clear that results presented here do not consider the second-order effects of reduced wood and dung consumption resulting from the use of improved stoves.

8.2.2 Household and community tree planting and fuel wood availability

Based on experience from Western Kenya, Scherr (1995) made three main generalizations: that agroforestry evolved historically in response to land-use intensification; that differing livelihood strategies, and resource constraints implied differing choices of agroforestry practice on particular farms, and that associated risks influence farmers' adoption of agroforestry technologies, which were partly evident in our case. Patel *et al*., (1995) analyzed tree -growing and tree -planting decisions of households in Kenya, and Mekonen (1998) carried out the same analyses in Ethiopia. But, by and large, none of them dealt with the question of whether or not household and community tree planting translates into being used for fuel. Moreover, Patel *et al*., employed an ordered *logit* model whereas Mekonen used a *probit* model in the case of the decision to grow or plant trees, and then OLS and *tobit* model in the second step. However, while the ordered *logit* model involves loss of information, the *tobit* model generally fails to take into account the selection bias.

Two attributes of household tree planting considered in this thesis were a household's decision to plant trees, and the extent of tree growing. Apparently, availability of male labour, cultivated land area of a household, homestead area, number of cattle, and the location factor influenced the household's tree planting decision. Whereas households with more land were found less likely to be involved in tree planting, homestead area was consistent with expectation. Availability of male labour still influenced the extent of tree growing of the household, i.e., number of tree grown per household. It turns out that planting wood trees is essentially a male activity and female labour availability has no significant effect. Patel *et al*. (1995) found out that farmers are responsive to incentives to plant trees and tree planting is competitive with other production activities. Results in this thesis, however, suggested that tree planting might not necessarily compete with other land use options, with activities such as crop cultivation and home gardening. In fact, findings suggests that it does not matter how much cultivated land area or homestead area the household has when it comes to the extent of tree growing or the number of trees grown by the household.[31] Results also show the diverse nature of the agro-ecological specificity of activities like tree planting or agroforestry.

Results in this thesis also revealed that wood is a normal good with positive income elasticity and that wood consumption increases as income increases. The magnitude of the income elasticity of demand is also found to be within the range suggested by Arnold *et al*. (2006). However, the fact that it turned out to be positive is contrary to Amacher *et al*. (1993), who argued that both fuelwood and combustible crop residues tend to be inferior goods depending on the level of income of the household. This also makes much more sense in the context of rural area settings where there is little or no access to modern energy sources and fuelwood remains the most important fuel source. As regards to the question of whether household tree planting (growing) transpires into being used as fuel, results of all trees regression revealed a quite clear positive relationship between number of mature trees and

[31] Kidanu (2004) found out that planting Eucalyptus as field (plot) boundary leads to stabilizing the livelihoods of resource poor farmers and would help smallholder farmers to increase their income and achieve food security. Therefore, it could be that farmers who grow trees as field (farm) boundaries do not affect cultivated land or homestead area. It would not compete with other activities such as crop cultivation.

fuel wood consumption of the household. Indeed, a claim could be made that 'yes tree planting in the aggregate contributes to household fuelwood consumption' and that 'it transpires into being used as fuel'. Nonetheless, such a generalization based on aggregate variables might lead to the conclusion that any species planted translates into being used as fuel. Therefore, this thesis went a step further and investigated how important the various species are in terms of their contribution to a household's fuelwood consumption. Among all the species considered the species *A. ethbaica* was found positively and significantly related to fuelwood consumption of a household, whereas the rest turned out to be insignificant. Despite the fact that Eucalyptus was the tree species most widely promoted, it turns out that indigenous tree species such as *A. ethbaica* are important in terms of household fuelwood use or consumption.

Community woodlots have been encouraged as a remedy to the fuel problem in many countries like Ethiopia. Empirical evidences concerning their role in redressing the problem are extremely scanty. Indeed, earlier works have emphasized the determinants of collective action and on the tradeoffs between level of devolution of woodlots management and their environmental impact or benefits and, consequently with their role in smallholder -income diversification and empowerment (Gebremedhin *et al*., 2003; Jagger *et al*., 2003). This thesis empirically analyzed the effect of community tree planting (woodlots) on household fuelwood consumption. To our dismay, findings revealed that they hardly have any significant effect on household fuelwood consumption, implying that they have no significant contribution to redressing the fuel problem. Results in this thesis suggested that, *ceteris paribus*, households residing around community woodlots with a relatively high biomass stock or volume consumed significantly less wood compared with those residing around woodlots with very low biomass stock or volume. It may be that there are institutional setbacks as regards the utilization of fuelwood from woodlots, which compel the households to depend on other fuel sources such as dung and crop residues and to consume less fuelwood so that they hardly have any significant effect.

8.2.3 Biogas innovation and reversing land degradation

Land degradation is the major cause of agricultural stagnation and rural poverty in Ethiopia (Hagos *et al*., 1999; Hengsdijk *et al*., 2005). Land degradation manifests itself in various forms, including soil erosion. The aspect of land degradation considered here is nutrient loss (depletion) through the removal of and /or/ burning of dung for fuel purposes. The burning of dung, which is a source of soil humus and fertility, is the main factor that has brought about a progressive decline in land quality and agricultural productivity. Nonetheless, the issue has been largely neglected, and until very recently research concentrated primarily on other biophysical constraints such as erosion. Indeed earlier modeling attempts to capture the impact of soil/land quality on productivity have emphasized soil loss due to erosion (McConnell, 1983; Byiringiro and Reardon, 1996; Kruseman and van Keulen, 2001). Likewise, the focus of most Ethiopian studies has been on water erosion, for example, such as effect of conservation practices (Holden *et al*., 1998; Sonneveld and Keyzer, 2003; Hengsdijk *et al*., 2005). But very few attempts have been made to systematically analyzed the problem of nutrient depletion. This thesis developed a conceptual framework to analyze the potential of biogas innovation in redressing land degradation. By simulating the relevant technology from experiences elsewhere it examined productivity improvements resulting from biogas innovation. It also provides a more pragmatic test for the economic viability of a biogas installation.

For countries affected by problem of land degradation, like Ethiopia, biogas innovation turns out to be an appropriate technology, both from the viewpoints of sustainability and technical or resource use efficiency considerations. As well as meeting the fuel demand of farm households, it enables farmers to replenish most of the nutrients that would otherwise be lost when applying conventional practices. Indeed, biogas innovation has considerable potential in reversing land degradation. Besides, as a biotechnology, biogas is both clean and environmentally friendly, with considerable positive environmental externalities. Biogas technology also provides considerable gains in 'fuel or energy efficiency' compared to the direct burning of dung in conventional furnaces (stoves). It also makes much more sense for countries like Ethiopia, given the high number of cattle in rural areas, both in per capita and average holdings terms.

It was evident that with biogas innovation, i.e., with fuel-augmenting technical change, farmers will be operating at higher production frontier. Productivity improvement or yield gains from adopting biogas innovation was analyzed for three levels of yield increases, namely 11%, 16% and 20% yield increase. Simulated yield increases on the basis of actual yield showed that, on average, biogas innovation results in a crop-specific potential gain of between 30.46 and 87.21 kg per farm or household, in yield terms, or between 45.69 and 113.97 Birr per farm or household, in value terms, depending on the type of crop and level of yield increase considered (see Chapter 6).

