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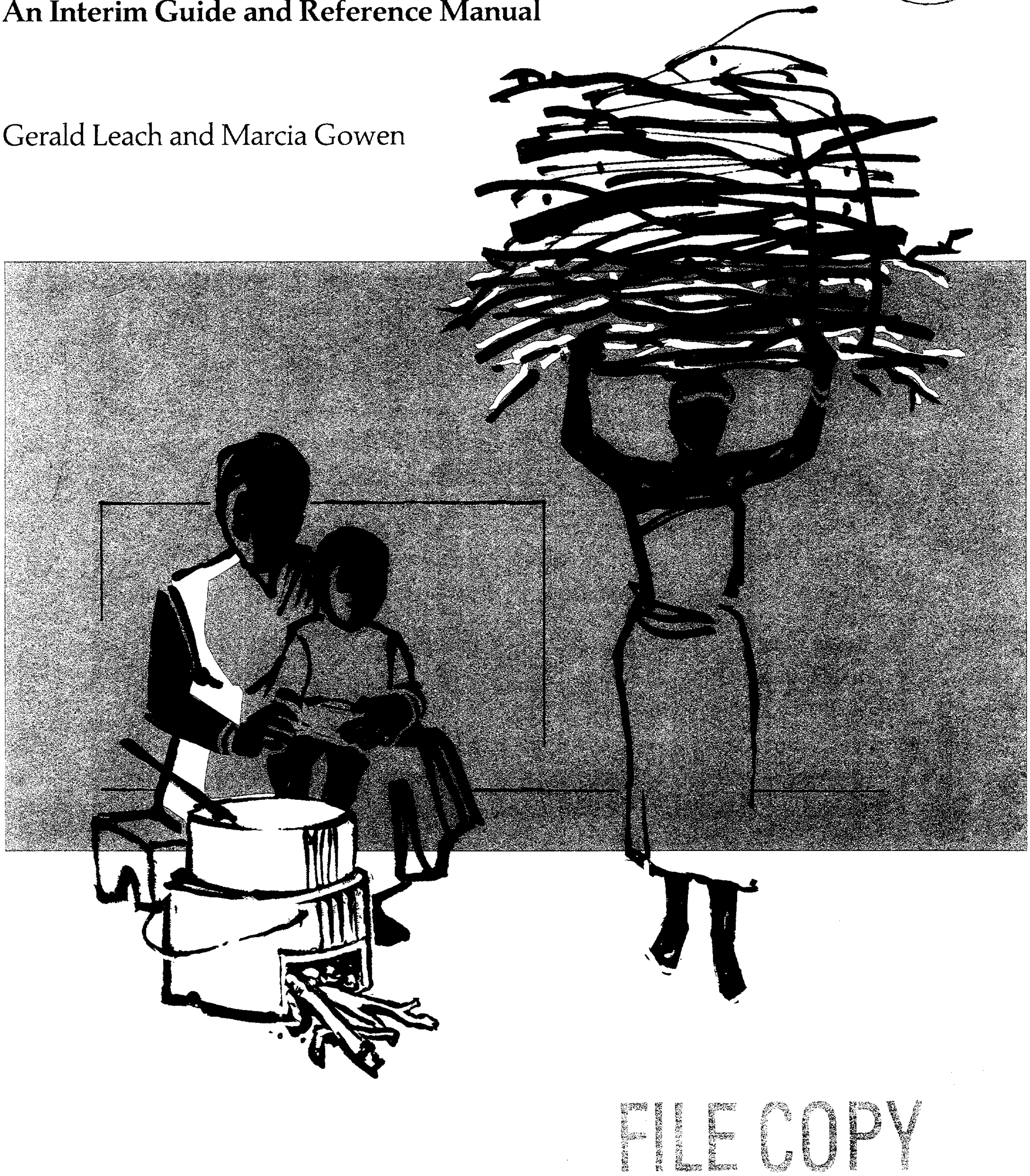
Household Energy Handbook

An Interim Guide and Reference Manual

Gerald Leach and Marcia Gowen



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An Interim Guide and Reference Manual

Gerald Leach and Marcia Gowen

under the guidance of
Richard Dosik, René Moreno,
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ABSTRACT

Traditional household fuels play a vital role in developing countries. More than two billion people depend on them to meet basic energy needs. Today many of these people are facing a deepening crisis of energy scarcity as local wood resources are depleted and more distant forests are cut down. The implications of this crisis extend beyond the supply of energy itself. As trees are lost, the land which provides their livelihood and feeds the nation may become more vulnerable to erosion and soil degradation. In some arid parts of the developing world this process has reached the terminal stage where the land produces nothing and starvation or migration are the only alternatives.

Much needs to be done to address the household energy problems of the developing countries. Household energy use must be made more efficient. Fuel substitution must be encouraged. Wood and other energy supplies must be augmented and priced affordably. However, to successfully implement these remedies requires a sound understanding of the basic supply and demand variables operating in the sector. These variables have been difficult to measure because traditional fuels are frequently not traded and because of the large variation in the availability and costs of energy supplies, in the levels and trends of consumption and mix of fuels employed, in end-uses, technologies, and energy-related preferences and modes of behavior.

A standard framework for measuring and assessing technical information on the household energy sector is needed to more adequately address these difficulties. This handbook is intended as a first step toward creating such a framework. Chapter I discusses energy terms and principles underlying the energy units, definitions, and calculations presented in the following chapters. Chapter II describes household consumption patterns and their relationship to income, location, and household-size variables. Chapter III evaluates energy end-uses and the technologies which provide cooking, lighting, refrigeration, and space heating services. Chater IV examines household energy resources and supplies, focusing on traditional biomass fuels. Finally, Chapter V demonstrates simple assessment methods and presents case studies to illustrate how household energy data can be used in different types of assessments.

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INTRODUCTION

Household energy has received increasing attention in recent years as the importance of the household sector in the energy balances of developing countries has become better understood and the problems of maintaining adequate supplies of household energy in many of these countries have become more critical. Still, information on household energy remains relatively scarce, interpretations of the data vary widely, and few non-specialists are familiar with the basic approaches to household energy analysis. This handbook is intended to assist in the understanding of household energy issues by presenting a standard framework for measuring and analyzing information on supply and demand in the sector. However, it is not exhaustive and does not pretend to provide the last word on a rapidly changing field of knowledge. Instead it is intended to serve as an interim guide and reference tool for practitioners and analysts, to be revised and updated as the state of the art changes.

The Importance of Household Energy in Developing Countries

Recent declines in international oil prices have reduced public interest in energy problems and have shifted the focus of national planning to more topical concerns. However, the economic and social costs of supplying energy in developing countries remain high, and the household sector in particular continues to pose major energy problems for many countries. Data from more than fifteen UNDP/World Bank country assessment reports show the household sector accounting for 30% to 99% of total energy consumption. The highest proportions are found in poorer countries where households depend almost exclusively on traditional fuels, 1/ the supplies of which are rapidly dwindling in many countries. Thus, while declining oil prices have eased the pressures of energy demand in the industrial sectors, these pressures continue to grow in the household energy sector.

As industrialization occurs and incomes rise, the proportion of total energy used by households declines to around 25-30%, as in the OECD and higher income developing countries. At the same time, urbanization and higher incomes lead to rapid growth in household consumption of

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1/ "Traditional fuels" refers to firewood, charcoal, crop residues and animal wastes. These are sometimes termed "biomass fuels" or "biofuels". They may be bought and sold ("commercialized," "monetized") or gathered without financial payment from the environment. Other energy sources, including coal, coke, kerosene, liquified petroleum gas (LPG), natural gas and electricity, are referred to collectively as "modern" or "non-traditional" fuels.

petroleum, electricity and other modern fuels. For example, in most developing countries the growth of electricity use by households exceeds 10-12% a year; and in a few, growth rates have exceeded 25% a year. Households are therefore a major contributor to the crises of capital, skills and foreign exchange deficits which beset many developing countries as they struggle to match their energy supplies to increasing demand.

Despite these trends, traditional fuels still play a vital role in most developing countries and will continue to do so for the foreseeable future. Some two billion people who depend on wood and other traditional fuels for their basic energy needs are facing a deepening crisis of energy scarcity as local resources are depleted and the more distant forests are cut down. The implications of this crisis reach far beyond the supply of energy itself. As trees are lost and people are forced to burn fuels that are taken from the fields, the land which provides their livelihood and feeds the nation may become increasingly vulnerable to erosion and soil degradation. In some arid areas of the developing world, this process has reached its terminal stages where the land produces nothing and starvation or migration are the only alternatives.

Recognizing the severity of the fuelwood crisis, the World Bank has increased the number of its projects dealing with social forestry, improved cooking stoves, charcoal production, and other aspects of biomass utilization. The direct linkage that exists between household energy consumption patterns and depletion of forest resources, loss of soil cover, and other environmental problems makes the analysis of household energy issues essential in evaluating these problems as well. This handbook, then, reflects the World Bank's increasing concern with these issues and its commitment to strengthening its analytical capabilities for dealing with them.

Characteristics of Household Energy

Compared with industry and commerce, the household sector has energy demand and supply characteristics which make assessment and project analysis at times difficult and unique. There are several critical differences between the household sector and other sectors.

First, the household sector consists of many individual users who live in a great variety of energy "landscapes." There is enormous diversity in the availability and costs of energy supplies; in the levels of consumption and mix of fuels employed; in end-uses such as cooking, water heating, space heating and lighting; and in technologies and energy-related preferences and modes of behavior.

Second, most household energy use is not recorded by supply agencies but must be ascertained through household surveys. This is so for the traditional fuels which dominate the household energy sector in most developing countries, since they are either collected or traded outside the monetary economy or bought and sold in a multiplicity of small markets. It is also true for anything but the most aggregate level of consumption for petroleum fuels such as kerosene and liquified petroleum gas (LPG or "bottled gas"), which are also bought at a myriad of retail outlets. Only with electricity and piped gas are there centralized and disaggregated records of household consumption, because these supplies are metered and billed.

Third, traditional fuels, especially in rural areas, represent only one aspect of the complex, interrelated systems for producing, exchanging, and using biomass materials of all kinds, including, for example, human food, animal fodder, timber and crop residues for construction materials, as well as fuels. "Energy" problems and solutions must almost invariably be considered within this total context. At the same time, there are no established market mechanisms in rural areas to bring supply and demand for traditional fuels into balance so that in many instances the depletion of biomass fuel resources continues unabated with severe impacts on other parts of the biomass system and on present and future household energy supplies. These impacts are usually most severe for the rural and urban poor, who are least able to adapt to the increasing scarcity and rising cost of resources.

Fourth, traditional household fuels and technologies for their use are often difficult to change, largely because alternatives are not known, there is no capital available to make use of alternatives, and households tend to prefer to continue with age-old customs.

These characteristics make it especially difficult to gather and assess basic energy data on the household sector. Furthermore, energy supply and demand patterns are location-specific. They normally vary considerably by region, district, village and town, and by household classes within towns. National energy studies must reflect these differences if they are to provide a valid basis for planning. Therefore these studies require a high degree of spatial and social disaggregation, which is extremely time-consuming and costly. The alternative of generalizing to the national or regional level from a few detailed surveys in some places may be quite misleading unless the survey sites are known to be representative. Such detailed studies are also time consuming. Consequently, there is a general lack of reliable energy data for the sector and, in particular, of comparable data for different time periods which can illuminate trends in energy demand and supply over time.

