Chapter 6 Rural Electrification & Renewable Energy in Ethiopia

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Research Highlights

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Environmental Policy Review 2011: Rural Electrification & Renewable Energy in Ethiopia

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- What renewable energy resources and technologies are available in Ethiopia that can lessen the negative environmental impacts of current energy use, specifically in rural areas?
- This paper provides a literature review and spatial analysis of institutions, the electrical grid system, and the current state of the rural energy sector. Alternative energy options are reviewed and evaluated based on environmental and economic costs and benefits.
- Case studies of Uganda and Kenya provide lessons for renewable technologies in East Africa and guide policy recommendations for Ethiopian government and civil society.
- There is a disparity between rural and urban energy use in Ethiopia, as rural areas are largely left off of the central electrical grid.
- Ethiopia has great potential to implement renewable technologies to decrease reliance on traditional fuel sources and increase rural electrification.
- Policies addressing the energy sector should be implemented in stages:
  - Immediate: Pursue energy efficiency through fuel efficient biomass cook stoves.
  - Short term: Increase rural electrification through small off grid hydropower facilities.
  - Long term: Expand the central electrical grid to rural areas and generate power through geothermal energy.

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Environmental Policy Review 2011: Rural Electrification and Renewable Energy in Ethiopia

By Jillian Howell

Executive Summary

"Rural Electrification and Renewable Energy in Ethiopia" is the sixth and final chapter in *Environmental Policy Review 2011,* a report produced by the Environmental Policy Group in the Environmental Studies Program at Colby College in Waterville, Maine.

The current energy regime in Ethiopia, one that is heavily reliant on the burning of biomass, has had major implications for the environment. The use of traditional fuels as the main source of energy by rural households, which comprise the vast majority of Ethiopia's population, is especially an area of concern. Deforestation, land degradation, decreases in agricultural productivity, and increased greenhouse gas emissions have resulted from these patterns of unsustainable fuel consumption, and are further exacerbated by Ethiopia's growing population's increased energy demands.

This research aims to describe the current energy context in Ethiopia, and evaluate the potential for various alternative energy technologies to increase electricity access in rural areas. Research was carried out through a literature review of institutions governing the energy sector and renewable energy resources and technologies, a spatial analysis exploring energy disparities between rural and urban areas, and case study comparisons of neighboring countries to see what lessons may be learned about rural electrification and renewable technologies from other East African nations.

Findings suggest that Ethiopia has an abundance of potential renewable energy sources that, if pursued, could significantly alter the nature of Ethiopia's energy sector and cause a shift away from the combustion of biomass and towards a future of country wide electrification. Efficient cook stove technologies are available to increase energy efficiency immediately while Ethiopia is still reliant on biomass, with Uganda providing an example of a country successfully reducing fuel wood consumption through improved cook stove use. In the short- to medium-term, off-grid small-scale hydropower can increase rural access to electricity, further reducing demand for traditional biomass fuels. Finally, central grid expansion to rural areas and electricity generation by geothermal energy should be the long term goal, and can be guided by Kenya's experience with geothermal energy.

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Introduction

Background

The current use of traditional biomass fuels cannot meet the energy needs of Ethiopia's growing population without compromising the health of the environment (Ethiopian Environment Review, 2010; Karakezi, 2003). For cooking and lighting needs, most Ethiopians rely on unsustainably sourced fuels such as charcoal and fuel wood. A 2010 report by the Ethiopian non-governmental organization (NGO), Forum for Environment, found the Ethiopian population as a whole is almost exclusively reliant on traditional biomass sources, using charcoal and fuel wood to meet 94% of total energy requirements, with petroleum and electricity representing the remaining 6%. Fuel wood consumption to this degree is a major issue, as it is associated with extensive deforestation and land degradation (Mulugetta, 2007; Karakezi, 2003; Karakezi & Kithyoma, 2002). While Ethiopia's urban population is currently increasing, following the global trend of the last half century, the overwhelming majority of Ethiopians still live in rural areas and will remain there into the foreseeable future. Because of these demographic realities, it is rural energy consumption patterns that need to be addressed if the energy sector is to become sustainable.

Ethiopia's dependence on traditional fuel sources has resulted in the depletion of fuel wood stocks faster than they can regenerate. This pattern, paired with the country's rate of population growth, will end in environmental disaster unless changes are made in the near future. In his 2007 report, Mulugetta (p. 4) states that

> Herein lies the current dilemma of Ethiopia's energy sector whereby consumption levels are alarmingly exceeding replenishment rates of natural resources, and yet consumption levels remain too 'near to the ground' to bring about any meaningful surge in economic and social development.

Dalelo (n.d.) further examines how developing countries often suffer from energy crises due to the depletion of locally available energy resources. These energy crises are inextricably linked to food shortages as deforestation rates soar to supply energy, leading to the degradation of agricultural land and reduced food production (Forum for Environment, 2010; Bishaw, 2001). Deforestation is exacerbated by growing populations' increasing energy demands, which is met by gathering more fuel wood and clearing more land for agriculture. Loss of forest cover contributes to soil erosion and the loss of nutrients necessary for agriculture. This cycle is positively reinforcing, as erosion and loss in agricultural productivity leads to the further clearing of forests for new farming plots (Forum for Environment 2010; Bishaw 2001). The Ethiopian Environment Review of 2010 recognized the problems of land degradation, decreases in agricultural productivity, and deforestation as detrimental environmental issues stemming directly from the current energy regime.

Environmental problems resulting from Ethiopian energy consumption also extend beyond national borders. The burning of biomass and the resulting emissions are contributing to global climate change. In particular, the incomplete and inefficient combustion by traditional cook stoves releases greenhouse gases including carbon monoxide, nitrous oxide, and methane into the atmosphere (Kees & Feldmann 2011; Panwar 2009). Meanwhile, other organic compounds and particulate matter from biomass combustion contribute to local and regional air pollution.