Cost-benefit analysis results reveal that the majority of the farms or households might not recoup their initial investment cost in the foreseeable future, particularly considering interest rate alone. However, results also showed that a biogas installation is still feasible for some of the farms (households) at the prevailing interest rate on loans and initial investment cost, even when subjected to more stringent tests for viability, which is quite an indication of opportunities for the economic viability of the innovation. The fact that the majority of the farms or households might not recoup their initial investment cost in the foreseeable future is related to the high initial investment costs. Indeed, the initial investment cost remains a barrier to the wide spread adoption of biogas innovation among smallholder farms. Therefore, a further analysis of the effect of the combination of policies excluding interest rate, was undertaken. Results also showed that a policy instrument that influences or acts on the initial investment cost could considerably improves the viability or suitability of biogas installation (innovation). The proportion of farms or households that recoup their initial investment in 10 years or less was more than doubled with the policy of 20% reduction in initial investment cost particularly at the higher levels of yield increase, as compared to results for the same interest rate with no reduction in initial investment cost (see Table 6.11 in Chapter 6). Moreover, a policy of 50% reduction, i.e., a further 30% reduction in initial investment cost, considerably improved the viability of the biogas installation. Indeed, it turns out that such a significant reduction in initial investment cost results in a quite significant proportion, i.e., nearly up to 15 to 48 percent of the farms or households being able to recoup their initial investment in 15 years or less, depending on the level of yield increase considered.

8.2.4 Urban fuel demand and the implication for rural hinterlands

Chapter 1 made it clear that the fuel problem and land degradation involve an urban dimension. Given this pressure of urban centres, it was apparent that rurally conceived and rurally focused solutions will be insufficient to reduce the environmental damage, and to address the problem which calls for the need of a broader rural-urban approach to the problem. But previous studies (cf. Amacher *et al*., 1993 and 1996; Heltberg *et al*., 2000; Kohlin and Parks, 2001) have emphasized the rural- side and little has been done with respect to the urban dimension of the problem. In addition, Pitt (1985), Kebede *et al*. (2002), Chambwera (2004), Heltberg (2004) and Edwards and Langpap (2005) are among the few existing studies in this respect. However, firstly, the focus of these studies has been on whether the poor can afford modern fuel (Kebede *et al*., 2002), instead of broader policy questions and the diverse potentialities there in to tackle the problem. Secondly, some of these studies (Edwards and Langpap, 2005) have looked at only specific fuel good in isolation from its related fuel good, which might make the findings incomprehensive. Thirdly, and more importantly, those that considered more than one fuel good (Pitt, 1985; Chambwera, 2004) applied empirical procedures that considered each fuel good individually or separately and fail to take into account the interdependencies. This thesis draws empirically the implication of urban fuel demand for rural hinterlands using a system of demand approach, thus including the whole set of fuel goods consumed by urban households.

In addition to prices of related goods household income (expenditure) and other household characteristics such as family size, age and education of head were important variables as regards explaining a household's decision to consume a particular fuel. Nonetheless, the relative importance of each of the factors varied from one fuel good to the other. While it increased the likelihood that the household would consume electricity, an improvement in income and education decreased the probability that the household would consume wood. This was quite interesting in the sense that it means reduced pressure on wood resources. Concerning price elasticities, the demands for firewood, charcoal and kerosene were found to be price inelastic with own-price elasticity of less than one. The fact that the demands for firewood and charcoal turned out to be price inelastic is consistent with Arnold *et al*., (2006). Nonetheless, the magnitude is substantially larger, i.e., -0.83 in the case of firewood, than what is suggested by them, which implies that urban households in Ethiopia are relatively more price responsive than might be the case for other African countries or South Asia. The cross-price elasticities related to firewood, charcoal, and electricity were also important in terms of explaining the quantity demanded of the respective fuel good. Elasticity of electricity demand with respect to price of wood unexpectedly turned out to have a negative sign. Income elasticities for all the fuel goods were found to be positive, suggesting that none of the fuels considered are inferior goods. The magnitude of the income elasticities, however, varied across the different fuel goods. For example, while the demand for electricity was found to be income-elastic (>1) the demand for wood, charcoal, and kerosene were found to be income-inelastic. Moreover, the magnitude of the income elasticities of demand for both firewood and charcoal is found to be substantially larger (Chapter 7) than what is suggested by Arnold *et al*. (2006). Evidence in this thesis also supports our claim that it is how the market for the good in question is organized that matters rather than the geographic clustering of households. We therefore challenge the idea that clustered households face the 'same price'.

Traditional biofuels of rural origin constitute major sources of fuel for urban households, while electricity is still mainly used for lighting. The results in this thesis draw interesting insights in terms of how the pressure from urban centres on their rural hinterlands could be reduced. The findings suggest a significant positive impact in slowing down the pressure of urban centres on their rural hinterlands through raising the levels of education and income of the public. In this respect, at least three things appear to be evident from the findings. firstly, income and education were found negatively related to a household's decision to consume fuelwood. Although for rural households, Chen *et al*., (2006) showed that more education decreases fuelwood consumption. Secondly, results showed household income and education to be positively associated with a household's decision to consume electricity. Finally, income and education also enhanced the probability of the household adopting the electric stove. In addition, findings also reveal considerable potentialities for reducing the pressure on local forest resources switching from fuelwood to electricity and through the widespread use of more efficient fuel-saving cooking appliances (stoves). Switching from fuelwood to electricity would result in the entire amount of fuelwood that would have been consumed by the household being saved. However, it should be noted that such fuel switching is dependent on the widespread use of the electric *mitad* cooking appliance (stove). Therefore, tackling bottlenecks to the dissemination of this stove is of paramount importance.

8.2.5 Synthesis of main results

By piecing together the various aspects of the puzzle, this thesis quantitatively analyzes the behavioral factors underlying household fuel demand and supply in rural-urban Ethiopia. The preceding four sections tried to discuss and position findings of this thesis in relation to the existing scientific knowledge (international literature). In this section, we draw together the main results and outline the contributions of the thesis to the existing literature.

Scherr (2000) identifies soil erosion, soil fertility (nutrient) depletion, de-vegetation, loss of biodiversity, soil compaction, acidification, and watershed degradation as common problems of land degradation in the densely-populated marginal developing regions. This thesis outlined the causalities (interactions) among fuel problem, land degradation and rural poverty (livelihoods) as well as the factors underlying these causalities, particularly in the context of Ethiopia, as a conceptual basis (framework) for defining the relevant topics of study. Scherr also argued that conditions affecting the adoption of resource-conserving technologies, local endowments as well as local institutions that are supportive to the poor are key factors that determine the interactions between poverty and environment. In this thesis, we analyze the factors that determine the adoption of resource-conserving technologies such as improved stove as well as its role as a means to deterring the environmental (land) degradation.

In general, findings in this thesis reveal that the use of an improved stove is correlated with lower cooking frequencies, less time spent collecting fuel (both wood and dung), and increased cattle ownership. Savings in cooking frequency, time spent collecting wood and cattle numbers were all statistically significant factors explaining adoption. Only those households located in the upper highlands were found to be less likely to adopt new stoves. Moreover, own price (shadow), prices of related goods (shadow), household income, family size, number of cattle, and location factor affected the demand for fuelwood and dung for both adopting and non-adopting households. By using the improved stove as opposed to the traditional one, not only are the times spent collecting dung and wood reduced, but also less wood and dung were used for cooking purposes. On a per household basis, adopters collect about 70 kg less wood and about 20 kg less dung each month, which clearly indicates that adoption of the new stove reduces harvesting pressure on local forest stands. However, results also showed that adoption of an improved stove could have mixed environmental benefits since grazing pressure on communal lands is likely to go up due to the number of cattle *increasing* by an average of 0.6 per household.