Purpose of the Handbook

The major purpose of this handbook is to assist those involved in energy demand or supply planning, national energy assessments, or project design for the household sector. To do this the authors have brought together from developing countries data on household energy consumption, resources, and technologies and, wherever possible, put them into a consistent framework. This has been a challenging task, partly because of the diversity of inputs mentioned above, and also because of the prevalence of unreliable or incomplete data. Although many bits and pieces of sound energy information exist, they are scattered through a vast literature and are often expressed in such a way that comparisons and integrations are difficult or impossible unless the information is reworked altogether. The Handbook is thus intended to provide a set of reference tools for conducting household energy analysis, and guidance on where to find this information and how to use it in energy assessments and project design. Before discussing these issues, two cautions are noted.

First, the extreme diversity of household consumption and supply patterns usually means that truth can only be found at the local level. Generalizations from these situations may often be necessary, but one should always recognize that they can be, at best, risky and, at worst, downright misleading. Consequently, the patterns and data described in this book are no more than signposts for what to look for in particular locations.

Second, energy studies often fail to reach behind the facts to the underlying questions and relationships. Why, for example, don't people plant trees when firewood is scarce and its collection takes up many hours a week? Who is able to respond to fuelwood scarcity? Are energy demands the main cause of tree loss? Unless such questions are examined carefully in each location where action is contemplated, that action will most probably fail. Over the past decade the experience of energy policies and projects that attempted to address the needs of families in developing countries has not been altogether a beneficial one. Project failures often can be traced to a lack of understanding of local conditions and the way people see their own priorities and options for action.

Organization of the Handbook

The Handbook is divided into five sections. Chapter I discusses basic energy terms and principles critical to understanding the energy units, definitions, data and calculations presented in the following chapters. Chapter II describes household energy consumption patterns and their dependence on key variables such as income, urban-rural location, and household size. Chapter III takes a close look at the end-uses of energy and the technologies which provide such services as cooking, heat, lighting, refrigeration and space heating. This initial focus on demand emphasizes the fact that energy supplies are required only to satisfy personal needs, and that families frequently respond both to demand and supply options in intensely personal ways.

Chapter IV examines household energy resources and supplies, focusing almost entirely on traditional biomass fuels, including tree growing and firewood, charcoal, crop residues and animal wastes. Non-traditional energy sources such as petroleum products and electricity are not discussed, since there is a vast and easily available literature on these topics.

Finally, Chapter V provides examples of simple assessment methods and case studies to illustrate ways in which household energy data can be put to work in energy, economic and technical assessments, and to warn of some methodological pitfalls.

CHAPTER I

ENERGY MEASUREMENT AND DEFINITIONS

A. OBJECTIVES AND STRUCTURE

This chapter explains and compares the main conventions of energy measurement in general use, paying particular attention to the traps and ambiguities which lie in wait in energy reports, surveys and statistics. Although experienced energy analysts may be familiar with much of the subject matter, they are advised to skim through the chapter to ensure that they understand which conventions are used in later chapters.

Section B below describes general measurement systems and discusses key definitions and terms of energy analysis. It also provides basic methods for adapting the definitions for one's preferred system of measurement. Section C focuses on some major analytical problems associated with end-use technologies, such as cooking stoves and lighting equipment, especially with measures of efficiency and utilized energy. Section D provides a brief guide to basic statistical techniques for assessing the validity of survey data.

B. BASIC MEASUREMENT CONCEPTS

Measurement Systems and Reference Data

The System International (SI) and British system are the most commonly used physical measurement systems. This book uses the SI system, as it has been adopted by most international agencies and many developing countries as well.

Production and Conversion Systems

All use of fuels (including electricity) involves a series of energy conversions, as shown in Table 1.1. Usually these conversions change the physical nature of the fuel, or the form of energy, in order to increase its utility. An example is the conversion of crude oil into kerosene, followed by the conversion of kerosene to heat in a cooking stove and finally into cooked food. Invariably some energy is lost to the environment during these conversion processes.

This concept is basic to energy measurement and to such important factors as the energy content of fuels and the efficiency of conversion processes. However, by comparing different stages in the production-conversion chain one can derive various definitions and

Table 1.1: Example of Energy Production-Conversion-Consumption Stages: Kerosene for Cooking

General Term for Stage	Form of Fuel or Energy	Conversion Technology	Comments
A. Resources, Reserves	Crude oil in ground		Estimates uncertain
Recoverable Reserves	Crude oil in ground		Varies with finds, technology, costs
B. Primary Energy a/	Crude oil extracted	Production well	Energy use, losses (e.g. gas flaring)
C. Secondary Energy	Kerosene	Refinery	Energy use, losses
D. Delivered Energy a/ (heat of combustion)	Kerosene (purchased by household)	(Distribution & Marketing)	Energy use, losses
E. Utilized Energy a/ for Cooking (PHU or % heat utilized	Heat absorbed by cooking food, etc. (cooked food)	Cooker and cooking pot, etc.	Delivered energy minus heat escaping around cooking pot, radiation losses from stove body, etc. See Figure 1.5.

a/ These terms are the most commonly used.

measures of these important values. Care therefore must be taken to use consistent definitions and to appreciate what definitions others are using before applying their results. To illustrate these points, Table 1.1 presents a simplified chain for the production of crude oil, its conversion to kerosene, and the use of kerosene in cooking. The terms used in this book for each stage are given in the first column. Some comments on each may be useful:

Resources and Reserves have various subdivisions to indicate the certainty of the estimates or the availability of reserves under different technological and economic conditions. For fuels such as oil, gas and coal the meaning of these terms is usually indicated clearly in reserve assessments.

Primary Energy is sometimes called Primary Production (UN), Total Energy Requirement (OECD) and Gross Consumption (EEC). It measures the potential energy content of the fuel at the time of initial harvest, production, or discovery prior to any type of conversion. It is often used for recording the total energy consumption of a country, which is misleading because it ignores the conversion efficiencies at which the fuel is used.

Secondary Energy is sometimes called Final Energy (EEC, OECD). It differs from Primary Energy by the amount of energy used and lost in supply-side conversion systems, such as oil refineries, power stations, biomass gasifiers, and charcoal kilns.

Delivered Energy is sometimes called Received Energy since it records the energy delivered to or received by the final consumer, such as a household. Examples are domestic kerosene purchases and firewood as collected and brought "to the doorstep." In most energy statistics, Delivered and Secondary Energy are the same for fossil fuels and electricity because Secondary Energy is estimated from sales to final consumers (i.e. Delivered Energy). Any (small) losses incurred in distribution and marketing are therefore included in the conversion from Primary to Secondary Energy.

Utilized Energy is sometimes called energy output, end-use delivered energy, or available energy. The term "utilized" is the most appropriate because we are measuring the amount of work or utilized heat to perform a specific task or service. The provision of these services is the ultimate purpose of the entire energy production and conversion system. Utilized energy may be as little as 5-8% of delivered energy with an inefficient conversion technology such as an open cooking fire, or as high as 95-100% of delivered energy in the case of electric resistance space heating.

Since utilized energy records the utility to the consumer of his or her consumption of fuel for any desired task, it is frequently used as the basis for comparing fuel prices (e.g. dollar ($) per MJ of utilized heat for cooking) and for examining the economics and energy savings due to fuel and technology substitutions (e.g., switching from open cooking fires to closed stoves).

However, the concept of utilized energy is sometimes difficult to apply. For example, if a cooking fire provides multiple end-use services--such as space heating and lighting, as well as heat for cooking--it is neither practical nor sensible to try to measure the utilized energy for each service. The same is true of lighting, where the distance from the light source to the user and the quality of light output (i.e., the spectral range) is at least as important to the amount of energy used or the consumer's motivations to switch technologies as any measure of utilized energy. For these reasons, it is often better to consider energy use and compare technologies in terms of specific fuel consumption for a particular task or time period: e.g., the amount of cooking fuel per standard meal or weight of staple foods, or the kWh of lighting electricity per household per day. These issues are discussed further in Section C.

Measurement Units

Four basic types of units are used in energy measurements and assessments:

> Stock energy units measure a quantity of energy in a resource or stock, such as the amount of oil in a reserve, kerosene in a can, or wood energy in a tree at a given point in time. Examples are: tons of oil equivalent, or multiples of the Joule (MJ, GJ, PJ). Although stocks may appreciate or decline over time, these changes are often most usefully given as stock units: e.g. for a growing fuelwood plantation, as the "standing stock" in units of weight or energy equivalent at the start of one year and of the following year.
>
> Flow or rate energy units measure quantities of energy produced or consumed per unit of time and are used for Primary, Delivered, and Utilized Energy consumption. Examples are: million barrels of oil per day (MBD), PJ/year, or MJ/day of cooking fuels. Frequently, the time unit is omitted: as when a country's (annual) primary energy consumption is given as so many million tons of oil equivalent (TOE). These units are the same as power units, e.g., kilowatts (kW).
>
> Specific energy consumption relates a quantity of energy to a non-energy value. It is often referred to as an energy intensity. Examples are: MJ per kg of cooked food, or MJ per unit of household income (MJ/$).
>
> Energy content or heating value measures the quantity of energy in a fuel per unit weight or volume. Examples are MJ/kg and MJ/litre.

Gross and Net Heating Values

The heating value (HV) of fuels is recorded using two different types of energy content--gross and net. Although for petroleum the difference between the two is rarely more than about 10%, for biomass fuels with widely varying moisture contents, the difference can be great. Unfortunately, the basis on which HVs are recorded is often omitted and one frequently finds both methods used for different fuels in the same report or energy survey.

Gross Heating Value (GHV), sometimes erroneously referred to as "higher heating value," refers to the total energy that would be released through combustion divided by the weight of the fuel. It is used in the energy statistics of the United Kingdom, the USA and many developing countries, and in many household energy surveys.

Net Heating Value (NHV), sometimes called the "lower heating value," refers to the energy that is actually available from combustion after allowing for energy losses from free or combined water evaporation. It is used in all the major international energy statistics (UN, EEC, OECD). Net values are strongly recommended and are used throughout this book.

The NHV is always less than GHV, mainly because it does not include two forms of heat energy released during combustion: (1) the energy to vaporize water contained in the fuel, and (2) the energy to form water from hydrogen contained in hydrocarbon molecules, and to vaporize it. A simplified view of the combustion process should clarify this difference:

Combustion Process Outputs

Fuel + Air: Combustion
1. Heat = NHV
2. Hot water vapor formed from hydrogen, including its latent heat of vaporization
3. Hot water vapor from contained water, including latent heat
4. Carbon Dioxide and monoxide, Nitrogen oxides, etc.
= GHV

Note: 1 = NHV
1+2+3+4 = GHV

Clearly, the difference between NHV and GHV depends largely on the water (and hydrogen) content of the fuel. Petroleum fuels and natural gas contain little water (3-6% or less) but biomass fuels may contain as much as 50-60% water at the point of combustion. It is also fairly obvious that few household combustion appliances can utilize the outputs labeled 2, 3 and 4. Consequently, on a net basis the energy value of a fuel reflects the maximum amount of heat that normally can be obtained in practice (i.e. output 1). On a gross basis the energy value overstates this quantity by the ratio GHV/NHV, or $\frac{\text{(Outputs 1+2+3+4)}}{\text{Output 1}}$.

Heating Values and Moisture Content

Annex 1 presents typical NHVs for the most common solid, liquid and gaseous non-biomass fuels. With solids there can be large variations in heating value due to differences in water, ash and volatile content. Liquid fuels have a much more uniform energy content but there are still slight differences due to refinery specifications and blending, etc. Local values should be used, if possible; otherwise the data in Annex 1 can be used for reasonable approximations. In any analysis, particularly when dealing with 'wet' fuels, the energy contents (NHV's) employed should be recorded clearly.

For biomass fuels special care must be taken to measure and record the water (moisture) content, wherever possible. The moisture content can change by a factor of 4-5 between initial harvesting and final use and is critical both to the heating value on a weight or volume basis and to differences between GHV and NHV. This section aims to clarify these concepts and provides conversion factors for the commonly used measures.