According to Girma Hailu, an "adequate and reliable supply of energy is crucial for the economic development of any country," and ease of access to affordable energy is often associated with a nation's stage of economic development (2000, p. 9). Industrial countries that have already achieved high living standards have high per capita energy consumption, while the least developed counties of the world, such as Ethiopia, have extremely low per capita energy consumption. The World Bank Group points to electricity as a crucial element to human development, as the technology leads to more free time, improved health, and higher education levels (2010). In places reliant on traditional fuels such as Ethiopia, women and children spend hours of their day walking to gather fuel for cooking and lighting purposes, leaving no time to pursue other economic opportunities. Wood burning also results in indoor air pollution that has major health implications (Mulugetta, 2007).

Developing nations have sought to escape environmental ruin through the expanded use of energy efficient and renewable technologies. Ethiopia's renewable energy potential is considerable, with abundant biomass efficiency, biogas, solar, hydropower, wind, and geothermal possibilities available (Forum for Environment, 2010; Mulugetta, 2007 & 1999; Karekezi, 2003). But to date, the potential in rural electrification through these renewable technologies, and the implementation of energy efficient technologies in biomass consumption have largely gone untapped. While challenges to implementation of these technologies may be considerable, the environmental harm from the continuation of the current energy regime will result in even greater challenges for Ethiopia.

This chapter explores Ethiopia's current rural energy sector and the potential for a more sustainable future by answering the following question:

- What renewable energy resources and technologies are available in Ethiopia to lessen the negative environmental impacts of current energy use, specifically in rural areas?

This question was broken down into the following three parts:

- What is the current status of the Ethiopian rural energy sector?
- What renewable energy sources are available for electricity generation, and which of these are best suited to Ethiopia?

- What insights can other nations offer into renewable energy implementation in Ethiopia?

The chapter will continue with an outline of methods used to conduct this research. This is followed by an explanation of institutions that govern the Ethiopian energy sector, including the government bodies, energy laws, policies and programs. Findings from the literature review and spatial analysis on rural and urban energy disparities are then presented, followed by an exploration of alternative energies and electricity generating technologies. The cases of Uganda and Kenya and their experiences with renewable resources and technologies is then laid out. Next, the discussion section elaborates on the rural-urban energy divide, and considers the roles of energy efficiency and rural electrification over time in Ethiopia. This report concludes with policy recommendations outlining how the future of Ethiopia's energy sector can be clean, renewable, and sustainable.

Methods

In order to explore the current energy sector of Ethiopia, as well as possible options for a more sustainable future, four methods were used. First, a literature review was conducted to explore the institutional framework of the energy sector, and to understand how these institutions affect patterns of electricity access in Ethiopia. The institutions studied include the federal government and its ministries, laws, policies, and international agencies. Second, spatial analyses were conducted using ArcGIS 10 to develop a map of the current electrical grid system and examine electricity access across rural and urban areas.

Third, renewable energy alternatives available in Ethiopia that could potentially alleviate rural dependence on traditional fuel wood were reviewed. Feasibility of implementation was evaluated based on the environmental and economic costs and benefits of each technology. Information was gathered through a literature review of relevant articles about renewable technologies, as well as reports from international agencies such as the World Bank.

Finally, two case studies of successful renewable resource use by neighboring East African nations were explored in order to gain insight, and inform immediate policy recommendations. Uganda and Kenya were chosen as the comparable case studies. Uganda has been successful in the implementation of energy efficient biomass cook stoves, and Kenya has developed geothermal energy resources to generate electricity. Table 6.1 shown below summarizes basic information about Ethiopia, Kenya, and Uganda.

Table 6.1 East African country summary, African Development Bank Group, 2005.

	Ethiopia	Kenya	Uganda
Population (millions)	83.0	40.5	33.4
Population Growth (annual %)	2.1	2.6	3.2
Urban Population (millions)	14.6	9.0	4.5
% of Population that is Urban	17.6	22.2	13.3
Rural Population (millions)	68.4	31.5	29.0
% of Population that is Rural	82.4	77.8	86.7
Electricity Access (population %)	12.0	13.1	33.4
Electricity Access (urban population %)	85.9	51.4	3.2
Electricity Access (rural population %)	2.0	3.6	4.45
Annual Growth of Electricity Access (population %)	0.4	0.5	13.3
Surface Area (km^2)	1,104,300	580,400	241,000
Forest Area (km^2)	123,000	34,700	30

Laws and Institutions

The Ethiopian energy sector operates under a framework comprised of the federal government and its various agencies, autonomous regulatory bodies, federal level laws and policies, and international institutions. The Ethiopian federal government is the primary creator of energy policy and law which comes in the form of proclamations, program initiatives, laws, plans and constitutional amendments. Ministries and agencies of the government are charged with regulating and enforcing these set rules, and international aid agencies and private investors often provide financial assistance to projects in the energy sector. Table 6.2, located at the end of this section, summarizes important institutions that provide the framework under which the Ethiopian energy sector operates.

Regional Bureaus

Regional States have established bureaus to follow energy matters in their particular states, but these bureaus have no power to influence or affect federal policy and law in their state (Forum for Environment, 2010; Hailu, 2000).

Federal Government

The Federal Democratic Republic of Ethiopia has nine Regional States and two municipality administrations, and is comprised of a two-tier government structure with federal and regional levels. The federal government is mandated with defense, foreign affairs, immigrations, currency, and criminal matters, while the regional councils are concerned with political, economic, and social affairs for each particular state, as well as any matters delegated to them by the federal government. The primary sources of energy law come from the national stage in the form of constitutional provisions and parliamentary legislation (Hailu, 2000). Overall, specific laws and proclamations regarding energy and electricity are not easily accessible and are characterized by broad generalizing policy initiatives and goals rather than specific programs (Hailu, 2000).

National Energy Policy of 1994

The National Energy Policy of 1994 was implemented with the goal of addressing the problem of energy supply and its utilization. The policy promotes agro-forestry and efficient use of biomass fuels, while facilitating the shift to greater use of modern fuels. The policy also encourages privatization through the removal of government restrictions on private sector participation in electricity generation, the elimination of all subsidies, and the commercialization of public utilities. The rationale behind the reform of the electricity industry was to demarcate regulatory and operational responsibilities in order to increase efficiency through private participation in the investment and management of industry (Forum for Environment 2010; Hailu 2000; Dalelo, n.d.).