Availability of male labour, the cultivated land area of the household, the homestead area, number of cattle, and location factor influenced a household's tree planting decision. Whereas households with more land were found less likely to be involved in tree planting, the homestead area was consistent with expectations. Availability of male labour still influenced the extent of tree growing of a household, i.e., number of trees grown by a household. It turns out that planting wood trees is essentially a male activity, and female labour availability has no effect. Moreover, household income and location factors affected the extent of tree growing of a household. Cultivated land area was found to have no effect on the extent of tree growing of a household, and the homestead area was found inversely related to the number of trees grown by a household. In fact, the findings suggest that it does not matter how much cultivated land area or homestead area the household has, and that tree planting does not compete with other land use options, such as with crop cultivation or home gardening. With regard to the question of whether household tree planting (growing) transpires into being used as fuel, results of the all trees regression (model 1) revealed a significant positive relationship between the number of mature trees and the fuelwood consumption of a household. Consequently, tree planting might reduce the future use of manure as fuel. However, among all the species considered, the species *A. ethbaica* was found to be positively and significantly related to the fuelwood consumption of a household, in the species regression (model 2). It turns out that indigenous tree species such as *A. ethbaica* are important in terms of household fuelwood use or consumption, despite the fact that Eucalyptus was the favored tree species that had been widely promoted. Moreover, despite the fact that community woodlots have been encouraged as a remedy to the fuel problem in the country, findings revealed that they hardly have any significant effect on household fuelwood consumption. It appears that the households depend on other fuel sources such as dung and crop residues, and consume less fuelwood.

Productivity improvements or yield gains from adopting biogas innovation was analyzed, and cost-benefit analysis was carried out to test for the economic viability of investing in the biogas innovation (installation). Results revealed that biogas installations are only profitable for a few farm households and that the majority of the farms or households might not recoup their initial investment costs in the foreseeable future. The initial investment cost of biogas remains a challenge for the widespread adoption of biogas innovation among smallholder farmers. Therefore, profitability might increase if family farms were to combine their efforts. A simulation of policy combinations involving significant reductions in initial investment costs also resulted in quite a significant proportion of the sample farms (households) being able to recoup their initial investment in 10 to 15 years or less, suggesting that opportunities exist for the economic viability of the innovation.

Traditional biofuels of rural origin constitute major sources of fuel for urban households, while electricity is still mainly used for lighting. Results in this thesis also reveal that redressing the urban fuel problem cannot be seen in isolation from broader development policies aiming at raising the levels of education and income. In addition to prices of related goods, household income or expenditure and other household characteristics such as family size, age and education level of the head of the family were significant factors explaining a household's decision to consume a particular fuel. Probit regression results of a household's decision to consume fuel also revealed that charcoal and kerosene are substitutes (interchangeable) and that wood and electricity are interchangeable. Concerning price elasticities, the demands for firewood, charcoal and kerosene were found to be price inelastic with an own-price elasticity of less than one. The cross-price elasticities related to firewood, charcoal, and electricity were also important in terms of explaining the quantity demanded of the respective fuel goods. Income elasticities for all the fuel goods were found to be positive, suggesting that none of the fuels considered are inferior goods. Moreover, household income or expenditure and other household characteristics such as family size, age and education level of head of the family significantly enhanced the probability of the household adopting the electric *mitad* stove.

Arnold *et al*. (2006) concluded that fuelwood remains to be the main source of domestic energy for the rural poor whereas charcoal remains to be a major source for the urban poor. However, evidences in this thesis reveal that the rural poor substitute dung for fuelwood particularly in the face of scarcity (Chapter 4) and that dung constitute the main source of energy in some circumstances and fuelwood in another (Chapter 6). That relative prices (shadow), income and local endowments are the important factors that determine the type of fuel good (energy source) the rural poor mainly rely on. The conclusion that charcoal remains to be a major source for the urban poor also presupposes that charcoal and fuelwood are perfect substitutes, that they are perfectly interchangeable. For example, they argue that *charcoal is a 'transition' fuel to which the fuelwood users are most likely to switch in urban areas* (p600). Nonetheless, results in this thesis reveal that charcoal and kerosene are substitutes (interchangeable) and that wood and electricity are interchangeable. That charcoal and fuelwood might not be perfectly interchangeable. Moreover, such a generalization based on aggregate data fails to recognize the diversity of lifestyles[32] and end-uses (purposes) for which these fuels are used in different local circumstances. For example, in countries like Ethiopia where *injera* baking and normal cooking are the two typical end uses as far as urban domestic energy consumption is considered (Chapter 7), fuelwood is mainly used for *injera* baking while charcoal is mainly used for normal cooking. The cooking appliances or stove technologies involved are also quite different which also inhibits the ease of substitution. Evidences in this thesis also suggest a growing role of modern fuels such as electricity and kerosene and a declining role of dung and charcoal, particularly in urban areas, however, do not support for the *energy ladder* hypothesis. This could be because Ethiopia is at the bottom of the energy ladder. Results also reveal that, if designed correctly, supply-side interventions devoted to provision of woodfuels such as household tree planting (growing) might help alleviating the fuel problem

This study contributes to the existing literature in four important respects. Firstly, it provides insights into the role of using an improved stove in redressing land degradation,

[32] The term *lifestyle*, in here, is used to mean how people (individuals or in group) live, how they cook including their food habits.

besides determining the factors that affect the stove adoption decision. Secondly, the thesis empirically analyzes the role that household and community tree planting play in redressing the fuel problem. It also investigates two attributes of household tree growing, i.e., a household's decision to grow trees and the extent of tree growing, in an econometrically consistent framework. Thirdly, it investigates the potential of environmentally clean technologies such as biogas installation at farm level as an opportunity to redress land degradation. Fourthly, it draws empirically the implication of urban fuel demand for rural hinterlands using a demand system approach.

8.3 Implications for Policy

Dissemination of fuel saving (efficient) stoves

It has been made clear elsewhere in this thesis that most of the stove technologies currently in use have a very low efficiency and about 85 to 90 percent of potential energy is wasted, which means an increased demand for fuelwood, and hence an increased pressure on local forests. Moreover, it has been shown that one way that could be envisaged to tackle the fuel problem and land degradation is through technological alternatives such as the use of fuel-efficient or fuel-saving cooking appliance or stove technologies. By using the improved stove as opposed to the traditional one, it was shown that not only does the times spent collecting wood and dung decrease, but also less wood and dung are used for cooking purposes. On a per household basis, adopters collect about 70 kg less wood and about 20 kg less dung each month, which clearly indicates that the adoption of the improved stove reduces harvesting pressure on local forest stands and land degradation. Therefore, it is quite clear that considerable gains could be made in redressing the fuel problem and land degradation through an expanded or widespread diffusion of such fuel-efficient or fuel-saving stoves. In this regard improved stoves such as the '*three-stove*' model, and the *Tehesh* could be envisaged particularly in the context of rural areas and *Mirte* stove in urban areas.

Enhanced stove R&D efforts

Besides the widespread diffusion of fuel-saving stoves, our findings recommend enhanced stove R&D efforts. Other things remaining constant, adoption of fuel-efficient or fuel-saving improved wood stoves with conversion efficiency of say 20 to 30 percent could reduce fuelwood consumption of the household by 50 percent compared to the traditional one. Electricity was found to be mainly used for lighting and fewer households were found to have adopted the electric *mitad* despite the fact that most of the urban households were found to be using electricity. The main reason identified for non-adoption was that it is too expensive. It was also shown that local production of biogas installations using local materials could considerably reduce the initial investment cost and enhance widespread adoption. Moreover, standard comparisons cannot be made across all the improved wood stoves. For example, reported fuel-savings efficiency of the '*three stove* model' is compared to the '*Tigrai* type stove. That of *Tehesh* is in contrast to the *Tigrai* variants that have only a single wall. In the case of '*Mirte*' stove it is in contrast to open fire tripod. Therefore, enhanced stove R&D efforts turn out to be quite essential. Four lines of stove improvement (R&D) efforts are strongly recommended: (i) stove R&D to increase the efficiency of the improved wood stove, for example, doubling the current level of efficiency of the '*three stove* model'; (ii) least cost, or less expensive, material searching for the electric *mitad*; (iii) concerted R&D effort to identify and encourage the local production of biogas installations using local materials; and, (iv) continuous testing and standardization of stove technologies.