Moisture content can be given on a "wet" or "dry" basis. The basis should always be specified (although many reports omit this necessary information). Moisture content dry basis (mcdb) refers to the ratio of the weight of water in the fuel to the weight of dry material. Moisture content wet basis (mcwb) is the ratio of the weight of water in the fuel to the total weight of fuel. Both are expressed as a percentage. The respective formulae are:

$$\begin{array}{l}\text{Moisture content (\%)}\\ \text{Dry basis (mcdb)}\end{array} = \frac{\text{Water weight in fuel}}{\text{Dry weight of fuel}} \times 100$$

$$\begin{array}{l}\text{Moisture content (\%)}\\ \text{Wet basis (mcwb)}\end{array} = \frac{\text{Water weight in fuel}}{\text{Water weight + dry weight of fuel}} \times 100$$

$$= \frac{\text{Water weight in fuel}}{\text{Total weight of fuel}} \times 100$$

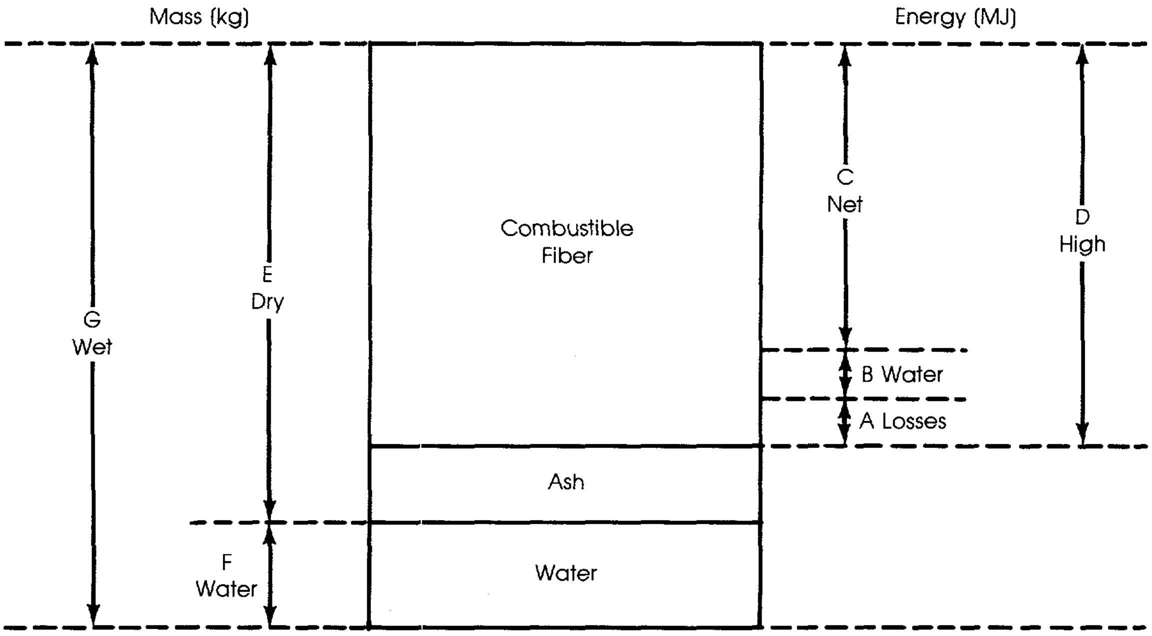
To convert between wet (W%) and dry (D%) basis the following formulae are used:

$$W = D/(1 + D/100) \qquad D = W/(1 - W/100)$$

This relationship between the several heating value definitions is graphically represented in Figure 1.1

Heating values of biomass fuels are often given as the energy content per unit weight or volume at various stages: "green," air-dried," and "oven-dried" material. They correspond to the following:

FIGURE 1.1: Relationship between Several Heating Value Definitions



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HEAT VALUE FORMULAE

High (Over-dry) Heating Value = $\frac{D\ (MJ)}{E\ (kg)}$

Gross Heating Value = $\frac{D}{E + F}$ $\frac{D\ (MJ)}{A\ (kg)}$

Net Heating Value = $\frac{C}{E + F}$ $\frac{C\ (MJ)}{A\ (kg)}$

MOISTURE CONTENT FORMULATE

Moisture Content Wet Basis = $\frac{F}{E + F}$ $\frac{F}{G} \times 100\ \%$

Moisture Content Dry Basis = $\frac{F}{E} \times 100\%$

Green refers to the living plant, or the plant at the point of harvest;

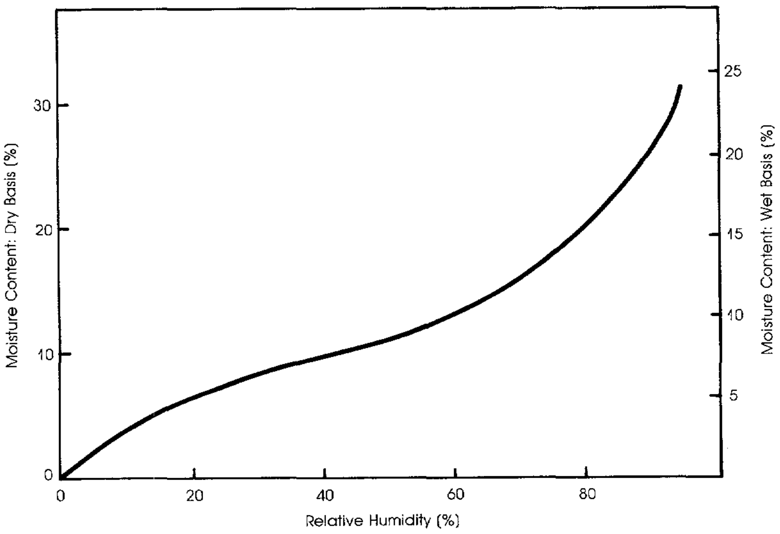
As received refers to the moisture content at a given point in the fuel chain.

Air-dried refers to the stage after the fuel has been exposed for some time to local atmospheric conditions; i.e. at any stage from harvesting to the conversion of the fuel either to another fuel or by combustion to heat energy.

Oven-dried means that a fuel has zero moisture content and is sometimes referred to as "bone dry."

Moisture contents of green and air-dried wood will differ depending on several factors including: (1) the species, (2) atmospheric humidity and hence climatic and seasonal factors, (3) drying time, and (4) drying conditions, including temperature and ventilation. In the humid tropics "green" wood may typically have a moisture content of 40-70% mcwb. After prolonged air drying this value will fall to 10-25% mcwb, depending on atomospheric humidity. (See Figure 1.2) Since many families keep a short-term stock of wood in the kitchen, and often close to the cooking fire, further drying may occur to give moisture contents as low as 10-20% mcwb. Typical values for the moisture content of wood as burned are in the 7-15% mcwb range. However, substantially higher moisture contents are found in zones or seasons of heavy rainfall and/or where wood is scarce so that the air-drying time between cutting and burning is reduced to only a few days (and in exceptional cases, as little as 24 hours).

FIGURE 1.2: Effect of Relative Humidity on Equilibrium Mositure Content of Wood



Source: Shaar (1972)

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The oven-dry (OD) heating value is an unambiguous measure of the energy content of the combustible material in solid fuels and is frequently given in reference data. [FAO 1983c; OTA 1980]. It is determined in the laboratory by weighing a sample before and after it is dried in an oven until the weight no longer changes, so that one can assume that all moisture has been driven off, and then measuring the heating value of the dried sample.

The procedure for converting the oven dry gross heating value to net heating value or gross heating value for any moisture content is fairly simple and accurate. Considering a 1 kg piece of wood containing W kg of water, the weight of oven-dry combustible material plus ash, etc., is (1-W) kg. Suppose that the oven dry gross heating value of this material is Z MJ/kg. Then the gross heating value of the wood sample is Z(1-W) MJ/kg. For the net heating value we must deduct the heat energy for the "hydrogen water" and "free water." Most oven-dry woody materials contain close to 6% of hydrogen by weight which would correspond to a hydrogen term of 1.3 MJ per kg dry material, or 1.3 (1-W) for the sample. For the free water, a value of 2.4 MJ/kg is frequently used. The "water term" is thus 2.4 (W). The net heating value of the wood sample in SI units (MJ/kg) is therefore: $Z(1-W) - 1.3\,(1-W) - 2.4\,(W)$. This reduces to $Z - 1.3 - W(Z+1.1)$.

To summarize, in SI units of MJ/kg the conversion formulae are:

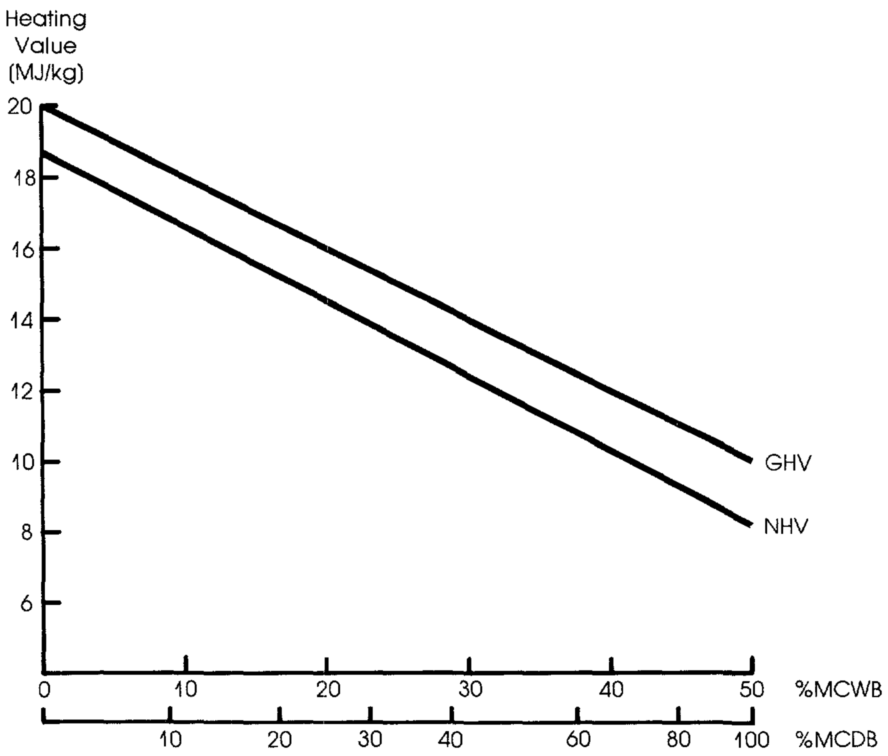
$$\text{NHV, wet basis} = Z-1.3 - (W/100)\,(Z + 1.1)$$
$$\text{NHV, dry basis} = (100Z - 130 - 2.4D)\,/\,(100 + D)$$
$$\text{GHV, wet basis} = Z(1 - W/100)$$
$$\text{GHV, dry basis} = Z\,(1-D/(100 + D))$$

where Z is the oven-dry gross heating value; and W and D are the percentage moisture contents on a wet and dry basis, respectively.

For easy reference, these values are plotted against moisture content in Figure 1.3, using a reference wood of 20 MJ/kg, oven-dry gross heating value.

This reference value is a reasonable first order approximation in the absence of actual measurements. Tests on 111 species of tropical fuelwoods from Africa, Asia and South America obtained an average of 20.0 MJ/kg (oven-dry GHV) with a standard deviation of under 0.6 MJ/kg, or less than 3% of the mean value. [Doat and Petroff, 1975] The lowest value was 18.4 MJ/kg and the highest 22.0 MJ/kg. These differences are less important than variations due to moisture content, as Figure 1.3 makes clear. However, some fuelwoods with a high ash or silica content such as bamboo and coconut have lower values of about 17 MJ/kg (oven-dry GHV), while resinous woods such as the American pine species have values in the 24-28 MJ/kg range.