Hailu (2000) outlines the following as some of the basic principles of the 1994 Energy Policy:

- The reliance on traditional energy sources as well as its use in an unsustainable manner has resulted in forest depletion, environmental degradation, and fuel wood shortages;
- the failure of other economic sectors to meet development goals and increase productivity has been due to the inability to carry out energy plans and use resources;
- inefficient energy production, major systems losses, and energy waste continue to occur due to a lack of institutions, human capacity, and financial resources to undertake effective energy development programs; and
- energy price imbalances have created difficulties in stabilizing market variations.

The National Energy Policy of 1994 overall emphasized the need for equitable distribution of electricity across regions in order to facilitate socioeconomic development (EEPCo, 1996). The generation of electricity was envisioned through the development of hydro, geothermal, natural gas, coal, wind, and solar energy resources based on socioeconomic and environmental factors.

As a result of this reform, the Ethiopian Electric Light and Power Authority, formed in 1955 with the main objective of power generation, transmission, distribution and selling throughout the country, was restructured and became the Ethiopian Electric Power Corporation (EEPCo). The EEPCo, formerly a public entity, became a fully autonomous commercial power utility through Regulation No. 18/1997. A new regulatory agency, the Ethiopian Electric Agency (EEA), was also created in 1997 and was vested with the power to supervise and regulate the electric sector. Additionally, the New Investment Code Proclamation No. 37/1996 and Amendment Code Proclamation No. 116/1998 promoted private investment in the electricity sector (EEPCo, 2011; Hailu, 2011; Dalelo, n.d.).

Ethiopian Power System Expansion Master Plan of 2003

Updated in 2006, the current Ethiopian Power System Expansion Master Plan outlines Ethiopia's energy plan for the next 25 years, with specific recommendations made for the first ten years, and several scenarios outlined for the following fifteen. The most recent master plan update called for investment in wind and geothermal energy resources in order to generate electricity. It also predicts increases in demand for electricity, which will be met through the implementation of new hydropower facilities. Plans for connecting Ethiopia's national grid to other countries in the region, such as Eritrea and Sudan, were also set forth (EEPCo, 2006).

Ministry of Mines and Energy (MME)

The principle government organ responsible for the formulation of energy policy, laws, and directives that influence the development of energy resources in Ethiopia is the Ministry of Mines and Energy (MME), comprised of two main sectors, mines and energies. Since 1993, MME has undergone significant structural change and reform because of the government's overall trend in reducing its involvement in the commercial activities of the energy sector. The energy institutions held accountable to the MME include the Ethiopian Electric Agency, the Ethiopian Rural Energy Development and Promotion Center, and the National Petroleum Depot Administration. The MME is charged with the tasks of:

- Policy formation strategy concerning energy development, and (upon approval), supervising implementation;
- the collection and maintenance of a depository of energy data;
- the undertaking of studies and research;
- ensuring availability of gas and petroleum across the country;
- determining the volume of energy reserves and ensuring its maintenance;
- issuing licenses for energy exploration;
- issuing and supervising the implementation of directives concerning small-scale production and supply of electric energy; and
- establishing research and training centers to enhance the development of energy resources (Hailu, 2000).

Ethiopian Electric Agency (EEA)

The Ethiopian Electric Agency was established in 1997 as a regulatory body to separate institutions that are a part of the electrical industry (and benefit from profits) from those regulating the industry. The specific responsibilities of the EEA include:

- Determining the quality and setting the standard of electric services;
- ensuring that the generation, transportation, and distribution of electricity are carried out in accordance with electricity proclamations, regulations and directives;
- issuing, suspending, and revoking licenses for the generation, transportation, distribution, and sale of electricity; and
- the appraisal and supervision of the implementation of tariffs in the electric sector (Hailu, 2000).

Ethiopian Electric Power Corporation (EEPCo)

Although the EEPCo is an autonomous company and no longer a public entity, it has retained its monopoly on electricity production. The EEPCo operates two systems: the Interconnected System (ICS), and the Self Contained System (SCS), which will be explained in depth in the findings section.

Ethiopian Rural Development and Promotion Center (ERDPC)

The ERDPC is responsible for:

- The technological research and development of renewable and household energy;
- the collection and analysis of data;
- training that focuses on rural energy issues;
- the identification of energy resources suitable for rural areas;
- improving local energy technologies and adapting foreign ones; and
- studying energy supply, demand, and consumption patterns in rural areas (Hailu, 2000).

The ERDPC also administers the Rural Electrification Fund, which is part of Ethiopia's private-led rural electrification strategy focusing on rural areas not included in the EEPCo's system expansion plans over the next ten years. Funded by the African Development Bank, the ERDPC's Rural Electrification Fund provides loans and technical assistance to eligible rural electrification private and non-government project promoters (Development Bank of Ethiopia, 2006).

Ministry of Water Resources (MoWR)

The MoWR was established to undertake the management of water and energy resources of Ethiopia with the overall goal of enhancing and promoting national efforts towards the efficient, equitable and optimum utilization of the available water resources for significant sustainable socio-economic development. The ministry operates on the fundamental principles that:

- Water is a natural endowment owned by the Ethiopian people;
- all Ethiopian citizens should have access to water that meets basic human needs in terms of quality and quantity;
- water is a social and economic good; and
- water resources development should be approached using a "rural-centered, decentralized management, participatory approach" and an "integrated framework," promoting participation of all stakeholders (MoWR, 2010).

Under the current water management policy, there are three important sub-sectoral policies, which include water supply and sanitation, irrigation, and hydropower. The hydropower subsector covers small, medium, and large scale power development activities and projects, with the overall objective being "to enhance efficient and sustainable development of the water resources and meet the national energy demands as well as cater for external markets to earn foreign exchange"(MoWR, 2010). The hydropower component of the national water management policy aim to ensure that:

- All potential hydropower projects are studied and designed to be ready for immediate implementation;
- there has been long term planning;
- projects are economically viable;
- environmental, technical, and safety standards are met;
- local human capacity for hydropower development is strengthened;
- trans-regional river hydropower development is promoted though cooperation and mutual understanding; and
- negative environmental impacts of hydropower are mitigated to the greatest extent possible (MoWR, 2010).