Encouraging household tree planting

Results in this thesis have revealed quite a clear positive relationship between household tree planting and fuelwood consumption of the household. Indeed it was quite apparent that household tree planting in the aggregate contributes to household fuelwood consumption. Therefore, this implies the potential for redressing the fuel problem, particularly in rural areas, through encouraging household tree planting. Among the various tree species grown by farmers it turned out that indigenous tree species such as *A. ethbaica* are more important as far as household fuelwood use is concerned. Despite the fact that Eucalyptus tree species has been widely promoted it turned out to have no significant effect on household fuel consumption. Moreover, three issues stand out as being quite apparent from the findings with respect to encouraging household tree planting as a remedy to the fuel problem. First, the policy of promoting household tree planting should take into account the diverse nature of the agro-ecological specificity of activities like tree planting or agroforestry. Second, recognizing the role of indigenous tree species in household tree planting, and giving more emphasis to them. Thirdly, the strategy of household tree growing as a remedy to the fuel problem should take account of the multiplicity of purposes involved in household tree growing.

Address bottlenecks to utilization and improve productivity of community woodlots

Community woodlots have been encouraged as a remedy to the country's fuel problem. However, findings revealed that they hardly have any significant effect on household fuelwood consumption. In fact, households around community woodlots with relatively high biomass stock or volume consumed significantly less wood. It turned out that the households depend on other fuel sources such as dung and crop residues, and hence consume less fuelwood. The reasons were: firstly, there are institutional setbacks as regards to the utilization of fuelwood, poles, and other timber products by members or households from, particularly, woodlots with better biomass stock or volume; secondly, the available biomass stock of the woodlot is not sufficient for members or households to depend on. Therefore, for community woodlots to fulfill their intended role, it would be necessary to address bottlenecks to utilization, i.e., institutional setbacks, and improve the productivity of community woodlots.

Technological alternatives: disseminating biogas innovation

For countries with problem of land degradation, like Ethiopia, and where animal dung constitutes an important source of domestic fuel, biogas innovation was found to be an appropriate technology, both in terms of sustainability, and technical or resource use efficiency considerations. Besides meeting the fuel demand of farm households, it enables farmers to replenish most of the nutrients that would otherwise be lost when applying conventional practices. Indeed biogas innovation was found to have considerable potential in reversing land degradation. It also makes much more sense given the high cattle number in rural areas of Ethiopia, both in terms per capita and average holdings. Despite such potentialities, biogas dissemination in the country is at an infant (demonstration) stage. Results revealed that biogas installation is still feasible for some of the farms or households, even at the prevailing interest rate on loans and initial investment cost. Therefore, substantial gains could be made in reversing land degradation through technological alternatives or widespread dissemination of biogas innovation, particularly if family farms were to combine their efforts.

Redressing the urban fuel problem or pressure of urban centres on rural hinterlands

Wood and tree resources, or biofuels of rural origin, still constitute major sources of fuel for urban households while electricity is mainly used for lighting. This in turn implies an increased pressure on the rural hinterlands. The *Tehesh* and *Mirte* stoves were found in the hands of a limited number of households and a lot needs to be done in terms of disseminating these improved wood stoves. In addition, results in this thesis enable us to draw conclusions in terms of how the pressure of urban centres on their rural hinterlands could be reduced or how the urban fuel problem should be redressed. Findings revealed that reducing the pressure of urban centres on their rural hinterlands cannot be seen in isolation from broader development policies aiming at raising the levels of education and income of the public. Therefore, two policy options could be envisaged to redress the urban fuel problem and reduce the pressure on the rural hinterlands: (i) enhancing levels of education and income of the public; and (ii) disseminating fuel-efficient stove with a much higher level of energy efficiency such as the *Tehesh* and the *Mirte*, and electric *mitad*. However, for a real effect to be gained the cooking appliances or stove technologies should be adopted by the majority of the households.

Broader rural-urban approach to the fuel problem

Findings in this thesis revealed that traditional biofuels are still the main sources of fuel, and constitute over 80 percent of a household's fuel consumption both in rural and urban areas. It has been quite apparent that this intensifies the pressure on the existing forests' resources. This also implies that rurally conceived and rurally focused solutions will be insufficient to reduce the environmental damage and address the problem, and hence the need for a broader rural-urban approach to the problem. Moreover, to achieve meaningful results in this respect the supply-side interventions should be accompanied by appropriate demand-side interventions. In the case of the rural areas, on the demand-side, disseminating fuel-saving or fuel-efficient stoves like the '*three stove'* model and the *Tehesh* could be considered. On the supply-side, encouraging household tree planting, recognizing the role of indigenous tree species, or giving them more emphasis, addressing bottlenecks to utilization, and improving the productivity of community woodlots could be envisaged. On the urban side, enhancing levels of education and income of the public, and disseminating the fuel-efficient electric *mitad* could be considered.

Distinguishing between short- and long-run options

The policy implications drawn form the analyses cannot and need not be put into action all at the same time. It appears quite important to distinguish between short- and long- run options. With respect to dissemination of biogas innovation for redressing land degradation, two issues were apparent: firstly, disseminating the biogas innovation among farms or households for which it is still viable even at the prevailing interest rate and initial investment cost; secondly, a concerted R&D effort to identify and encourage local production of biogas installation using local materials for the widespread adoption of the innovation. The first issue could be looked into or considered as a short-run option. Whereas in the case of the second quite some time will be taken up searching and testing local material for the local production of biogas installation, and this should therefore be regarded as a long run option.

As regards redressing the pressure of urban centres on rural hinterlands, two solutions that emerged from the analysis were: the widespread dissemination of wood stoves such as *Tehesh* and *Mirte*, and encouraging fuel switching from fuelwood to electricity. The diffusion of wood stoves such as *Tehesh* and *Mirte,* and tackling bottlenecks affecting the diffusion of these stoves could be envisaged as a short-run option. While encouraging fuel switching from fuelwood to electricity could be seen as a long-run option.

8.4 Issues for Further Research

This thesis was essentially based on micro econometric analysis of household survey data. The analysis is partial in the sense that it looked at ceteris paribus effects of a change in exogenous variables on the endogenous variable in question. The analyses presented in this thesis were also static, with no time dimension. There are a number of questions left open and we suggest the following issues for further research.

Dynamic analysis

The analyses presented in the foregoing chapters are apparently static, with no time dimension. Nevertheless, firstly, household characteristics such as family size and composition change over time. Households generally tend to 'smooth' their consumption through borrowing and lending and through some insurance mechanisms, when their income flow overtime fails to correspond with their desired consumption pattern, or when their income fluctuates due to external shocks. Moreover, current production decisions are influenced by the desired pattern of consumption. But, more importantly, the activities such as tree growing, technological change or technology adoption, and land management or land degradation for that matter, are dynamic decision issues involving long-term investment and decision-making. All these are best suited for or analysed in an intertemporal dynamic optimization framework.

Secondly, although such static analyses are obviously the simplest possible case to begin with, they imply a serious gap in information. For instance, in static or comparative static analysis, it is often assumed that the process of economic adjustment inevitably leads to equilibrium. However, this might not necessarily be the case.

Thirdly, off-farm employment opportunities might induce a shift in household fuel preferences through its effect on household time allocation and choice of activity. It is not clear, however, whether such labour market integration and involvement in off-farm work induce the household to differentiate into fuel buyer, be it fuelwood or more sophisticated modern fuels such as kerosene. Or whether the household turns out to be practicing farm forestry or tree growing on its own farm or homestead for fuelwood, in response to changes in relative factor and product prices. Therefore, we propose conducting further research into the dynamics of fuel demand.