FIGURE 1.3: Heating Values for Wood as a Function of Moisture Content (for "reference" wood of 20 MJ/kg oven-dry, gross heating value)



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These values refer to "large" pieces cut from the trunk or main branches. For small branches and twigs, which are widely used as fuels by the poor, heating values tend to be both lower and more variable than for stemwood from the same species. Typical values are not as well recorded as they are for stemwood but one series of tests in South India found a mean value of 17.4 MJ/kg (oven-dry GHV) for 15 species with a standard deviation of only 0.2 MJ/kg. [Reddy 1980]

However, it is a reasonable practice to use 20 MJ/kg oven dry if no original measured data are available for the wood concerned and there is no basis for believing that a markedly lower or higher value obtains. If the design of combustion systems is involved, then actual heating values should be obtained through laboratory analysis.

Volume, Density and Moisture Content

Fuelwood resources, production and consumption are often reported in volume terms. This is the usual practice among foresters, since timber is normally sold in units of volume -- usually as the actual (or "solid") volume of the wood. Frequently, and especially in informal markets and household surveys, the only record of fuelwood quanitites produced, sold or consumed is a volume measure based on the outer dimensions of a loose "stack" or load containing air spaces between the wood pieces, such as the stere, cord, truckload, headload or bundle.

To use such measures for energy analysis, two approaches can be taken. The first is to convert stacked volume to a weight and then proceed as outlined above. This can be done for small loads by weighing a number of samples with a spring balance; or for a large load (e.g., truckloads) by use of a weighbridge. The second approach is to convert stacked volume to solid volume. This can be done for small loads by immersing them in water and measuring the volume of water displaced. If direct measurements are impractical, local conversion factors or "rules of thumb" must be used: these are usually known by foresters, fuelwood truckers, wholesales and retailers, etc. No general guidelines can be given here since both conversions (stacked volume to weight, stacked volume to solid volume) vary greatly by location.

If it is not possible to convert volumes to weights, for energy analysis the volumes of fuels have to be converted to a volumetric measure of energy content. To do this, a series of three conversions is often required. These are described below. However, one should first note that the "basic density" and the specific gravity of wood are always reported on an oven-dry basis. For consistency, the conversion formulae are based on weights in kilograms (kg).

1. Conversion of oven-dry volume to oven-dry weight

$$\begin{array}{lclcl} \text{Oven-dry weight (ODW)} & = & \text{Volume} & \text{x} & \text{Basic density} \\ \text{(kg)} & & (\text{m}^3) & & (\text{kg/m}^3) \end{array}$$

and since

$$\begin{array}{lclcl} \text{Basic density} & = & \text{Specific gravity} & \text{x} & 1000 \\ (\text{kg/m}^3) & & \text{of dry matter} & & \text{(gm/kg)} \\ & & (\text{gm/cm}^3) & & \text{(kg/ton)} \\ & & (\text{tons/m}^3) & & \end{array}$$

then

$$\text{Oven-dry weight (ODW)} = \text{Volume} \text{ x } \text{Specific gravity} \text{ x } 1000$$

2. Conversion of oven-dry weight to actual weight for specific moisture content

   Actual wet weight = ODW/(1-W/100)

   where W is the percentage moisture content, wet basis (mcwb).

3. Conversion of actual wet weight at specific moisture content to net heating value, given the oven-dry value

   Use actual weight and the formulae given on page 14 for heating value per unit weight. These formulae can be combined to give a single formula for converting

   from: Volume (V), basic density (BD), oven-dry gross heating value (Z), and percentage moisture content wet basis (W)

   to: the net heating value (NHV), as recommended and used in this book.

   NHV (of given volume)

$$\text{NHV} = \frac{V \times BD}{1 - W/100} \times (Z - 1.3 - (W/100) \times (Z + 1.1))$$

   where volume is in m^3, weight is in kg, and energy is in MJ.

The critical importance of correctly applying all the concepts discussed above deserves illustration with an actual example of a fuelwood production and delivery chain.

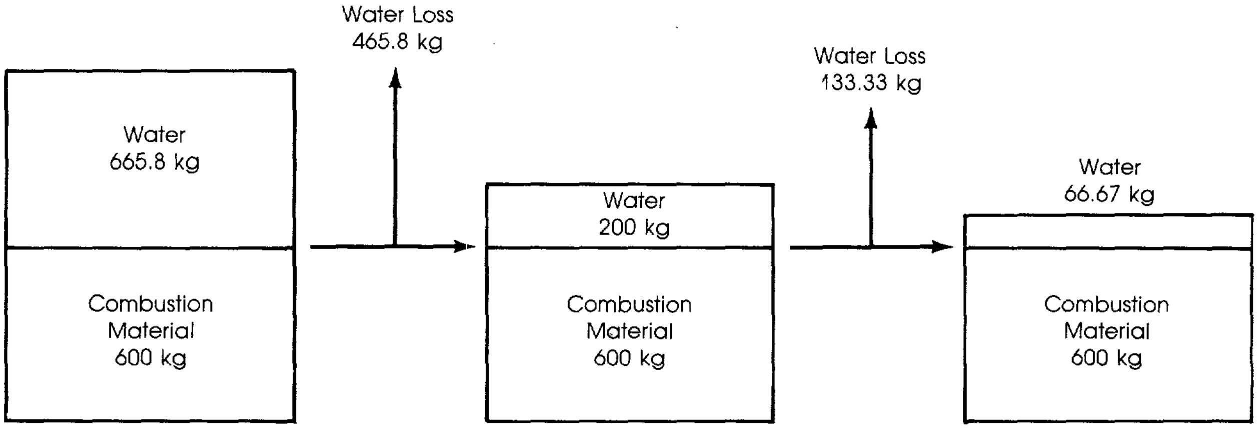
The starting point of the chain in this example is one solid m^3 of green wood at the point of harvest weighing 1,265.8 kg. (See Figure 1.4). The basic density of the material is 0.6 (600 kg/m^3) and the oven-dry energy value is 20 MJ/kg. The moisture content (mcwb) is 52.6%. Consequently, the volume of combustible material is one m^3 and its weight 600 kg.

The wood is air-dried in two stages: between harvesting (primary energy) and its purchase by a household (delivered energy); and between this stage and its use in a cooking fire (delivered energy at the point of use). Figure 1.4 records at each stage the values of volume, weight, moisture content, actual density, and total energy measured in gross and net heating values (GHV and NHV).

As one would expect, since water is lost between each stage, the weight, density, and moisture content decrease progressively. 2/ However, this is not so for the net heating value or for the total energy content of the sample on an NHV basis.

2/ Volume also decreases slightly with drying, by about 5% in the example shown. [FAO 1983 c]. Figure 1.4 assumes a constant volume.

FIGURE 1.4: Changes in Physical Quantities during States of Air-Drying Fuelwood



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"ENERGY STAGE"	Harvest Primary	Point of Sale Delivered	Point of Use Delivered (point of use)
Volume (m^3)	1	approx. 1	approx. 1
Weight (kg)	1,265.8	800	666.67
Density (kg/m^3)	1,265.8	approx 800	approx 666.67
Moisture			
content (mcwb)	52.6%	25%	10%
Content (*mcdb)	111 %	33.3%	11.1%
TOTAL ENERGY (MJ)			
GHV basis	12,000	12,000	12,000
NHV basis	9,620	10,744	11,060
(NHV MJ/kg)	(7.50)	(13.43)	(16.59)

<u>Basic Data</u>: Basic density: 600 kg/m^3
Oven-dry gross heating value: 20 MJ/kg

On a GHV basis, both the heating value (MJ/kg) and the total energy content of the sample (MJ) remain constant.

Using a NHV basis, the heating value and the total energy content of the sample <u>increase</u>. This is not a case of creating energy out of nothing, since the energy content in question refers to the heat that can be usefully extracted from the fuel in a device such as a cooking fire. This is so much greater per unit weight for dry wood than wet wood, that it more than compensates for the loss of weight due to drying.

C. UTILIZED ENERGY, EFFICIENCY AND SPECIFIC FUEL CONSUMPTION

The delivered energy content of a fuel measures the potential heat available from it. When the fuel is used for a specific end-use task such as cooking food, only a fraction of this energy is usefully employed for that task. This quantity is called the utilized energy (for that specific task). The fraction of the energy utilized defines the efficiency of the end-use device (for that task): Efficiencies are usually defined in terms of delivered energy but can also be given on a primary energy basis. In the first case:

$$\begin{array}{l} \text{Efficiency for task} \\ \text{(Delivered Energy basis)} \end{array} = \frac{\text{Energy utilized for task}}{\begin{array}{l} \text{Energy delivered to conversion} \\ \text{device for task} \end{array}}$$

For household applications, stove or appliance efficiency is commonly referred to. This is the utilized energy efficiency, expressed as Percentage Heat Utilized (PHU).

This seems simple enough. However, few energy conversion devices--least of all cooking fires and stoves plus cooking equipment--are simple in terms of their energy flows. Still less are they simple in the way in which people use them. The critical importance of correctly measuring efficiency and utilized energy for the household sector demands that we examine these concepts carefully.

Primary and Delivered Energy Efficiencies

This topic is relatively simple. It is demonstrated in Table 1.2, which compares the primary and delivered energy requirements of a wood fire, a kerosene stove, and an electric cooker which perform the same task of providing 10 units of utilized energy for cooking.

The table shows that although the electric cooker has the highest delivered to utilized efficiency, it has the lowest primary to utilized efficiency and hence consumes the most primary energy of the three cooking methods. If electricity is generated from oil, more oil would be consumed than with the kerosene cooker. For the consumer, it is the delivered to utilized energy efficiency that matters since this determines the energy cost for the task: i.e., delivered energy (MJ) x unit price ($/MJ).

Table 1.2: Primary and Delivered Energy Consumption and Efficiencies for Three Types of Cooking Devices

	Wood Fire a/	Kerosene Stove	Electric Cooker
Primary energy (PE) a/	67	37	56
Conversion efficiency: Primary to Delivered b/	1.15 (air drying)	0.9 (refinery)	0.30 (generation)
Delivered energy (DE) a/	77	33.3	16.7
Conversion efficiency: Delivered to Utilized = UE/DE	0.13	0.30	0.60
Utilized energy (UE) a/	10	10	10
Conversion efficiency: Primary to Utilized = UE/PE	0.15	0.26	0.14

a/ Energy values in units to cook an arbitrary unit quantity of food.

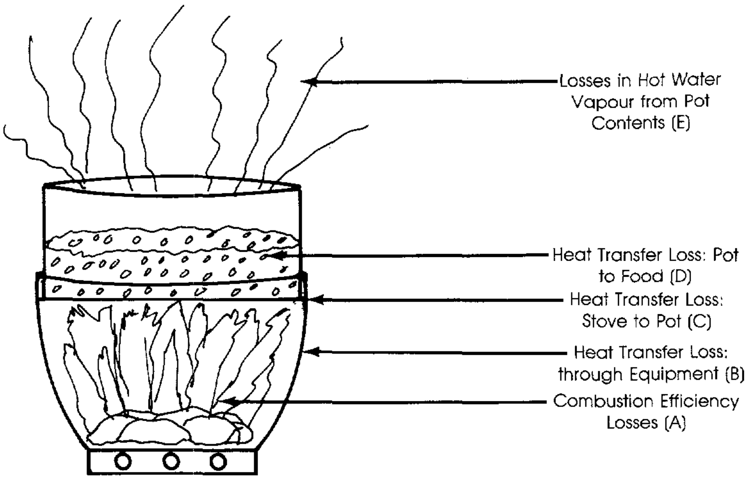
b/ Excludes transmission and transport.