International Institutions

International institutions including the World Bank, African Development Bank, and the United Nations Development Programme also play a large role in the energy sector. In a developing nation such as Ethiopia where government funds are limited, international development agencies often take on the role of sustainability project financiers (i.e. the World Bank Ethiopia Electricity Access Rural Expansion Project, Phase II - GPOBA 2008; the World Bank Electricity Access (Rural) Expansion

Project Phase II, 2007; the World Bank Energy Access Project, 2005). Many of the projects funded by these agencies are renewable energy projects carried out in rural areas. One example is the World Bank's 2007 project, "Accelerated Electricity Access (Rural) Expansion," which aims to "establish a sustainable program for expanding access to electricity in rural communities, thus supporting broad-based economic development and helping alleviate poverty" through expanding the national grid and access to mini-grids, and developing stand-alone systems in rural areas (World Bank Group, 2011).

The major institutions governing the Ethiopian energy sector are summarized in Table 6.2

Table 6.2 Institutions governing the Ethiopian energy sector, adapted from Hailu, 2000.

Law	Government Institutions	International Institutions
National Energy Policy of 1994	Federal Gov. & Regional Bureaus	World Bank
Proclamations Privatizing Sector	Ministry of Mines and Energy	African Development Bank
Ethiopian Power System Expansion Master Plan of 2003	Ministry of Water Resources	UN Development Programme
	Ministry of Water and Energy	
	Ethiopian Electric Agency	
	Ethiopian Rural Development and Promotion Center	

Findings

Grid Extension and Off-Grid Options

The Interconnected System (ICS) is responsible for generating more than 98% of the total supply capacity in Ethiopia and consists of 11 hydroelectric facilities, 15 diesel power plants, and one geothermal power plant, with total capacities of 1842.6, 172.3, and 7.3 MW respectively (EEPCo, 2011). The ICS is the central electrical grid of Ethiopia, which supplies most urban areas. The Self Contained System (SCS) is the decentralized system responsible for most rural electrification, and is comprised of mini grid systems as well as unconnected household technologies. The mini grids are supplied by three small hydro plants and a number of isolated diesel generators (Forum for Environment, 2010). These small-scale hydropower facilities have a capacity of 6.15 MW, and the diesel generators are capable of generating 31.34 MW of electricity (EEPCo, 2011). Off-grid and stand-alone technologies of the SCS operate where it is not cost-effective or geographically feasible to extend ICS transmission lines (Brent et al., 2010; Dalelo, n.d.).

The extension of the national electrical grid is often the simplest, most cost efficient way to increase access to electricity. With low cost per connection and ease of implementation due to pre-existing infrastructure, grid extension is often the best way to electrify urban and peri-urban areas (World Bank Group, 2010). In some cases, extension of the central grid can be the most cost effective solution in rural areas as well, although most rural electrification has been realized through off-grid measures. In Ethiopia, due to geographical barriers, the dispersed nature of rural communities, and the lack of existing infrastructure, rural electrification projects have largely been based on mini grid and stand-alone household technologies (Barry et al., 2011; World Bank Group, 2010; Dalelo, n.d.). Mini grid and stand-alone systems are relatively new technologies in electrification, emerging just two decades ago. Technological development and improvement of small-scale renewable energy-based technologies, including solar photovoltaic (PV) systems, small wind generators, and micro hydropower, along with the progress made in service delivery systems, make a sustainable, low emission, renewable rural electricity sector possible. As technology continues to improve, prices are expected to go on decreasing (World Bank Group, 2010).

Spatial Distribution of Electricity Access

The map featured below shows the 11 hydroelectric plants, 15 diesel plants, and one geothermal plant that make up the Interconnected System (ICS) in Ethiopia as of 2011. Also shown are the three small hydro plants of the Self Contained System (SCS). The diesel generators of the SCS are not displayed because information about them was not available. Medium to high voltage transmission lines connecting the ICS are also featured. Population density was used as an indicator of rural and urban areas, with areas containing more than 150 people/km^2 classified as urban (OECD, 2010). The power plants and transmission lines are shown to be concentrated in urban areas.