Optimal stove efficiency, threshold rate of spread and forest resources dynamics

The foregoing empirical chapters were concerned with specific issues and the analyses involved investigating the effect of a single measure or intervention such as the role of stoves or of biogas in redressing land degradation or whether household and community tree planting contributes to redressing the fuel problem. It did not look into the interaction of the various aspects considered such as the interaction among technology (stove efficiency), rate of spread, fuel demand, and forest resource stock.

It was evident that diffusion and adoption of improved fuel-saving or fuel-efficient stoves results in less wood and dung being used for cooking purposes. It was also quite apparent that two things should hold for the stove technologies to have a real effect on the rehabilitation of local forests. Firstly, the technology must be widely used in the economy beyond minimum threshold level. Secondly, stove technologies particularly the improved wood stoves should be significant in terms of fuel saving. However, it is not clear what the minimum threshold rate spread or diffusion should be as this might partly depend on stove efficiency. additionally, it is not clear what the optimal or target level stove efficiency should be. Moreover, it is not known how these interact with, or what it means to, the forest resources stock. In fact, all these are quite important for practical and policy purposes. For example, stove efficiency improvement programs might be interested in the optimal or target level stove efficiency that need to be aspired. Therefore, it would be more insightful to put them all into context; stove efficiency, diffusion rate, fuel demand and forest resources stock, to analyze the interaction and determine the optimal outcome for sustainability. This could be done in an optimal control theory framework.

Economy-wide analysis

It is obvious that the problems such as land degradation and deforestation (or fuel problem) have broader economy-wide consequences. However, as explained earlier, the analyses presented in this thesis are partial and did not look into the economy-wide implications. This thesis has also shown that the use of improved stove technology results in less wood and dung being used for fuel. It is not clear, however, whether this results in increases in demand from gains in real income upon the use of more efficient appliances. Moreover, it did not deal the general equilibrium feedback effects of income changes. Therefore, we suggest a broader economy-wide analysis of the implications and their feedback effects.

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Summary

Poverty and environmental degradation appear to be the two main manifestations of rural-urban areas in many developing countries. Environmental degradation resulting from the unsustainable use of forests and failure to replenish (recycle) the soil nutrients removed in the production cycle are widespread in Africa. The same applies for Ethiopia, where the country's forest resources, which previously covered a substantial proportion of its total landmass, have declined considerably because of deforestation that occurred over years. The deforestation (devegetation) has had two major consequences: the loss of topsoil and a shortage of fuelwood (fuel crisis). As a result, fuel wood has increasingly been replaced by dung and crop residues. The burning of dung and crop residues, which are sources of soil humus and fertility, has brought about a progressive decline in land quality and agricultural productivity. Indirect estimates suggest that the reduction in agricultural productivity from lost nutrients associated with the use of animal dung for household fuel accounts for about 7 percent of the agricultural GDP. This in turn has increased farmers vulnerability to shocks and food insecurity.

The central goal of this study is to look for options to improve or address the fuel problem and land degradation through a broader understanding of the behavioral factors underlying household fuel demand and supply in rural-urban Ethiopia. To fulfill this central goal, this research used four different data sets. More specifically, this study used data sets from sample rural-urban areas in Tigrai, northern Ethiopia, to provide answers to the following key research questions:

1. How effective is the improved stove being promoted as a remedy to the fuel problem and land degradation?
2. Would household or private tree growing imply more wood being available for fuel?
3. What technological alternatives could be envisaged to alleviate the fuel problem and the attendant land degradation?
4. What is the potential to reduce the pressure of urban centers on the rural hinterlands (or, in general, how should the urban fuel issue be addressed)?

In Chapter 4, the role of using an improved stove in redressing land degradation was investigated. A two-step procedure was used. In the first step, two-stage least square (2SLS) regression was used for analyzing the system of four equations regression model for adopting and non-adopting households. The four equations regression model estimated was used for calculating predicted savings in cooking frequency, number of cattle, time spent collecting

wood and time spent collecting dung. Then the calculated predicted savings were used as explanatory variables in the probit regression of the improved stove adoption equation. Moreover, seemingly unrelated (SUR) regression with double-logarithmic specification was used for estimating the demand for fuelwood and dung for both adopting and non-adopting households. These results from demand estimation were subsequently used to determine savings, in terms of woody biomass and dung, through the adoption of the improved stove technology.

In general, findings revealed that the use of an improved stove is correlated with lower cooking frequencies, less time spent collecting fuel (both wood and dung), and increased cattle ownership. Savings in cooking frequency, time spent collecting wood and cattle numbers were all statistically significant factors explaining adoption. Only those households located in the upper highlands were found to be less likely to adopt new stoves. Moreover, own price (shadow), prices of related goods (shadow), household income, family size, number of cattle, and location factor affected the demand for fuelwood and dung for both adopting and non-adopting households. By using the improved stove as opposed to the traditional one, not only are the times spent collecting dung and wood reduced, but also less wood and dung were used for cooking purposes. On a per household basis, adopters collect about 70 kg less wood and about 20 kg less dung each month, which clearly indicates that adoption of the new stove reduces harvesting pressure on local forest stands. However, results also showed that adoption of an improved stove could have mixed environmental benefits since grazing pressure on communal lands is likely to go up due to the number of cattle *increasing* by an average of 0.6 per household.

In Chapter 5, the potential of the tree growing strategy, i.e., both at community and household levels, as a remedy to the fuel problem was examined. Four issues of empirical interest there in were the household's decision to plant (grow) trees, the extent (amount) of tree growing, household tree planting (growing) and fuelwood availability, and community tree planting and fuelwood availability. A Heckman selection model was used to analyze the first two issues or attributes of household tree planting, i.e., household's decision to plant trees and the extent (amount) of tree growing. Availability of male labour, the cultivated land area of the household, the homestead area, number of cattle, and location factor influenced a household's tree planting decision. Whereas households with more land were found less likely to be involved in tree planting, the homestead area was consistent with expectations. Availability of male labour still influenced the extent of tree growing of a household, i.e., number of trees grown by a household. It turns out that planting wood trees is essentially a male activity and female labour availability has no effect. Moreover, household income and location factors affected the extent of tree growing of a household. Cultivated land area was found to have no any effect on the extent of tree growing of a household, and the homestead area was found inversely related to the number of trees grown by a household. In fact, the findings suggests that the amount of cultivated land area or homestead area the household has does not influence the extent of tree growing or the number of trees grown by the household. Findings also suggested that tree planting does not compete with other land use options, such as with crop cultivation or home gardening. Additionally, results also depict the diverse nature of the agro-ecological specificity of activities like tree planting.

Ordinary least square (OLS) regressions were used in the case of the latter two issues The impact of household tree planting on fuelwood availability was analyzed by running two models:- model 1 (all trees) and model 2 (species) regressions of the household's fuelwood consumption function, where aggregate number of trees (model 1) and number of trees by species (model 2) were included as regressors. Results of the all trees regression (model 1) revealed a significant positive relationship between the number of mature trees and the fuelwood consumption of a household. However, among all the species considered, the species *A. ethbaica* was found to be positively and significantly related to the fuelwood consumption of a household, in the species regression (model 2). The species *O. europaea*, *F. albida* and both *Eucalyptus* species turned out to be insignificant. It turns out that indigenous tree species such as *A. ethbaica* are important in terms of household fuelwood use or consumption, despite the fact that Eucalyptus was the favored tree species that had been widely promoted. Community woodlots have been encouraged as a remedy to the fuel problem in the country. However, findings revealed that they have hardly any significant effect on household fuelwood consumption. It appears that the households depend on other fuel sources such as dung and crop residues and consume less fuelwood, so that this turned out negative.