Definitions of Efficiency

When fuel is burned its energy is usually transferred to the end-use task in several stages. Energy losses of various kinds occur on the way. Measures of efficiency and utilized energy therefore depend critically on the stage at which the heat flow is measured: for example, with a cooking stove and pot, whether one measures the heat from the stove opening, the heat absorbed by the pot, or the heat absorbed by the food.

This point is illustrated in a highly simplified way in Figure 1.5. In practice, the energy flows and losses are much more complex than this so that it is often difficult to determine what definitions of utilized energy and efficiency are being used when different technologies are assessed. Since different definitions can greatly affect the reported results, efficiency and utilized energy should be used with caution. Alternatively, one should rely on less ambiguous measures such as the specific fuel consumption of a particular end-use appliance and task; i.e. a measure of the fuel actually used for a process such as cooking a particular foodstuff or meal in the actual environment where some intervention is planned.

FIGURE 1.5: Energy Losses during Cooking With a Stove and Pot



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In order to compare technologies (see Chapter III), some distinction has to be made between the various measures of efficiency. In this book three basic terms for efficiency are used 3/:

a. Combustion Efficiency allows for energy losses in the combustion process and heat that does not reach the point where it could, in theory, be transferred to the the final task (e.g. A and B in Figure 1.5).

$$\text{Combustion Efficiency} = \frac{\text{Heat Generated by Combustion (MJ)}}{\text{Delivered Energy of Fuel (MJ)}}$$

b. Heat Transfer Efficiency allows for energy losses between the combustion outlet and the end-use task, especially heat transfer and radiation losses (C, D and E in Figure 1.5).

$$\text{Heat Transfer Efficiency} = \frac{\text{Energy Absorbed by End-use Task (MJ)}}{\text{Heat Generated by Combustion (MJ)}}$$

c. System or End-use Efficiency is the product of the Combustion and Heat Transfer Efficiencies, or the overall efficiency. It is often referred to as conversion, gross, thermal and end-use efficiency.

3/ One sometimes finds the terms "net" or "Second Law" efficiency in the energy literature, especially in reports on household energy conservation. This is a source of much confusion. It refers to the thermodynamically minimum amount of delivered energy required to perform an end-use task. This is invariably much less than that for any practical device. Its use is not recommended since it is of little practical value in any consideration of actual technologies.

d. Percentage of Heat Utilized (PHU) is the energy utilized and expressed as a percentage of that available at any stage in the energy conversion process. The overall PHU is commonly referred to as appliance (e.g. stove) efficiency.

Specific Fuel Consumption, Energy Intensity, and Fuel Economy

The previous section discussed the difficulties in defining critical terms such as efficiency and utilized energy, even in controlled laboratory tests. These difficulties are greatly increased when one considers real life conditions.

In real life, cooks may light the cooking fire or stove well before they begin cooking. They may or may not quench the fire when cooking is finished. They cook a variety of meals, each using their own methods. Pot lids may be left on or taken off when simmering food. Equally important, the cooking fire may well serve multiple purposes, including space heating, water heating for washing or cleaning dishes and clothes, lighting, or a social focus. A recent survey of Maasai households in Tanzania, for example, found that the cooking fire was typically kept alight for about 16 hours a day, with widely varying rates of combustion and fuel use, in order to provide all the end-use services just mentioned [Leach 1984].

In these real circumstances, estimates drawn from laboratory tests of utilized energy and end-use efficiency are of limited value. Broader and looser measures based on actual observations of energy consumption for a class of end-use tasks should be used instead. These measures include specific fuel consumption (SFC) and energy intensity. Some examples are:

Cooking:	MJ per meal; MJ per person per meal: MJ per kg food cooked; MJ per household per day (for cooking).
Lighting:	MJ per lamp per day (allowing both for rate of consumption--watts, liters kerosene/hour--and for time period used--MJ per household per day (for lighting).
General:	MJ of woodfuel per household per day (used for inseparable end uses, including cooking and heating).

These measures can be used for assessing changes in technology and fuel just as effectively as measures of end-use efficiency or utilized energy. Of course, if a more efficient technology is introduced the specific fuel consumption is likely to fall. But it may not fall as expected from a direct comparison of the before and after efficiencies: the users may employ the new technology in a different manner from the old one, for example. Only a before and after comparison of specific fuel consumption can capture such effects. An example of its use in technology and fuel substitution is given below:

> Example: Substitution of cooking pot and cooking heat source:
>
> A family cooks on an open fire using clay pots (Technology 1). The kitchen is outside the house and cooking is the only service provided by the fire. Consumption of firewood is measured over a period. Further measurements are made of firewood energy consumption, over different periods of time, when the family uses (2) an aluminum cooking pot with the open fire, (3) a metal stove with a clay pot, and (4) a metal stove and aluminum pot.
>
> After normalizing the consumption for Technologies 2, 3 and 4 to the same time period as for Technology 1, the energy consumption levels in MJ are found to be:

Technology	Consumption MJ	 kg a/	Ratios
1. Open fire, clay pot	1667	83.4	4.0
2. Open fire, aluminum pot	833	41.7	2.0
3. Stove, clay pot	555	27.8	1.33
4. Stove, aluminum pot	417	20.9	1.0

a/ Based on a conversion ratio of 20 MJ/kg.

The consumption ratios give an unambiguous reading of the relative fuel consumption and savings in moving from one technology to another (for this family). For example, a 66% savings is achieved by switching from Technology 1 to Technology 3. Note particularly that it is not necessary to estimate either the utilized energy for cooking or the efficiencies of each technology package. Indeed, the relative fuel consumption for each technology option may well not be the same as the relative end-use efficiencies recorded independently of the household environment, since in moving from one technology to another the family may alter its cooking methods, time for cooking, etc.

In summary, efficiency and utilized energy are basic and invaluable tools for people who are designing and developing technologies. Efficiency measures are also important for comparing and marketing technologies: they provide an unbiased and standarized performance yardstick for each technology--an "energy label". They are also valuable for the energy planner and analyst when more direct data on the actual fuel consumption of real households is not available: as a first order approximation, one can assume that the fuel consumption of Technology A will differ from that of Technology B according to their relative end-use efficiencies (when used for the same tasks by similar classes of household). However, this assumption can be misleading, as we shall see in Chapter III where the substitution of kerosene by electricity for lighting is discussed. Wherever possible, actual consumption data and the concepts of specific fuel consumption or energy intensity should be used for broad household energy assessments.

D. BASIC STATISTICS

Data Validity

Most quantities related to household energy use show substantial variation, for example, between households or in the same household from day to day. Although the average (mean) of any such collection of data is a useful figure, it is rarely sufficient. One usually also needs an indication of the degree of certainty associated with the average. This is particularly important when comparing two sets of data, such as the energy consumption of a cooking stove and the traditional fire that it is intended to replace.

To illustrate a typical situation where such an exercise would be desirable, Table 1.3 below gives two sets of data on firewood use for cooking, derived from field tests in 13 households in South India. One set is for clay cooking pots, the other for aluminum pots. On average, cooking with aluminum pots seems to require about two-thirds as much fuel as with clay pots: the averages for each sample are 0.99 and 1.50 kg respectively. However, there is a large spread in consumption in each case. In order to establish whether this observed difference is statistically significant we would need to establish the certainty associated with the average values. This is called "analysis of variance" and is used to test hypotheses. For example, the hypothesis might be that the average consumption for each type of pot is indeed different. The test is then used to accept or reject the hypothesis.

Table 1.3: Specific Firewood Consumption for Clay and Aluminum Pots
(kg wood per kg food cooked)

	Predominant pot type	
	Clay	Aluminum
Original data (13 measurements)	1.87	0.69
	1.45	1.97
	0.90	0.91
	1.60	0.68
	1.67	0.53
		1.41
		0.88
		0.85
Mean weight =	1.50	0.99
No. of observations (N)	5	8
Standard deviations (SD)	0.367	0.475

Source: Geller and Dutt [1983].

With analysis of variance one could conclude from the above sample, with 95% certainty, that the average firewood consumption for a large population using clay pots lies between 1.05 and 1.95, and similarly that the 95% confidence interval for the aluminum stove would be between 0.60 and 1.38. Since these intervals overlap we cannot be 95% certain that average firewood consumption with the two types of pots is indeed different.

Even if the above intervals had not overlapped, we would only be able to place as much significance on the results as the reliability of the sample figures themselves. In other words, one should not let the mathematics produce a false sense of reliability in the conclusions beyond the reliability of the data itself.

Elasticities

The use of "elasticities" is common in the household energy literature. An elasticity indicates the quantity by which one (dependent) variable changes when a second (independent) variable is changed by a unit amount. For example, an electricity-income elasticity of 0.8 for the household sector indicates that domestic electricity consumption increases by 0.8% for each 1% increase in household income, when other factors are held constant. An electricity-price elasticity of -0.3 means that consumption falls by 0.3% for every 1% increase in electricity prices (other factors remaining constant). The following equation links electricity consumption to income and price using these elasticities.

$E = A \times I^b \times P^c$ (or in the above case: $E = A \times I^{0.8} \times P^{-0.3}$)

where E is electricity consumption, I is income, and P is electricity price; A is a constant; and b and c are the income and price elasticities of electricity consumption, respectively.

The above relationship between consumption and price is known as the own-price elasticity of demand since it reflects the extent to which demand for a particular fuel would change in response to a change in its own price. However, because households can substitute a number of different fuels to meet their household energy needs, changes in the price of a particular fuel will affect the consumption of other fuels as well. This effect is known as the cross-price elasticity of demand; it represents the percentage change in consumption of fuel A as a result of a 1% change in the price of fuel B.

We can represent this relationship mathematically by an equation:

$$F_A = AI^{b} P_A^{d1} P_B^{d2} P_C^{d3} \cdots P_G^{d7}$$

where A is a constant, I the income level, P_i the price of fuel i and F_A the consumption of fuel A. Then b would as before represent the income elasticity of demand for fuel A and d1 the own-price elasticity of demand for fuel A, while d2, d3,....d7 would be the respective cross-price elasticities of consumption of fuel A with respect to the prices of fuels B, C,...G. While d1 (the own-price elasticity) will in general be negative, d2 through d7 (the cross-price elasticities) will generally be positive, since an increase in the price of fuel B is likely to lead to an increase in the consumption of fuel A.

Studies have shown that cross-price elasticities (and therefore relative prices) are important in explaining shifting consumption patterns of the various household fuels. For example, a study in Syria found that, contrary to what might be expected, household kerosene consumption has been decreasing in recent years in the face of falling real kerosene prices (see Figure 1.6). [UNDP/The World Bank, 1986]. However, during the period under question, real LPG prices had been decreasing more rapidly than that of kerosene, creating an effective increase in the price of kerosene relative to LPG. Not surprisingly then, the consumption of LPG increased over that period. Thus, it is important to consider the own-price and cross-price effects when analyzing the consumption patterns and projections of the various household fuels and prices.