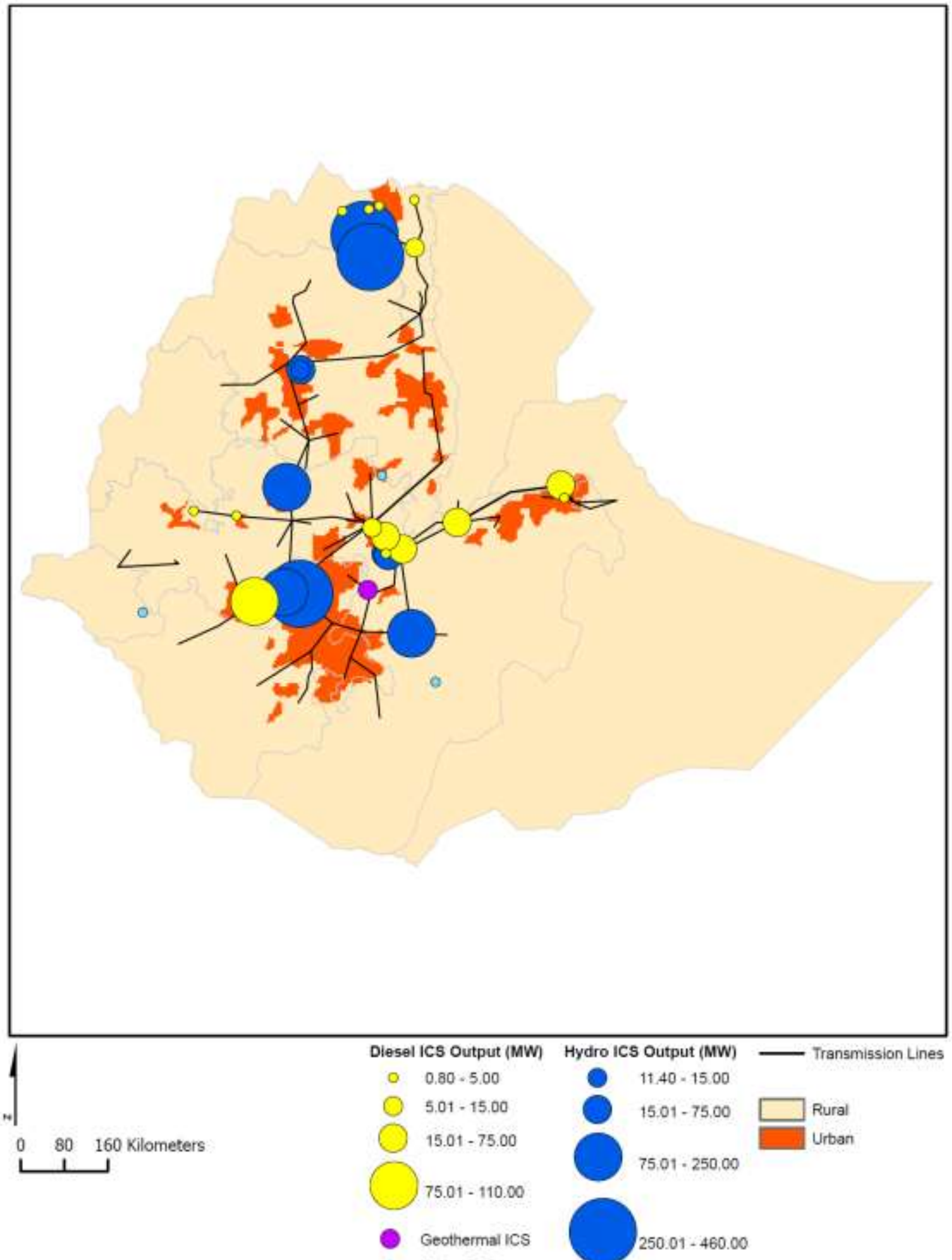

Figure 6.1 Current electricity generating facilities, EEPCo, 2011.

Disparities in energy consumption and access are reflected in the table below, which shows the type of fuel used for cooking amongst rural and urban populations, as well as the total population. The disparity between urban and rural areas is exemplified in the access to modern fuels. In rural Ethiopia, only .06% of people have access to modern fuels for cooking, while 27.08 % of urban populations have access. In addition to the divide between rural and urban energy access, these data also show how limited electricity access is to the country overall with only .02% of the rural population, and 1.31% of the urban population using electricity as cooking fuel. According to the 2010 Ethiopian Environment Report, which cites statistics from the EEPCo, overall access to electricity is at about 5% in rural areas, and 22% overall. It should be noted that access as defined here does not necessarily mean a household electrical connection, but rather close proximity of the household to a low voltage distribution line (Forum for Environment, 2010). While the numbers shown in the table below are significantly lower than overall electricity rates, they reflect the general pattern of low electricity access and use in Ethiopia.

Table 6.3 Population percentages & cooking fuel type used in Ethiopia in 2005, African Development Bank Group.

	Rural	**Urban**	**Total**
Access to Modern Fuels	.06	27.08	3.3
Access to Traditional Fuels	99.94	72.92	96.70
Electricity	.02	1.31	.17
Kerosene/Gasoline/Paraffin	.05	24.62	2.99
Liquid Petroleum Gas	0	1.15	.14
Residual/Dung/Other	8.33	3.27	7.72
Wood/Charcoal	91.61	69.65	88.98

Renewable Energy Resources in Ethiopia

Although Ethiopia is reliant on traditional biomass fuels to meet its energy needs, there are abundant and diverse renewable resources and electricity generating technologies available that present Ethiopia with the opportunity to move away from the current energy regime. These resources and technologies include energy efficient biomass cook stoves, biogas, solar thermal and photovoltaic, large and small-scale hydropower, wind, and geothermal. Each resource and associated technology provide certain economic and environmental benefits and drawbacks. Table 6.4 at the end of this section summarizes these renewable energy possibilities.

The Case for Energy Efficiency

While Ethiopia's current energy regime is based on the consumption of renewable fuel wood, they have encountered problems because of the rate of consumption. Fuel wood stocks are unable to regenerate fast enough keep up with current rates of depletion. In order to make this consumption more sustainable, energy efficient technologies such as improved cook stoves could be pursued. While this would still leave people reliant on fuel wood, the amount of fuel wood needed to generate the same amount of energy would decrease, helping to alleviate pressure on forests. This strategy can be implemented immediately because of the affordability of fuel-efficient cook stoves on a household level, low maintenance requirements, and little training needed for use. Many different models of stoves have emerged, but all aim to either improve combustion efficiency, which reduces harmful emissions, increase heat transfer to cooking surfaces, which reduces fuel use, or both (Kees & Feldmann, 2011: Ruiz-Mercado et. al, 2011; USAID, 2010). One major challenge to implementation of this technology is that it requires a change in behavior. Cooking on an energy efficient stove will not happen if the use of this stove is perceived as inconvenient, ineffective, or if people are not able to prepare the same dishes as they could on their old stove. Awareness of the fuel wood problem and knowledge about the benefits of improved cook stoves also needs to be raised in order to create demand for the product. Donor organizations, especially international organizations, and the public sector have the potential to create this demand through campaigns highlighting problems associated with traditional cook stoves, and the benefits of cleaner ones (Kees & Feldman, 2011).

The Case for Biogas

Biogas is generated through the fermentation of oxygen-deprived organic material, and can be used for electricity generation on household and mini grid levels. Ethiopia's large livestock population, and the involvement of most rural households in subsistence farming, which includes animal husbandry, makes animal dung readily available for biogas generation. Benefits of this technology include low investment levels on a household level. Also, it alleviates pressure on fuel wood demand, and soil fertility is maintained as the bio-slurry that remains after the gas is produced can be used as organic manure. Challenges arise though in the collection of dung, which can be difficult if livestock are not penned in one location. Also, herds must be large enough to ensure steady generation of electricity, which may prove difficult for farmers with small herds. Additionally, deforestation may be encouraged if grazing lands are expanded at the expense of forest lands (Getachew et al., 2006; Karekezi, 2003).