In Chapter 6, the potential of the biogas innovation for redressing the problem of land degradation in Ethiopia was examined by simulating the relevant biogas technology from experiences elsewhere. Productivity improvements or yield gains from adopting biogas innovation was analyzed for three alternative levels of yield increase, i.e., 11%, 16%, and 20%, for the three different crops considered; barley, teff and wheat. Results showed significant productivity gains from biogas innovation. A cost-benefit analysis was carried out to test for the economic viability of investing in the biogas innovation (installation). Results revealed that the majority of the farms or households might not recoup their initial investment costs in the foreseeable future. clear opportunities for economic viability of the innovation. However, results also revealed that a biogas installation is still feasible for some (few) of the farms (households) at the prevailing interest rate on loans and initial investment costs, even after a more stringent test for viability was carried out. The initial investment cost of biogas remains a challenge for the widespread adoption of biogas innovation among smallholder farmers. A simulation of policy combinations involving significant reductions in initial investment costs, however, resulted in quite a significant proportion of the sample farms (households) being able to recoup their initial investment in 10 to 15 years or less.

In Chapter 7, the potentialities for reducing the pressure of urban centers on the rural hinterlands was analyzed. It draws empirically the implication of urban fuel demand for rural hinterlands from three analyses: one, a probit model regression of the decision to consume particular fuel; two, an estimation of a system of demand equations for the different fuel goods considered; and, three, a probit model regression of adoption of a fuel-efficient or fuel-saving electric *mitad* stove. Estimated results of a fuel demand system were used to calculated price and income elasticities of demand and to characterize respective fuel goods. In addition to prices of related goods, household income or expenditure and other household characteristics such as family size, age and education level of the head of the family were significant factors explaining a household's decision to consume a particular fuel. Probit regression results of a household's decision to consume fuel also revealed that charcoal and kerosene are substitutes (interchangeable) and that wood and electricity are interchangeable. Concerning price elasticities, the demands for firewood, charcoal and kerosene were found to be price inelastic with an own-price elasticity of less than one. The cross-price elasticities related to firewood, charcoal, and electricity were also important in terms of explaining the quantity demanded of the respective fuel good. Income elasticities for all the fuel goods were found to be positive, suggesting that none of the fuels considered are inferior goods. Moreover, household income or expenditure and other household characteristics such as family size, age and education level of head of the family significantly enhanced the probability of the household adopting the electric *mitad* stove.

This study contributes to the existing literature in four important respects. Firstly, it provides insights into the role of using an improved stove in redressing land degradation, as well as determining the factors that affect the stove adoption decision. Secondly, it empirically analyzes the role of the household and community tree planting in redressing the fuel problem. It also investigates two attributes of household tree growing, i.e., a household's decision to grow trees and the extent of tree growing, in an econometrically consistent

framework. Thirdly, it reveals the potential of environmentally clean technologies such as biogas innovation in redressing land degradation. Fourthly, it draws empirically the implication of urban fuel demand for rural hinterlands using a system of demand approach.

This study concludes with a number of policy implications or suggestions for redressing the fuel problem and land degradation. Mainly, three broader policy suggestions are sought: firstly, it emphasizes the need for a broader rural-urban approach to the problem. Secondly, for meaningful results to be achieved in redressing the problem, the supply-side interventions should be accompanied by appropriate demand-side interventions. For example, in the case of the rural areas, on the demand-side there is disseminasion of fuel-saving or fuel-efficient stoves like the '*three stove'* model and *Tehesh*. Specific policy suggestions on the supply-side are the encouraging of household tree planting, recognizing their role or giving more emphasis to indigenous tree species, addressing bottlenecks to utilization, and improving the productivity of community woodlots. On the urban side, enhancing the education and income of the public and disseminating the fuel-efficient stove electric *mitad* are suggested. Thirdly, enhanced stove R&D efforts, as well as the widespread dissemination of fuel-saving stoves.

Samenvatting (Summary in Dutch)

De twee belangrijkste kenmerken van de landelijke en stedelijke gebieden in veel ontwikkelingslanden zijn armoede en degradatie van het milieu. Degradatie van het milieu als gevolg van het niet-duurzame gebruik van bossen en het niet aanvullen (recyclen) van bodemstoffen, die tijdens de productiecyclus uit de grond opgenomen zijn, komt in Afrika op grote schaal voor. Dit geldt ook voor Ethiopië waar de bossen, die voorheen een belangrijk deel van het totale landoppervlak bestreken, door de jaren heen voor een belangrijk deel als gevolg van ontbossing verdwenen zijn. Deze ontbossing (devegetatie) heeft twee belangrijke gevolgen: verdwijnen van de bovengrond (bouwvoor) en gebrek aan brandhout (brandstofcrisis). Om die reden wordt brandhout steeds vaker vervangen door mest en oogstresten. Het verbranden van mest en oogstresten, als bronnen voor humus en vruchtbaarheid, heeft een gestage achteruitgang in zowel de grondkwaliteit als de landbouwproductiviteit te weeg gebracht. Indirecte schattingen wijzen op een verlies van ongeveer 7 procent van het bruto binnenlands product (BBP) als gevolg van verminderde landbouwproductiviteit door een tekort aan grondstoffen door het gebruik van dierlijke mest als brandstof. Dit heeft vervolgens de boeren kwetsbaarder gemaakt voor onverwachte veranderingen en voedseltekorten.

Het voornaamste doel van deze studie is het zoeken van mogelijkheden om het brandstofprobleem en de landdegradatie op te lossen of aan te pakken. Dit kan door de gedragsfactoren te onderzoeken en inzichtelijk te maken: gedragsfactoren die ten grondslag liggen aan vraag en aanbod van de brandstof in de landelijke en stedelijke gebieden van Ethiopië. Om dit doel te bereiken, wordt er in dit onderzoek met vier verschillende datasets gewerkt. Ter verduidelijking, deze studie heeft bij het beantwoorden van de hierna genoemde centrale onderzoeksvragen datasets uit landelijke-stedelijke voorbeeldgebieden in Tigrai (Noord Ethiopië) gehanteerd:

1. Hoe effectief is de verbeterde kookgelegenheid (=stoof) als oplossing voor het brandstofprobleem en de degradatie van het land?
2. Betekent privé bosaanplant dat er meer hout voor brandstof beschikbaar komt?
3. Welke technologische alternatieven komen in aanmerking om het brandstofprobleem en de hiermee gepaard gaande landdegradatie te verminderen?
4. Welke bestaande mogelijkheden kunnen de druk van de stedelijke centra op het achterland verminderen (of hoe kan, in het algemeen, het stedelijke brandstofprobleem aangepakt worden)?

In hoofdstuk 4 wordt de rol van het gebruik van de verbeterde kookgelegenheid bij het herstel van landdegradatie onderzocht. Er is een twee-stappen procedure gehanteerd. Stap 1 hanteert een 2SLS (*two-stage least squares*) regressiemodel van vier vergelijkingen regressiemodel om accepterende en niet-accepterende huishoudens te analyseren. Het vier vergelijkingen regressiemodel werd gehanteerd om de te verwachte besparingen in kookfrequentie, aantal koeien, tijd besteed aan het verzamelen van hout en tijd besteed aan het verzamelen van mest, te berekenen. Vervolgens zijn de berekende verwachte besparingen gehanteerd als verklarende variabelen in de probit-regressie, waarmee het al of niet accepteren van een verbeterde kookgelegenheid is geanalyseerd. Bovendien is een SUR (*Seemingly Unrelated Regression*) schatting met een dubbel-logaritmische specificatie gebruikt om de vraag naar brandhout en mest voor zowel accepterende als niet-accepterende huishoudens te schatten. De resultaten van de vraagschatting zijn vervolgens gebruikt om besparingen in termen van houtbiomassa en mest door het accepteren van de verbeterde kookgelegenheidtechnologie vast te stellen.