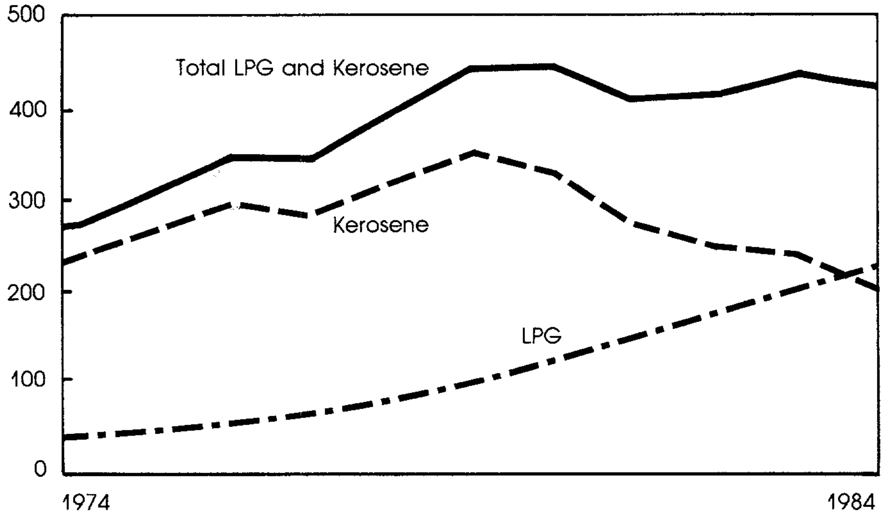
Elasticities, when mathematically part of a homogeneous relationship as above, can be estimated by "regression" of the basic data. Regression methods are explained in most introductory texts on statistics.

Two important measures are normally given with elasticity estimates of this kind to indicate the statistical uncertainty associated with the reported value: The "adjusted coefficient of determination" (adjusted R^2) measures the proportion of the variance or "spread" in the dependent variable "explained" by the independent variables and adjusted for the degrees of freedom. The maximum value is 1. Thus, if the regression of electricity consumption on income and price has an adjusted R^2 of 0.9, it indicates that income and price account for about 90% of the observed differences in electricity consumption.

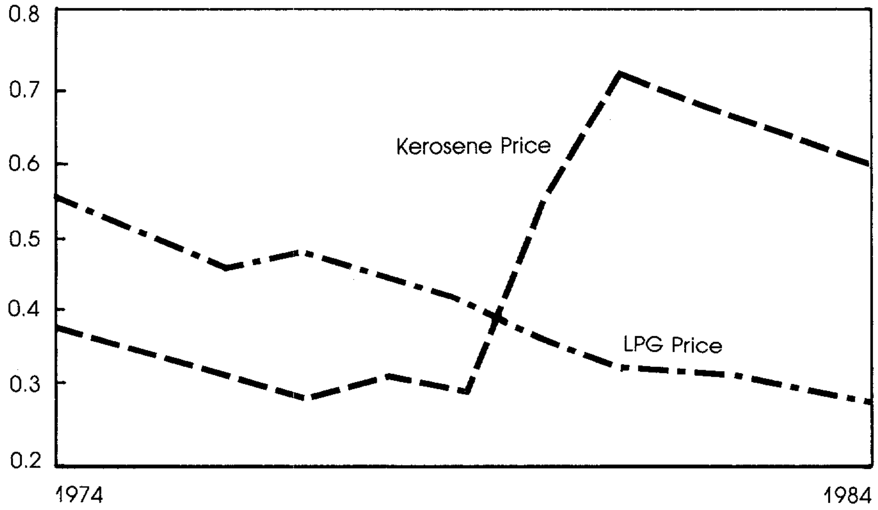
The t-statistic indicates the reliability or statistical significance that can be placed on the reported elasticity. It equals the value of the estimated coefficient (elasticity) divided by its standard error. The larger the t-statistic, the more "reliable" is the estimate of the coefficient. Roughly speaking, if the t-statistic is less than 2.0, the coefficient has little explanatory power and should be ignored.

FIGURE 1.6:

Household Kerosene and LPG Consumption
(Thousand Tons)



Comparison of Real Price of Kerosene and LPG
(1980 SL per liter)



Source: UNDP/World Bank (1986).

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CHAPTER II

HOUSEHOLD ENERGY CONSUMPTION

A. OBJECTIVES AND STRUCTURE

Households use energy for many purposes. How much they consume and the types of fuel they use depend on a variety of factors. These include issues of supply such as the availability of fuels and the personal or cash costs entailed in obtaining and using them. But they also include many factors which can only be understood well by looking at the needs and behavior of energy consumers. A major objective of this chapter is to show why an understanding of household energy must be rooted in a sensitive approach to issues of demand as well as those of supply.

The second main objective is to describe and attempt to explain the enormous variety of household energy consumption patterns that is found across the developing world. These patterns usually differ greatly not only between countries and national regions but even between locations only a few miles apart. In most cases, remedies for fuel supply and demand problems have to be based on a good understanding of local conditions and the key variables that affect the levels of demand and types of fuels that are used.

Section B takes up these issues by describing the major sources of data on household energy consumption and what they can--and cannot--tell one about present demand patterns and their likely evolution over time.

Section C examines the major variables that determine the level of household energy consumption and types of fuel used, such as income, rural and urban location, and household size. One aim of this section is to highlight the intricate and personal nature of many household energy choices.

Section D gives an overview of the typical responses of rural families to increasing fuel scarcity and compares them to the reactions of urban households. This provides a useful framework for considering household energy demand and supply issues.

Section E provides a brief introduction to energy end-uses, such as cooking, heating and lighting, by discussing their relative importance in total household consumption. The more detailed examination of end-uses and end-use technologies is deferred to Chapter III.

B. DATA RESOURCES

Within any country there may be four main types of data sources that provide information on household energy use and related variables. Their quality varies widely and each has its own advantages and limitations.

National Energy Balances

Most countries have energy balances which record domestic production, trade, conversions and losses, and delivered energy consumption for the major types of non-traditional energy. Usually these energy balances are developed on a regular, annual basis but they may exist for only a few sample years. Final consumption is broken down in greater or lesser detail by major sector. Data on energy prices sometimes are included.

At the present time, most energy balances are based only on supply data. This has two serious drawbacks for making assessments of the household sector. First, it is difficult from the supply side to separate household consumption from that of the commercial sector (shops, hotels and restaurants, artisanal workshops, etc.) and public sector. So households are often grouped with these sectors. Even if they are not, they are almost invariably treated as a homogeneous unit with no breakdowns by crucial energy-related variables such as urban-rural location, income, or sub-region. Second, the consumption of traditional fuels--if they are included at all--will be very approximate. As mentioned in the introduction, traditional fuels are either collected from the local surroundings or traded in "unofficial" markets. The only way to determine the quantities involved is by taking (local) surveys of household and fuel trading practices. Although many such surveys have been conducted across the developing world, few of them have been large enough or carefully enough prepared to provide reliable estimates of national or sub-regional consumption of traditional fuels. Without such surveys, national energy balances are of little value for assessing time trends in household energy use.

National Budget Surveys

The few nationally representative surveys that have been conducted are usually undertaken by the national statistical office or finance ministry to determine the patterns of household expenditure or demographic, educational, and other socio-economic factors. Since these are important measures for economic analysis and planning, the survey samples are usually large--often around 10,000-20,000 households--and truly representative of regional, urban-rural and income differences.

National surveys are normally the only statistically valid sources of data on household energy consumption and related variables.

However, the richness and reliability of the energy data they provide varies considerably. For example:

a. Information is normally based on respondents' recollections of expenditures over a recent period, such as the preceding week. With electricity and piped gas, billing data is normally used so that estimates are reasonably good. With all other energy sources there are obvious risks that respondents either underestimate or overestimate their expenditures. If they do both equally, the average for each group should be fairly reliable. However, there is evidence that for various reasons respondents may consistently bias their answers one way or the other. 1/

b. Budget surveys rarely include information such as indications of fuel availability or abundance/scarcity, energy prices, or ownership and type of energy-using equipment. Their value as tools for technical energy assessments therefore is limited.

c. Large, nationally representative surveys are rarely conducted more frequently than every five years or so due to their high cost. With each survey the range of data collected and sampling procedures may change. Therefore it is rare to find consistent time series data on consumption in relation to key variables.

d. Budget surveys usually include "expenditures" on non-marketed, gathered fuels by converting estimates of consumption in physical terms into cash equivalents using an imputed price. These expenditures are, of course, imaginary. Furthermore, the imputed price may not be published, so one cannot work back to physical quantities. However, this imputed price can usually be obtained from the originators of the survey.

e. Care must be taken in converting expenditure data for electricity and gas to consumption in physical units because tariff structures usually create different unit prices for small and large consumers. If the tariff structure is known, the conversion can be made fairly simply.

1/ In a survey of 180 households in Central Java, people estimated how much wood they consumed. Consumption was also weighed. The ratio of estimated/weighed consumption ranged from 0.28 to 2.2, using average results for 32 sub-groups based on village and household size. Yet the ratio for the whole sample was 0.95, or very close to unity [Kuyper and Mellink 1983]. This "balancing out" of individual differences is not found in all surveys and should not be relied on.

National Energy Surveys

In some countries (or provinces, states, etc.) relatively large, representative surveys have been conducted specifically to measure household energy consumption in relation to major variables. These variables include types of energy using equipment, measures of fuel abundance or scarcity, and whether fuels are gathered or purchased, etc. The surveys have varied objectives and differ greatly in the quality and range of data collected and analyzed. Nevertheless they can be an invaluable resource for energy assessments.

When examined in relation to each other, these surveys provide a considerable body of information which can be used to improve the design of future surveys. Recent publications have begun to compare and analyze the experiences and methods used in the various energy surveys. These comparative publications are very useful reference sources for designing new surveys and interpreting their results (e.g. Howes, 1985).

Local "Micro" Surveys

Much of the good quality data on household energy use in developing countries has come from small-scale "micro" surveys. These usually cover a maximum of 300-500 households in 10-20 villages but may only cover 5-10 households over a few days. Within a limited budget, the relatively small samples allow careful quantitative measurements of consumption and related factors, although this is not always the case. One particularly valuable feature of these surveys is their coverage of qualitative variables such as attitudes to existing energy-related problems. Indeed, the main objective of these surveys often is to understand the social, anthropological and micro-economic complexities of household energy demand and supply.

Valuable information and insights can also be gained from "micro" village or urban studies by social scientists: anthropologists, sociologists, argicultural economists, and the like. These studies do not focus on energy exclusively but nevertheless contain a lot of information on demand and supply, and critical linkages in the system. For example, linkages between the fuel resources system and the total biomass system of village economies may be revealed, as well as linkages between the labor and other demands of fuel collection and cooking, and other household activities. Any planner working in these areas should always attempt to find these studies.

Although local surveys and studies can be rich and reliable sources of information, they generally suffer from four problems:

a. The quality of data is not always good. Fuel consumption in particular often is recorded in terms of weights without any record of moisture content or measured heating values. Conversions to energy quantities therefore must be fairly rough and ready.

b. Most surveys focus only on fuel consumption and ignore critical supply factors, such as local stocks of trees or flows of crop residues, which may be the most important determinants of consumption levels and the mix of fuels employed. Crucial questions of access to--and hence the availability of--different forms of fuel by various socio-economic classes (e.g., the landless, non-farm laborers, small, medium and large farmers) often also are ignored.

c. Surveys of the same locality at different points in time are extremely rare. Consequently, they provide little or no information on changes in energy consumption patterns through time or how one group of people responds to trends such as rising income or increasing biomass scarcity.

d. Good micro-surveys are too few in number to provide an accurate national or sub-regional picture of demand and supply patterns. Instead, they tend to highlight the enormous diversity in energy consumption. An obvious consequence of this fact is that local micro-surveys should never be used as the basis for macro-level assessments or national planning unless there are excellent grounds for thinking that the sample locations are typical, or one is content to use rough, order of magnitude figures to explore some issue.