The Case for Solar PV and Thermal

Solar energy has the potential to be used in both small- and large-scale electrification measures, and can be utilized in two forms; thermal energy and photovoltaics. Thermal energy is the use of heat to run a heat engine to generate electricity, while photovoltaics involve the direct conversion of sunlight into electricity. On a household scale, solar thermal and PV can be used to generate electricity for cooking and lighting, while larger outputs of electricity could be produced at the community level through mini grids, and at an industrial level through grid extension. Solar PV is a technology that is being widely pursued around sub-Saharan Africa with the support of international development agencies (Karakezi, 2003; Karakezi & Kithyoma, 2002).

Despite their large-scale promotion, solar PV has encountered challenges that thus far have been insurmountable to make the technology successful on any extensive scale. Not only can solar PV only be used for lighting and powering low-voltage appliances, it is extremely expensive to install, especially for low income rural populations. According to Karekezi and Kithyoma's 2002 report,

> …the cost of a typical low-end PV household system is several times higher than the GNP per capita of most sub-Saharan African countries. This comparison actually underestimates the relative high cost of the PV systems because the GNP per capita figure overestimates rural incomes by including the high-income urban residents (p. 1075).

The Case for Wind

Wind is currently included in the EEPCo's master plan for the upcoming 25 years, although the variability of the resource presents a problem to its adoption in Ethiopia. Because of the pervasiveness of low wind speeds in sub-Saharan Africa, especially in the land-locked countries, most wind machines have been used to pump water rather than generate electricity. High technological costs, low levels of technical skills, and little awareness of the potential of the technology also create barriers to implementation. Logistically, transporting wind turbines is also a major problem because of the lack of basic transportation infrastructure. Because of these factors, neither grid connected nor off-grid wind projects have been undertaken in Ethiopia (Karakezi, 2003). A study performed by Bekele (2009) also reflected the low, variable potential of this resource. In the study, wind potential was measured from four specific sites in Ethiopia, and results found that wind energy may be integrated with other systems, including solar PV, diesel generators, and battery to generate electricity, however the potential may not be sufficient for independent wind systems.

The Case for Hydro

Hydropower is suited to areas with steep rivers that flow year round, a condition which Ethiopia satisfies (Kabaka, 2007). Currently, hydropower is the main source of electric power in Ethiopia, with only about 2.4% of the exploitable potential being used (Ethiopian Environment Review, 2010). Most of this hydropower generation though, is in the form of large-scale operations that send electricity through the Interconnected System. While hydropower is technically renewable, there are risks associated with near complete reliance on this form of production, including vulnerability to climate change and geohazards (Ethiopian Environment Review, 2010). Due to the precipitation and siltation of the reservoirs, some of the hydro power plants are losing storage volume, resulting in reduced energy output throughout the year. Another restriction of the hydro system is caused by the variability of rainfall. In years of low rainfall and drought, the amount of water available during the rainy season from July until September does not allow for the reservoirs to be completely filled (Karakezi, 2003). Additionally, while hydropower is a clean renewable resource, damming of rivers can have major negative environmental impacts on ecosystems.

Environmental impacts associated with small-scale hydropower are much less than those connected to larger operations. Small-scale hydro is also amenable to the mini grid system, making it ideal for rural areas. Like large-scale hydropower facilities though, small-scale hydro is susceptible to periods of drought and the effects of climate change (Teklemeriam, 2000). Reliance on hydropower with little diversification could pose problems for Ethiopia in the future (Heckett & Akilu, 2008).

The Case for Geothermal

The Great East African Rift System, a hotspot of geological tectonic activity, extends for about 6500 km from the Dead Sea-Jordan Valley in the Middle East to the north, down to Mozambique in the south. The rift system is comprised of three main branches; the Red Sea Rift, the Gulf of Aden Rift, and the East African Rift, the last of which runs through Eritrea, Ethiopia, Kenya, Tanzania, Zambia, Malawi and northern Mozambique (Teklemariam et al., 2006). At the East African Rift Valley, heat energy from the interior of the earth escapes to the surface in the form of volcanic eruptions, earthquakes, hot springs and fumaroles. This energy possesses a geothermal electricity generating potential that if tapped, would provide a clean, renewable, local resource with enough capacity to meet the needs of not only Ethiopians, but would be an exportable, profit-generating commodity (Teklemariam et al., 2000).

Geothermal exploration began in Ethiopia in 1969, and research since this time has shown geothermal energy potential in both the Ethiopian Rift Valley and the Afar depression, which are both part of the great East African Rift System. Within Ethiopia, the Ethiopian rift extends for over 1000 km from the Ethiopia-Kenya border to the Red Sea, covering an area of 150,000 km^2, and providing an estimated potential of about 700 MW of geothermal energy. Despite this extensive potential, Ethiopia only has one geothermal power plant. The Aluto-Langano geothermal pilot power plant has been open since July 1998, although technical problems have hindered its operation throughout its lifetime, and generation is currently only at 3MW (Teklemariam et. al., 2000). Plans for greater geothermal energy use are currently included in the EEPCo's master plan for the upcoming 25 years.

There has already been much research into potential geothermal sites, and of these areas, about 16 have been deemed suitable for geothermal electricity generation with adequate potential and capacity, while other locations have been determined capable of being developed for the direct utilization of geothermal heat in agriculture (Teklemariam, 2006; Teklemariam et. al., 2000).
Using today's technologies, Eastern Africa has the potential to generate about 2,500-6,500 MW of energy from geothermal power. Benefits of geothermal include the diversification of the electricity sector. Hydroelectric generation is dominant, despite its vulnerability to drought, silting, and climate change, as well as the damaging effects of dam creation. Challenges to development of geothermal energy include high initial costs, risky financial investments, a lack of government and institutional support, limited technical or scientific knowledge the resource, and the geologic hazards associated

with building and setting up a power plant on an active fault line in the Rift Valley. In order to overcome these constraints, support, especially financial support in the form of loans and grants from donor and development agencies is necessary. The participation of private sector investors may also provide necessary financial backing (Teklemariam et. al, 2000).