In het algemeen laat het onderzoek zien dat het gebruik van een verbeterde kookgelegenheid gepaard gaat met een lagere kookfrequentie, minder tijd nodig voor het verzamelen van brandstof (hout en mest), en een verhoogd aantal eigen koeien. Besparingen in kookfrequentie, tijd nodig voor verzamelen van hout, en aantal koeien waren allen statistisch significante factoren die adoptie van de verbeterde kookgelegenheid verklaarden. Alleen de huishoudens op het hoogplateau waren minder bereid om de verbeterde kookgelegenheid te accepteren. Daarnaast beïnvloeden de schaduwprijs van het toestel, de schaduwprijs van verwante goederen, inkomsten van een huishouden, grootte van de familie, aantal koeien, en locatie de vraag aan brandhout en mest bij zowel de accepterende als de niet-accepterende huishoudens. Door in plaats van de traditionele kookgelegenheid de verbeterde versie te gebruiken, werd er niet alleen minder tijd aan het verzamelen van mest en hout besteed, maar werd er ook minder hout en mest voor koken gebruikt. Per huishouden verzamelden accepteerders ongeveer 70 kg minder hout en ongeveer 20 kg minder mest per maand, wat duidelijk aangeeft dat acceptatie van een verbeterde kookgelegenheid de oogstdruk op het lokale bosbestand vermindert. Echter, de resultaten laten ook zien dat acceptatie van een verbeterde kookgelegenheid gemengde milieuvoordelen kan opleveren, aangezien de graasdruk op gemeenschapsland waarschijnlijk omhoog gaat tengevolge van een toename in het aantal koeien met een gemiddelde van 0.6 per huishouden.

In hoofdstuk 5 werden de mogelijkheden van de bosaanplantstrategie, d.w.z. zowel op gemeenschaps- als op huishoudenniveau, als oplossing voor het brandstofprobleem onderzocht. Vier empirisch belangrijke zaken die hierbij aan de orde kwamen, waren de beslissing van een huishouden om bomen te planten (bosbouw), de omvang (aantal bomen) van het bos, bosaanplant per huishouden (bosbouw) en de beschikbaarheid van brandhout, en bosaanplant door de gemeenschap en de beschikbaarheid van brandhout. Er is een Heckman selectiemodel gehanteerd om de eerste twee zaken of kenmerken van bosaanplant door een huishouden te analyseren, d.w.z. de beslissing van een huishouden om bomen te planten en de omvang (aantal bomen) van de bosaanplant. De beschikbaarheid van mannelijke arbeidskrachten, het bewerkte landbouwgebied per huishouden, het woongebied, aantal koeien, en locatiefactor beïnvloeden de beslissing van een huishouden om bomen te planten. Daar waar huishoudens met meer land minder vaak betrokken waren bij boomaanplant, voldeed het woongebied aan de verwachtingen. De beschikbaarheid van mannelijke arbeidskrachten beïnvloeden steeds de omvang van de bosaanplant van een huishouden, d.w.z. het aantal bomen door een huishouden geplant. Het planten van bomen blijkt voornamelijk een mannelijke activiteit te zijn en de beschikbaarheid van vrouwelijke arbeidskrachten maakt niet uit. Tevens werd de omvang van de bosaanplant van een huishouden door het huishoudinkomen en door locatiefactoren bepaald. Bewerkt landbouwgebied bleek geen effect te hebben op de omvang van de bosaanplant van een huishouden, en het woongebied bleek omgekeerd gerelateerd aan het aantal bomen dat door een huishouden was aangeplant. Feitelijk gaven de resultaten aan dat de oppervlakte bewerkt landbouwgebied of het woongebied dat een huishouden bezit geen invloed heeft op de omvang van de bosaanplant of het aantal bomen dat een huishouden plant. Er wordt aangevoerd dat het planten van bomen niet concurreert met andere mogelijkheden van landgebruik, zoals akkerbouw of het hebben van een groentetuin. Bovendien laten de resultaten ook de gevarieerdheid zien in de agro-ecologische specificiteit van de activiteiten, zoals het planten van bomen.

Er zijn OLS (*Ordinary Least Squares*) regressies gebruikt bij de laatste twee zaken. De impact van bosaanplant door huishoudens op de beschikbaarheid van brandhout is geanalyseerd met gebruik van twee modellen: model 1 (alle bomen) en model 2 (boomsoorten) regressies van de functie van de brandhoutconsumptie van het huishouden, waar het totale aantal bomen (model 1) en het aantal bomen per boomsoort (model 2) werden gebruikt als regressoren. De resultaten van regressie van alle bomen (model 1) laat een significante positieve relatie zien tussen het aantal volwassen bomen en het brandhoutgebruik van een huishouden. Echter, van alle in aanmerking genomen boomsoorten was de *A. ethbaica* positief en significant gerelateerd aan het brandhoutgebruik van een huishouden, in boomsoortregressie (model 2). *O. europaea, F. albida* en beide *Eucalyptus*soorten bleken niet significant te zijn. Het bleek juist dat inheemse boomsoorten zoals *A. ethbaica* van belang zijn voor het huishoudbrandstofgebruik, ondanks het feit dat *Eucalyptus* alom werd gepropageerd. Het planten van gemeenschapsbospercelen is gestimuleerd als oplossing voor het brandstofprobleem in het land. Onderzoek toont echter aan dat dit amper een significant effect heeft gehad op het brandhoutverbruik van de huishoudens. Het bleek dat de huishoudens van andere brandstofbronnen afhankelijk zijn, zoals mest en oogstresten, en minder brandhout gebruiken, zodat dit negatief uitviel.

In hoofdstuk 6 zijn de mogelijkheden die biovergassing biedt voor het oplossen van het landdegradatieprobleem in Ethiopië onderzocht door relevante biogastechnologie vanuit ervaringen elders te simuleren. Productiviteitsverbetering of opbrengstverhoging door biovergassing is op drie alternatieve niveaus van opbrengstverhoging geanalyseerd, d.w.z., 11%, 16%, en 20%, voor de drie gewassen: gerst, teff en tarwe. De resultaten van biovergassing toonden (elders) een significante productiviteitsverhoging. Er is om de economische levensvatbaarheid van een investering in biovergassing (installatie) te toetsen, een kosten-batenanalyse uitgevoerd. De resultaten lieten zien dat het merendeel van de boerderijen of huishoudens de eerste investeringskosten niet in de nabije toekomst zouden kunnen terugverdienen. Echter, de resultaten lieten ook zien dat een biogasinstallatie tegen het huidige rentepercentage op leningen en eerste investeringskosten voor enkele bedrijven (huishoudens) wel levensvatbaar was, zelfs na het toepassen van strengere criteria. De eerste investeringskosten voor biogas maken het voor kleine boeren moeilijk maken om tot biovergassing over te gaan. Een simulatie van een beleidscombinaties waarbij substantiële kortingen op de eerste investeringskosten worden gegeven, leidde er echter toe dat een belangrijk deel van de bedrijven (huishoudens) in staat waren hun eerste investeringen binnen 10 tot 15 jaar of minder terug te verdienen.