The force of this last point is illustrated in Table 2.1, which shows the average per capita consumption of biomass fuels in Ethiopia. The figures were estimated in 1980 by the Beijer Institute and in 1983 by a World Bank mission, although neither source was based on measured (i.e., weighed input) surveys. The varying results obtained by the Beijer Institute and the World Bank suggest that estimates of national per capita fuel consumption can be inaccurate. Also shown are data from towns and cities in very different physical settings based on a third set of measured surveys by the Italian institute CESEN. It used quantitative estimates of supply to the whole community, though these estimates were not weighed by household consumption.

The enormous differences in the regional figures underline the point, which cannot be repeated too often, that household energy demand and supply must, wherever possible, be considered at the local level.

Table 2.1: Estimates of Average Per Capita Biomass Fuel Consumption in Ethiopia (kg/year)

	National Averages		Local Data (CESEN) by Region		
Fuel	Beijer	World Bank	Debre Markos	Chefe	Moyale
Firewood	424	476	352	1,618	417
Dung	373	246	77	0	0
Agricultural residues	232	161	87	3	0

(charcoal not shown due to differences in basis of estimates).

Sources: Anon [1981b], UNDP/World Bank [1984b], Bernardini [1983].

The paucity of micro surveys and the lack of repeated surveys over time are perhaps the most severe constraints to obtaining a good understanding of household energy demand and supply in developing countries. These constraints also limit our understanding of consumers' perceptions of their problems and willingness to respond to them, as well as the transformations that will occur in the future as conditions change.

C. MAJOR CONSUMPTION VARIABLES

Several attempts have been made to estimate national average household energy consumption levels by pooling the results of micro and other household surveys. A notable exercise of this kind was conducted by FAO for rural households based on nearly 350 surveys and rough estimates in 88 countries. [de Montalembert and Clement 1983] Table 2.2 shows the results of the exercise.

An indication of the range of local consumption levels is provided in Table 2.3, where annual per capita energy use is shown to vary by a factor of roughly 26, from 2.3 to 59.2 GJ, or from about 150 to 3,800 kg of woodfuel. Again, the data are for rural areas and are based on national budget surveys or micro surveys in which consumption was measured. Table 2.4 gives comparable data for urban areas.

A study of more than 100 household energy surveys shows that energy use and the choice of fuels consumed depend on most or all of the following interrelated variables:

<u>Supply variables</u>:

- Price and availability (for marketed fuels);
- Less easily defined measures of abundance or scarcity, especially the time and "effort" devoted to fuel gathering and fuel use; access to fuels by different groups; seasonal variation in supply; and cultural and socio-economic factors, such as gender differences over decision-making and divisions of labor;
- The availability of and competition between substitutes for fuel and non-fuel uses of biomass (e.g., animal fodder, construction materials, timber for sale, small wood for tools, etc., and soil conditioners or fertilizers);
- Fuel preferences (between biofuels, and biofuels versus modern fuels);
- Urban, peri-urban or rural location (i.e., settlement size and proximity to large towns or cities). These differences are closely related to supply factors such as fuel availability.

Demand variables

- Household income;
- Household size;
- Temperature and precipitation (for space heating and drying needs);
- Cultural factors (diet, cooking and lighting habits, number of meals, feasts and burial rituals);
- Cost and performance of end-use equipment.

Table 2.2: Annual Per Capita Consumption of Rural Household Energy and Woodfuels: Country and Regional Averages and Ranges

Region/Fuel Type	Per Capita Biomass Consumption m^3 Wood Equivalent	Total GJ	Percentage as Biomass
Africa: South of Sahara			
Lowlands: dry	1.0 - 1.5	10 - 14	95 - 98
humid	1.2 - 1.5	12 - 14	95 - 98
Uplands: (1500m)	1.4 - 1.9	14 - 18	90 - 95
North Africa & Middle East			
Large consumers a/	0.2 - 0.8	2 - 8	
Small consumers b/	0.05- 0.1	0.5 - 1	
Mountain areas c/	up to 1.5	up to 15	
Asia, including Far East			
Desert & sub-desert	0.3 - 0.5	3 - 5	
Agricultural regions, dry tropics:			
wood fuels }			20 - 50
crop residues }	0.2 - 0.75	2 - 7.5	20 - 40
animal wastes	0.45- 0.30	4 - 2.5	20 - 50
total	0.65- 1.05	6 - 10	80 - 90
Agricultural regions, moist tropics			
wood fuels }			20 - 50
crop residues }	0.3 - 0.9	3 - 9	20 - 40
animal wastes	0.55 - 0.4	5 - 3	20 - 40
total	0.85 - 1.3	8 - 12	80 - 90
Shifting agriculture, moist tropics	0.9 - 1.35	10 - 14	80 - 90
Mountain areas:			
wood fuels	1.25 - 1.8	13 - 18	65 - 85
other	0.55 - 0.2	4 - 2	10 - 25
total	1.8 - 2.1	17 - 20	90 - 95
Latin America			
hot areas	0.55 - 0.90	10 - 14	50 - 60
temperate areas	0.70 - 1.2	12 - 17	55 - 65
cold areas	0.95 - 1.6	18 - 23	50 - 65

a/ Tunisia, Iraq, Morocco, Algeria, Turkey.

b/ Lebanon, Egypt, Jordan, Syria, S. & N. Yemen.

c/ North Africa, Iraq, Turkey.

Table 2.3: Per Capita Rural Consumption of Household Energy and Biomass (GJ): Local Averages and Ranges

Country/survey	Average	Range	% Biomass	Source
	GJ			
Bangladesh:				
Ulipur village	6.8		100	Briscoe 1979
Sakoa village	8.9	7.0 - 19.3	97 - 98	Quader & Omar 1982
4 villages		8.3		" "
large survey	5.3		95	Mahmud & Islam 1982
large survey	4.9	3.8 - 5.5	97 - 100	Douglas 1981
budget survey (occupation)	5.1	3.7 - 6.1	79 - 91	Parikh 1982
Chile:				
8 villages	29.2	17.8 - 59.2	(100)	Diaz & del Valle 1984
India:				
large survey (income)	4.6	4.3 - 5.6	92 - 95	Natarajan 1985
Tamil Nadu, 4 villages	7.6	5.8 - 8.8	97 - 99	Aiyasamy 1982
Tamil Nadu, 17 villages	7.2	4.2 - 10.1	97 - 99	SFMAB 1982
Pondicherry (income)	11.0	10.2 - 11.2	91 - 97	Gupta & Rao 1980
Karnataka, 6 villages	10.1	8.9 - 11.4	97 - 98	Reddy, et al. 1980
3 villages	30.2	7.6 - 44.8	96 - 99	Bowonder & Ravishankar 1984
Indonesia:				
3 villages (and income)	7.6	5.3 - 10.6	45 - 97	Weatherly 1980
Mexico:				
3 zones (and income)	8.7	7.6 - 11.5	84 - 93	Guzman 1982
Nepal:				
Pangma village	9.0	4.0 - 37.8	(100)	Bajracharya 1981
Pakistan:				
budget survey (income)	4.5	3.5 - 5.8	81 - 92	FBS 1983
Papua New Guinea				
highland village (Jan.)	5.8	2.5 - 9.2	(100)	Newcombe 1984a
(May)	5.4	2.4 - 16.1	(100)	"
South Africa:				
7 villages	8.2	5.2 - 14.5	(100)	Furness 1981
Sri Lanka:				
6 regional zones	8.4	7.5 - 11.2	89 - 93	Wijesinghe 1984
budget survey (income)	4.4	2.3 - 5.4	86 - 92	DCS 1983
Tanzania:				
18 villages	10.9	4.4 - 26.1	(100)	Skutsch 1984

Note: Ranges are not for individual households: ranges for them are much greater. These ranges apply to averages at one level of disaggregation below the average shown in the table: e.g. income or caste groups in a one-village survey.

Table 2.4: Per Capita Urban Consumption of Household Energy and Biomass (GJ): Local Averages and Ranges

	Average	Range		
Country/survey	GJ		% Biomass	Source
Bangladesh:				
budget survey (occupation)	3.5	3.4 - 3.5	49 - 67	Parikh [1982]
India:				
Hyderabad (income) a/	2.4	2.1 - 2.9	26 - 72	Alam et al. [1983]
large survey (income)	3.3	3.1 - 3.9	36 - 78	Natarajan [1985]
Pondicherry (income)	5.9	5.7 - 6.6	70 - 84	Gupta & Rao [1980]
Pakistan:				
budget survey (income)	3.0	2.7 - 4.8	25 - 80	FBS [1983]
Papua New Guinea				Newcombe [1980]
squatters settlements	11.2	-	79	
government housing settlements	8.3	-	41	
high income housing	23.6	13.5 - 33.7	<1	
Sri Lanka:				
budget survey (income)	3.0	2.3 - 3.8	22 - 87	DCS [1983]
Togo:				
Lome' (income) b/	5.1	4.6 - 5.5		Grut [1971]

a/ Excludes electricity use.
b/ Wood fuels only.

Note: Ranges are not for individual households; those ranges are much greater. These ranges apply to the averages at one level of disaggregation below the average shown in the table: e.g. income or caste groups in a one-city survey, cities or towns in a multi-city survey, and income groups in a national urban survey.

The main effects of these variables are examined below. At the outset, it should be obvious that many of them overlap and that there is often no clear distinction between variables that affect demand and supply. For example, the cost of end-use equipment is listed as a demand variable since it concerns the final end of the energy supply-conversion chain and is linked to factors such as income, preferences for using certain fuels, and even tastes in the case of cooking equipment. But end-use technologies are often fuel-specific, as with a kerosene lamp or stove, and so depend on supply-side issues such as the availability and price of fuels, and the price of household equipment. Some other factors which are known to have major effects on consumption in developed country households, including dwelling size and daily occupancy patterns, are not listed because there is virtually no information on their effects in developing countries.

Gathered Fuels and Time Budgets

A fundamental division is made between households which gather fuels and those which buy them. This distinction is not always clear-cut, since fuel gatherers may hire a donkey or truck to collect fuel from a distant source or pay for fuels by bartering goods, services or their own labor. Many gatherers also buy some modern fuels, such as a little kerosene for lighting or for starting the cooking fire; and many households gather or buy traditional fuels at different times of the year.

Nevertheless, the distinction is an important one for two reasons:

a. It emphasizes the contrast between local and macroeconomic issues. Fuel gatherers have access only to local resources. Buyers are part of a more generalized, national system of prices and energy delivery infrastructures.

b. Gatherers "pay" for fuels by complex trade-offs between fuel preferences, fuel economies, and time available for energy-related and other household or productive activities. Their access to fuels is often governed by local rules on rights to use common land and client-patron relationships concerning the land of neighbors. Buyers tend to respond to conventional market forces.

For poor families, and especially for women in many societies, time is the major factor of production and a scarce resource [Cecelski 1984]. Thus, time expenditures on energy-related tasks are a major factor in household decisions about the level of energy consumption and the types of fuels used.

This decision process, which is not simple, has been well summarized by Cecelski [1984]:

> Rural households make decisions on the relative values of time in cooking and labor of household members during different periods, versus the cost and convenience of alternative fuels. Most of these decisions are made by women, but women do not always control income spent on fuel or the fuel types selected by other family members. Interactions within the household determine a 'total systems efficiency' of fuel procurement and use, to optimize labor and cost. 'Seasonal agricultural peaks can intensify labor and fuel demand conflicts.'

Table 2.5 indicates the range of fuel collection times that have been found in surveys: in person-hours per household they range from 8 minutes to 38 hours per week. However, other fuel-related time factors must also be considered, including fuel preparation (e.g., wood cutting and splitting, breaking and bundling crop residues, making dung cakes);

procuring alternatives such as kerosene; food preparation and cooking; and fire tending. All these factors must be judged alongside other time demands as well as alternative uses of biomass such as house construction material, thatching, animal feed, and fertilizer.