Table 6.4 Summary of renewable energy possibilities in Ethiopia, World Bank 2008; Dalelo; Mulugetta, 2007, 1999.

Resource	Details	Size	Benefits	Costs
Efficient Cook Stoves	Rocket stoves	Household	Affordable to individuals easy implementation	Still relies on direct combustion of biomass
Biogas	Large livestock population, cattle dung available	Household or mini grid	Not directly depleting forests	Financial limitations, may encourage deforestation
Solar	Thermal or Photovoltaic, strong solar regime	Household or mini grid	Clean	Not affordable to individual households
Wind	No operating wind facilities	Mini grid or grid	Clean	Wind variability, difficulty in turbine transport to site
Hydro	87% of electricity is generated from large scale hydropower	Mini grid or grid	Clean	High initial cost, variability of rainfall, silting at dams, dam disrupts ecosystem, need diversification
Geothermal	Electricity generating	Grid	Clean	High initial investment, requires skillful maintenance

Comparable Cases: Uganda and Kenya

Uganda's Energy Efficiency Promotion

Uganda, a country where people have historically cooked on relatively inefficient three-stone fires due to limited fuel wood access and low incomes, provides an example of successful efficient cook stove implementation on a large scale. Currently in Uganda, the GTZ (German Technical Cooperation) is implementing the Ugandan Energy Saving Stove Project (UESSP) on behalf of the German Federal Ministry for Economic Development and Cooperation. This program is part the larger Ugandan - German initiative, "Promotion of Renewable Energy and Energy Efficiency Programme" (PREEEP). The PREEP began in late 2004, and largely targets rural areas characterized by high population densities suffering from major fuel wood shortages (Kees & Feldmann, 2011).

The UESSP developed three stove models made from local materials (except for the portable metal stove) based on the "rocket stove" principle. The basic rocket stove design includes an insulated combustion chamber composed of lightweight materials that won't absorb heat to keep fires hot (above 650 ˚C) to burn wood more completely. The design also includes an elbow at the bottom of the stove to feed in the wood so that it burns slowly, and only at the tips (Still & Winiarski, 2001). Research and development are ongoing by GTZ at a testing center at the Makerere University in Kampala. Since 2005, around 500,000 households in Uganda have started using these energy efficient stoves, setting an unprecedented dissemination rate in Africa for this type of technology in such a short period of time. Dissemination of the stoves was able to move so rapidly due to the use of local materials, involvement of Ugandan artisans in product creation, participation of local NGOs, implementation of a system monitoring stove use, government support in the form of acknowledgement of the technologies' importance, and the setting of clear targets for the project. Additionally, the stoves were affordable, convenient, and perceived as a desirable modern technology. The project's success is reflected in the following excerpt from Kees and Feldmann's 2011 report:

> A family using the improved stove saves on average 3.1 kg firewood per day, seven hours per week in cooking time and on the collection of firewood, 26 EUR per year on fuel, if fuel is bought; and – every second woman reports suffering less eye irritation, coughs or accidental burns (Kees & Feldmann, 2011, p. 7599).

Kenya's Geothermal Exploration

Currently, Kenya is the greatest producer of geothermal energy in Africa. By harnessing this resource, Kenya generates a total of about 130MW annually, and thus can be looked to as a successful case study for Ethiopia to learn from (Teklemariam, 2000).

Kenya's exploration of its geothermal resources began in the 1950s. In 1982, Kenya became the first African country to tap geothermal energy for electric power generation. Limited hydro resources, combined with geothermal's renewability and abundance, were driving factors in the industry's growth. Kenya's first electricity generating geothermal plant has been operating for 24 years and has proven to be reliable and economical, which has in turn led to increased development of the industry. Over the past decades, Kenya has acquired considerable expertise in earth sciences and engineering related to geothermal resources, developing both human and technical capacity. Additionally, the development of the financial institutions necessary to support the undertakings of a risky, expensive energy producing process has followed. As of 2000, 105 wells of depths varying between 1,000 and 2,600 meters had been drilled for exploration, production, monitoring and injection. Recent studies estimate further development into the future, with total generating capacity estimated to be 1,260 MW by 2018 (Teklemariam et al., 2000).

Discussion

The Rural-Urban Divide

Currently, rural households are meeting energy demands with traditional fuels such as fuel wood and charcoal, mainly because they lack access to more modern energy technologies. Investment in the energy sector and the development of alternative energy technologies often neglects rural areas. Ethiopia is following the worldwide trend of urbanization, but the vast majority of its population still lives in rural areas. This demographic fact is at odds with the current patterns of electricity and energy generation. Mulugetta references the "modernization" development concept, which leads to the channeling of funds and investment to what is thought to be by some, the most productive and efficient centers, otherwise known as urban areas. This concept relies on the assumption that eventually, the booming urban center with the large scale energy systems including hydroelectric and thermal plants will boost industrial development and will incorporate the rural populations into the workforce where they too will reap the benefits. The reality has shown though that the rural populations, which comprise an overwhelming portion of the nation's people, are left on the fringes (Mulugetta, 2007).

The generation of electricity can be accomplished in a variety of ways, especially with Ethiopia's abundance of renewable resources. However, there are many constraining factors influencing the pursuit of these renewable resources. Major barriers include implementation and maintenance costs, lack of financial, technical and human capacity, little interagency coordination, and a lack of government support (Mulugetta, 2007). As Dalelo states, "rural electrification has long been top on the development agenda of many developing countries. Nevertheless, a vast majority of the population in these countries is still in the darkness" (n.d., p. 1).