In hoofdstuk 7 zijn de mogelijkheden geanalyseerd om de druk van de stedelijke centra op het achterland (platteland) te verminderen. De gevolgen van de stedelijke brandstofvraag op het achterland zijn empirisch uit drie analyses afgeleid: 1. Een probit-model van de beslissing om een bepaald soort brandstof te gebruiken. 2. Een systeemschatting van vraagvergelijking van de verschillende in aanmerking komende brandstoffen. 3. Een probit-model voor het accepteren van een brandstofefficiënt of brandstofbesparend elektrisch *mitad* kooktoestel. De geschatte resultaten van een brandstof-vraagsysteem werden gehanteerd om de prijs- en inkomenselasticiteit van de vraag te berekenen en de respectievelijke brandstoffen te typeren. Naast de prijs van verwante goederen, waren inkomen of uitgaven en andere kenmerken van een huishouden zoals de grootte van het gezin, leeftijd en opleidingsniveau van gezinshoofd significante factoren die de beslissing voor een bepaald soort brandstof verklaarden. Probit-regressie resultaten van een beslissing van een huishouden om brandstof te gebruiken lieten ook zien dat houtskool en petroleum en ook hout en elektriciteit onderling uitwisselbaar zijn. Waar het prijselasticiteit betreft, de vraag naar brandhout, houtskool en petroleum bleek niet prijselastisch, met een eigen prijselasticiteit kleiner dan 1. De kruislingse prijselasticiteit voor brandhout, houtskool en elektriciteit was ook belangrijk voor het verklaren van de vraag naar de verschillende soorten brandstoffen. Inkomenselasticiteiten bleken positief voor alle brandstoffen, waaruit valt op te maken dat geen van de brandstoffen als inferieur beschouwd werd. Bovendien verhoogde het inkomen of de uitgaven en andere kenmerken van een huishouden, zoals de grootte van het gezin, leeftijd en opleidingsniveau van het gezinshoofd, de waarschijnlijkheid waarmee een huishouden het elektrische *mitad* kooktoestel accepteerde aanmerkelijk.

Deze studie draagt op vier belangrijke punten bij aan de bestaande literatuur. Ten eerste verschaft het inzicht in de rol van het gebruik van een verbeterde kookgelegenheid bij het herstel van landdegradatie, en in het bepalen van factoren die de beslissing beïnvloeden om de verbeterde kookgelegenheid te accepteren. Ten tweede analyseert het empirisch de rol van bosaanplant door zowel huishoudens als de gemeenschap teneinde het brandstofprobleem op te lossen. Tevens onderzoekt het de twee kenmerken van bosaanplant door huishoudens, d.w.z. de beslissing van een huishouden om bomen te planten en de omvang van de bosaanplant in een econometrisch consistent kader. Ten derde laat het de mogelijkheden van milieuschone technologieën zien (biovergassing) bij het herstel van landdegradatie. Ten vierde geeft de studie empirische schattingen van de effecten van de stedelijke brandstofvraag op het achterland door gebruikmaking van een vraagsysteem.

Deze studie eindigt met een aantal beleidsimplicaties of -suggesties voor het oplossen van het brandstofprobleem en de landdegradatie. Er worden ‘in grote lijnen’ drie bredere beleidssuggesties gegeven. Ten eerste benadrukt deze studie de noodzaak voor een bredere landelijke-stedelijke benadering van het probleem. Ten tweede dienen de ingrepen aan de aanbodskant samen te gaan met de juiste ingrepen aan de vraagkant, wil het probleem met gunstig resultaat worden opgelost worden. Er is bijvoorbeeld in de plattelands gebieden aan de vraagzijde de verspreiding van brandstofbesparende of brandstofefficiënte kookgelegenheden zoals het '*three stove*' model en de '*Tehesh*'. Specifieke beleidssuggesties aan de aanbodkant zijn: het stimuleren van het planten van bomen door huishoudens, of het benadrukken van de rol van inheemse boomsoorten, waarbij de knelpunten bij het gebruik worden aangepakt, en het verbeteren van de productie van gemeenschapsbospercelen. Aan de stedelijke kant wordt verbetering van kennis en inkomen van de inwoners en verspreiding van het brandstofefficiënte elektrische kooktoestel *mitad* voorgesteld. Ten derde pleit de studie voor een verbetering van onderzoek en ontwikkeling van kookgelegenheden als de verspreiding van brandstofbesparende kookgelegenheden.

BIOGRAPHY

The author was born in *Adigrat*, Tigrai Province, on 19th January l965. He attended his elementary and secondary schools at Tsinseta Lemariam School and Agazi Comprehensive Secondary School there in *Adigrat*. He commenced higher education at the Ambo Junior College of Agriculture and was awarded a diploma in General Agriculture with distinction. He worked for the Ministry of Agriculture as Development Agent (DA), in Buno-Bedelle district of the then Illubabor Administrative Region. After four years of service the author joined the Alemaya University of Agriculture (AUA) in September 1988 to pursue his BSc. He was awarded a B.Sc. in Agricultural Economics in 1992. Then, after he joined the Tigrai Region Bureau of Agriculture and Natural Resources (BoANR) where he served at various positions. Then he joined the School of Graduate Studies, Alemaya University as graduate student in September 1998 in pursuit of his MSc and obtained the degree of Master of Science in Agricultural Economics (2001) with great distinction. He also had part-time teaching position at Mekelle University and has taught various courses to undergraduate students. In September 2002, he joined the Agricultural Economics and Rural Policy Group of Wageningen University as a PhD student. During his PhD period he obtained the diploma of the Netherlands Network of Economics (NAKE). Moreover, he stayed four months at the University of Victoria, Canada

The author is married and a father of a daughter and two sons.

COMPLETED TRAINING AND SUPERVISION PLAN

Name of course, seminar or summer-school	Department/ Institution	Year	Credit[33]
General courses			
Scientific Writing	MG3S[34]	2003	1
Research Methodology	MG3S	2005	2
Mansholt-specific courses			
Mansholt Introductory Course	MG3S	2002	1
Mansholt Multidisciplinary Seminar	MG3S	2006	1
Discipline-specific courses			
Microeconomic Analysis	University of Victoria, Canada	2004	4
Macroeconomics	CentER, Tilburg Universit	2002/03	4
Economic Models	Wageningen University	2003	4
Advanced Econometrics	Wageningen University	2003	4
Selected Topics in Game Theory	NAKE[35]	2003	2
Current Issues in Development Economics	NAKE	2003	2
Applied Dynamic General Equilibrium Modelling	NAKE	2003	2
Economics of Technological Change	NAKE	2003	2
Economics of Natural Resources	University of Victoria, Canada	2004	4
Intertemporal Allocation of Natural Resources and Intergenerational Justice	MG3S	2002	2
Behavioural Economics	MG3S	2003	3
Theory and Practices of Efficiency and Productivity Analysis: Parametric Approach	MG3S	2003	2
Multiple Criteria Decisions Making in Agriculture: Theory and Applications	MG3S	2005	2
Bayesian Methods in Theory and Practice	MG3S	2006	2
NAKE Workshops:			6
Tilburg, December 2002			
Patrick Bolton on "Incomplete Contracts and the Theory of the Firm"			
Lucrezia Reichlin on "Factor Models in Large Panels of Tim Series"			
Kerry Smith on "Choice and Economic Value"			

[33] 1 credit point represents 40 hours of course load.
[34] MG3S stands for Mansholt Graduate School of Social Sciences
[35] NAKE stands for Netherlands Network of Economics

Rotterdam, June 2003 Manual Arellano on "Panel Data Econometrics" Gilles Saint-Paul on "The Future of Labour" Mark P. Taylor on "The Economics of Exchange Rates" *Rotterdam, June 2006* David Laibson on "Behavioural Economics" Adrian Pagan on "Econometric Methods for Business Cycle Analysis" Ariel Pakes on "Econometrics and Theory in Empirical Industrial Organization" Randall Wright on "A Unified Framework for Monetary Theory and Policy Analysis"	
Paper Presentation at International Conferences:	2
• International Conference on 'Economics of Poverty, Environment and Natural Resource Use', 17-19 May 2006 Wageningen, The Netherlands. • 26th Conference of the International Association of Agricultural Economists, 12-18 June 2006, Gold Coast, Australia • 15th Annual Conference of the European Association of Environmental and Resource Economists (EAERE), 27-30 June 2007, Thessaloniki, Greece	
Total	52

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- Front cover: on the top, is a pile of dung cakes in a farmer's house near Kuha and, on the bottom, a biogas plant in a dairy farm at the outskirts of Mekelle
- Back cover: the traditional *Tigrai type* baking stove (*mogogo*) at work, with bread being baked on it and a cooking stove with coffee pot on it, in the kitchen of a farmer's house around Aynalem.

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