Current and Potential Roles for Energy Efficiency

Energy efficiency through efficient biomass cook stoves may be exactly what the Ethiopian energy sector needs right now. This technology provides a short-run alternative to rural electrification, and is relatively easy to implement because stoves are household technologies, so there is no need for the construction of new infrastructure. Biomass combustion is the main source of energy in sub-Saharan Africa, and will continue to be the main source into the foreseeable future. Keeping this is mind, in order to make real changes in the immediate future, energy efficiency rather than a complete change in technology should be implemented in Ethiopia. Uganda's experience with this technology may offer valuable insights as Ethiopia undertakes their own projects. An improved charcoal stove, the "Lakech," and a biomass stove, the "Enjera" or Mirt Lakech, as well as the Mirt stove were developed and have been introduced to Ethiopia. Thus far, they have been proven to provide energy savings over traditional stove and open fire stoves. Large-scale distribution of improved stoves would help to reduce pressure on the biomass resources, and according to the 2004 UNCCDP report:

> …if the whole rural and urban households (estimated to be about 14.44 million) in Ethiopia shift to the improved Lakech and Mirt stoves, a saving of about 7,778,800 tonnes of fuel wood which requires clear cutting of 137,192.24 hectares of forest will be achieved in an annual basis. This implies that sufficient distribution of these improved stoves will have significant contribution to save the biomass resources of the country in general and forest resource in particular and to combat land degradation and mitigate the effects of drought (p. 29).

Current and Potential Roles for Rural Electrification

Energy efficient technologies alone, though, are not enough. In the long term, Ethiopia should pursue an agenda of rural electrification. Electricity may not seem an appropriate technology to bring to some people in Ethiopia, as rural villages far from transmission lines with needs only for cooking and lighting may not appear to need electricity (Karakezi, 2003). The issue becomes complex though, when health and quality of life are affected by energy choices, or lack thereof. Development issues such as these are not unrelated to the environmental reasons focused on by this research that support electrification. Electricity has the potential to mitigate not only problems faced by individual households, but global climate change, and large-scale deforestation and land degradation. The recognition that the current pattern of traditional fuel consumption is degrading the environment by many developing countries has placed rural electrification on their development agenda, Ethiopia included (Mulugetta, 2007).

Electrification can proceed down a few different paths: extending the grid, establishing off-grid mini systems, or building off-grid stand-alone systems. As Figure 6.1 demonstrates, rural areas have mostly been left out of the national electricity grid system, and mini grid and stand-alone systems appear to be a more feasible option in villages characterized by low population density, and relatively large distances between households (Dalelo, n.d.). These systems, especially the off-grid mini systems, can be powered by a number of renewable resources. According to the renewable energy paradigm, small scale, decentralized systems are most efficient for renewable energy. These system types are also inherently conducive to rural settlements (Mulugetta, 2007).

Diversification of electricity generating technologies should be a priority of the energy sector in the long run (Heckett and Aklilu, 2008). If Ethiopia continues on its current track of urbanization and population growth, rural population patterns will change. Dispersion patterns affect cost effectiveness of connecting a village or household to the national grid. Increased urbanization and infrastructure building may change the potential scope of the national grid. Depending on rates of urbanization, development of infrastructure, and population growth, the ICS may become more cost-effective than the SCS in certain places in the future.

Plan For the Future: Strategies over Time

While Ethiopia's energy industry may be suffering from a lack of many things, options is not one of them. The future of Ethiopian rural electrification and environmental sustainability depend on the policy choices made, as well as the planning and research carried out today. If Ethiopia is to make a meaningful change, steps need to be taken immediately in the form of expanded dissemination and implementation of energy efficient biomass cook stoves. While this short-term solution is going on, a plan for the future needs to be crafted. In the near future, decentralized, off-grid methods appear to be the best fit. And with biogas technologies indirectly leading to deforestation, the high cost of solar PV, large-scale hydro power's vulnerability to environmental factors, and wind suffering from a low potential, small-scale hydro small appears to be the most attractive option. Ethiopia also already has experience and knowledge of hydropower technology.

The future though does not just include tomorrow, or the next few years, but decades down the road as well. In this longer term vision of the future, the central grid should be expanded so that rural areas are brought into the Interconnected System. Generation for this system should be diversified away from large scale hydroelectric power. One way to do this would be to seriously explore and if applicable, pursue geothermal energy generation (Niez, 2010; Karakezi, 2003; Teklemariam et al., 2000).

Conclusions

Underlying the energy problem in Ethiopia is the dichotomy between pressing energy needs now and the need for long term planning for the future of complex rural energy and electrical settings. Short-term solutions and plans for a sustainable future often seem at odds with one another (Mulugetta, 2007).

Energy policy matters to the environment, and it is especially relevant in a developing country such as Ethiopia that is currently reliant on traditional fuels. Ethiopia's growing population, and an increasing demand for energy are only compounding the unsustainable use of biomass, propelling

Ethiopia in the direction of disaster. The potential for change in the sector though, exists. Ethiopia is endowed with renewable resources ready to be used to sustainably develop the country. Ethiopia needs to look to its neighbors who have successfully implemented renewable technologies and use NGO and international development agencies to assist in technological dissemination and financing of projects. If properly planned and executed, Ethiopia's future could be a bright one.

Moving ahead, Ethiopia should consider the following policy recommendations:

- *Today*: Energy efficiency is the most feasible way to immediately impact the energy sector without making major changes to infrastructure. Ethiopia should therefore continue and expand its current programs of implementation of energy efficient cook stoves. Uganda has implemented an especially successful program, hence Ethiopia could adopt some of Uganda's methods, while also learning from the country's mistakes.
- *In the short term*: Planning and research in the short term should focus on implementing mini off-grid hydropower facilities to generate electricity for rural areas. Ethiopia has a history of hydroelectric power generation, and can therefore use the knowledge gained from this experience to bring hydropower to rural areas. Small-scale hydro will work in rural areas with dispersed populations, and is less environmentally detrimental than large hydropower facilities.
- *In the long term*: In the long term research and technical training for geothermal power and associated processes should be pursued. Geothermal energy has great potential as a renewable resource that could supply electricity to the entire country, and also generate enough energy to export for additional income. At the same time, however, the expansion of geothermal energy to rural areas will require the extension of the central grid to these areas, therefore significant planning for such major infrastructure construction will also be necessary.

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