Table 2.5: Fuelwood Collection Times
(Hours per Week per Average Household)

Country: Village	Mean	Range	Source
Bangladesh: (1 village)	2.5		White [976]
Burkina Faso: rural	0.9		McSweeney [1980]
Chile: (7 villages)	11.8	5.0 - 25.5	Diaz & del Valle [1984]
India: Karnataka (6 vill.)	11.6	8.4 - 16.4	Reddy et al. [1980]
T. Nadu (4 vill.)	9.5	2.6 - 18.6	Aiyasamy et al. [1982]
Indonesia: Java	2.1		White [1976]
Long Segar	0.14		Smith & Last [1984]
Kali Loro	0.63		Smith & Last [1984]
Nepal: (6 villages)	4.3		Acharya & Bennett [1981]
(1 village)	22	9.4 - 38	Spears [1978]
Peru: (3 villages)		3.5 - 11.6	Skar [1982]
S. Africa: (3 villages)		11.3 - 14.8	Best [1979]
Tanzania: (18 villages)	9.3	1.2 - 21.2	Skutsch [1984]
Lushoto		10 - 18	Fleuret & Fleuret [1977]

Due to these complexities, the relationship between physical measures of fuel scarcity and how people perceive the costs of fuel gathering is rarely simple. Although, as a general rule, greater fuel scarcity equates to greater collection distance and time, and hence to fuel substitutions and economies, these generalizations should always be checked. Local exceptions to the rule may spell failure for any project which is based on common expectations. Some examples of exceptions and key points to watch out for are given below.

Strong fuel preferences frequently override time considerations. For example, in one Tanzanian Maasai village, women walked several kilometers to chop wood from a particular species of living tree, returning with backloads of up to 60 kg, even though the nearby forest floor was littered with fallen branches of other wood species. The more distant species could be lit without any kindling wood or kerosene and burned for a long time with a steady flame [Leach 1985]. A large survey in Thailand found that distance to the fuel source and collection time had no impact on consumption levels or the replacement of wood by other fuels. In this case, there was a strong tradition of using wood as opposed to charcoal or kerosene [Arnold & deLucia 1982].

Seasonal factors may be important. In particular, the demand for labor in peak agricultural seasons often imposes severe time conflicts and leads to temporary reductions in fuel gathering and consumption. In Pangma village, Nepal, the average wood collection trip took 5 hours to gather a 40 kg bundle. In the peak agricultural season this was considered a burden. But in the slack season "going to the jungle" for wood was a chance for a group outing and "singing, dancing, gossiping and joking". Substantial differences in consumption were noted due to seasonal rather than other factors [Bajracharya 1981].

Collection time may not be related to distance, in which case it is almost invariably time and not distance that is the key factor. This could happen when the nearest wood resources are at the top of a steep hill, for example, as in one area of Lesotho [Best 1979]. Scavenging low quality fuels near the home may take longer than getting firewood from a more distant source, but may still be preferred because small amounts of fuel can be gathered rapidly. This collection pattern was frequently observed in the large Malawi rural energy survey [French 1981], for example among women who were caring for young children and could not leave home for long periods.

Fuel economies are often judged according to complex time considerations. Although it might seem obvious that saving fuel would save time on fuel gathering, economy measures may also consume considerable amounts of scarce time -- for example, the careful tending of the cooking fire. Energy savings therefore depend on a woman's complete time budget [Koenig 1984]. One consequence is that saving time in cooking is often given a higher priority than saving fuel, so that the cooking methods employed use more fuel than they would if time were not limited. In Tanzania [Ishengoma 1982] and Senegal [Madon 1982] women were interested in improved stove designs mostly because they saved cooking time rather than cooking fuel.

Time constraints are often greatest for the poorest. When fuels are very scarce, women are often forced to work even longer hours than usual or get other family members--usually children--to take over some of their workload. These adjustments are obviously more difficult in small households or where an adult member of the family is old, sick or disabled: conditions often associated with extreme poverty. For example, a survey in Orissa, India, found that half of the families had "seriously" reduced the time spent on household tasks in order to collect sufficient fuel, and that the consequences were most damaging in families which were both the smallest and the poorest [Samantha 1982].

Buying fuels is often the last resort for poor families. However, when the decision is made to purchase fuels it frequently is based on time considerations. Trade-offs are made between (1) the costs of fuels and the equipment to use them and (2) travel times and costs to reach fuel markets, time saved in fuel gathering, and the opportunities to earn cash in the time saved.

"Time Costs" of Fuel Collection

The previous section emphasized the critical importance of time constraints for fuel gatherers. A useful way of assessing and comparing these costs is to estimate the rate of fuel collection and convert it into a monetary value to give a cash measure of the opportunity cost of fuel collection.

An example of such a calculation, based on a Mexican village [Evans 1984], shows that the opportunity cost of firewood collection may be very high. The average collection rate was 6.2 kg/hour while the local market price of wood was MN$ 3 per kg. The "value" of wood collecting was thus MN$ 18.6 per hour. The minimum laboring wage at the time was MN$ 27.5 per hour. If jobs were available it would be more cost effective to earn cash as a laborer in order to buy wood than to collect it.

The fuel collection rate is also valuable as a single measure of fuel scarcity. It combines in one figure most of the pertinent information provided by other commonly used indicators such as distance to fuel sources, collection time, and density of the fuel stock at the collection site; and it does so for the two quantities that matter most to families: fuel consumed and the time cost of gathering it.

Table 2.6 shows the wide variation in collection rates. For average conditions in these surveyed locations the range is from 1.7 kg/hour in South India to more than 70 kg/hour in the Chilean subsistence village close to forest resources. In all these cases, wood was collected on foot and by headload or backload. Where animals (or trucks) are used, rates may of course be higher for the same conditions of fuel scarcity.

Table 2.6: Collection Rates for Firewood
(kg/hour)

Country: Village	Mean	Range	Source
Chile (7 villages)	26.5	12.5 - 71.4	Diaz & del Valle [1984]
India: Karnataka (6 villages)	2.8	1.7 - 3.8	Reddy *et al.* [1980]
Tamil Nadu (4 villages)	3.9	1.8 - 5.4	Aiyasamy et al. [1982]
Indonesia (3 villages)		10 - 20	Weatherly [1980]
Mexico (2 villages)		6.2 - 9.2	Evans [1984]
S. Africa (3 villages)	5.5	3.8 - 6.7	Best [1979]
Tanzania (18 villages)	12.1	4.3 - 44.4	Skutsch [1984]
Yemen (8 villages)	3.6		Aulaqi [1982]

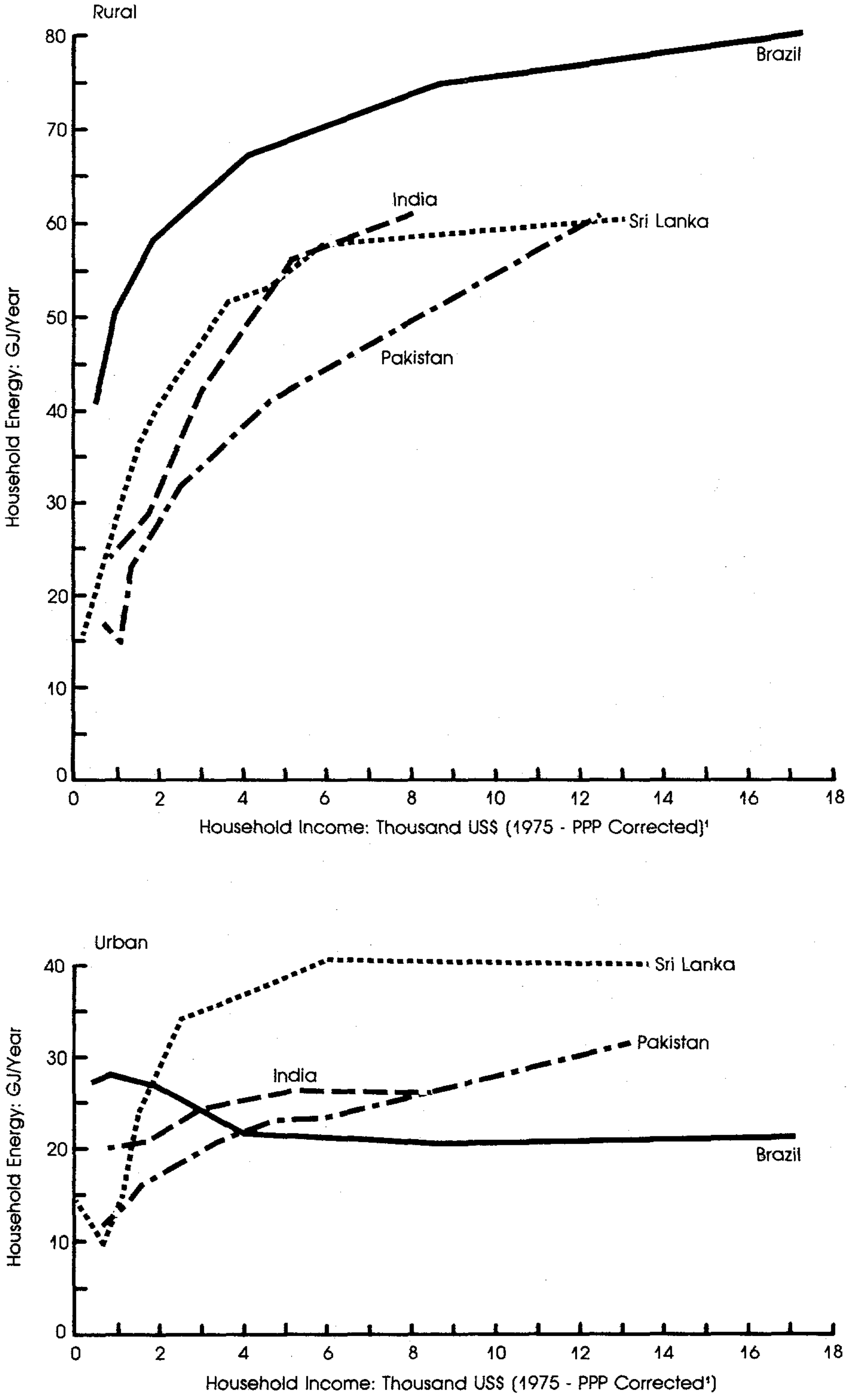
Income and Rural-Urban Differences

Income and rural-urban location are among the strongest variables in determining total household energy use, the mix of fuels employed, and consumption for the major end-uses such as cooking, lighting and electrical appliances. They are best considered together, as income has different impacts on fuel consumption patterns in rural and urban areas.

The broad effects of these variables on energy use can be seen in Figures 2.1 and 2.2, which are based on large, nationally representative surveys for Brazil (1979), India (1979), Pakistan (1979) and Sri Lanka (1982) [Goldemberg 1984; Natarajan 1985; FBS 1983; CBC 1985]. Several points are immediately obvious.

Energy consumption is much lower in urban than rural areas, especially for middle income groups. This is mainly because these groups, in urban areas, can obtain and afford high efficiency modern fuels and equipment to use them. On a utilized energy basis the rural-urban differences would not be so great. Figure 2.2 confirms this point by showing the share of traditional biofuels in total energy use across household income. In rural areas there is virtually no change with income and the shares are all within 85-95%, the remainder being mostly kerosene for lighting. In urban areas, the lowest income groups also depend mostly on traditional fuels with shares close to 80%, except for Sri Lanka (90%). As incomes increase, the share of traditional fuels drops sharply to a minimum of around 25-30%, again except in Sri Lanka. The substitution of modern for traditional fuels, in these cases, depends on (a) urbanization, and (b) rising urban incomes.

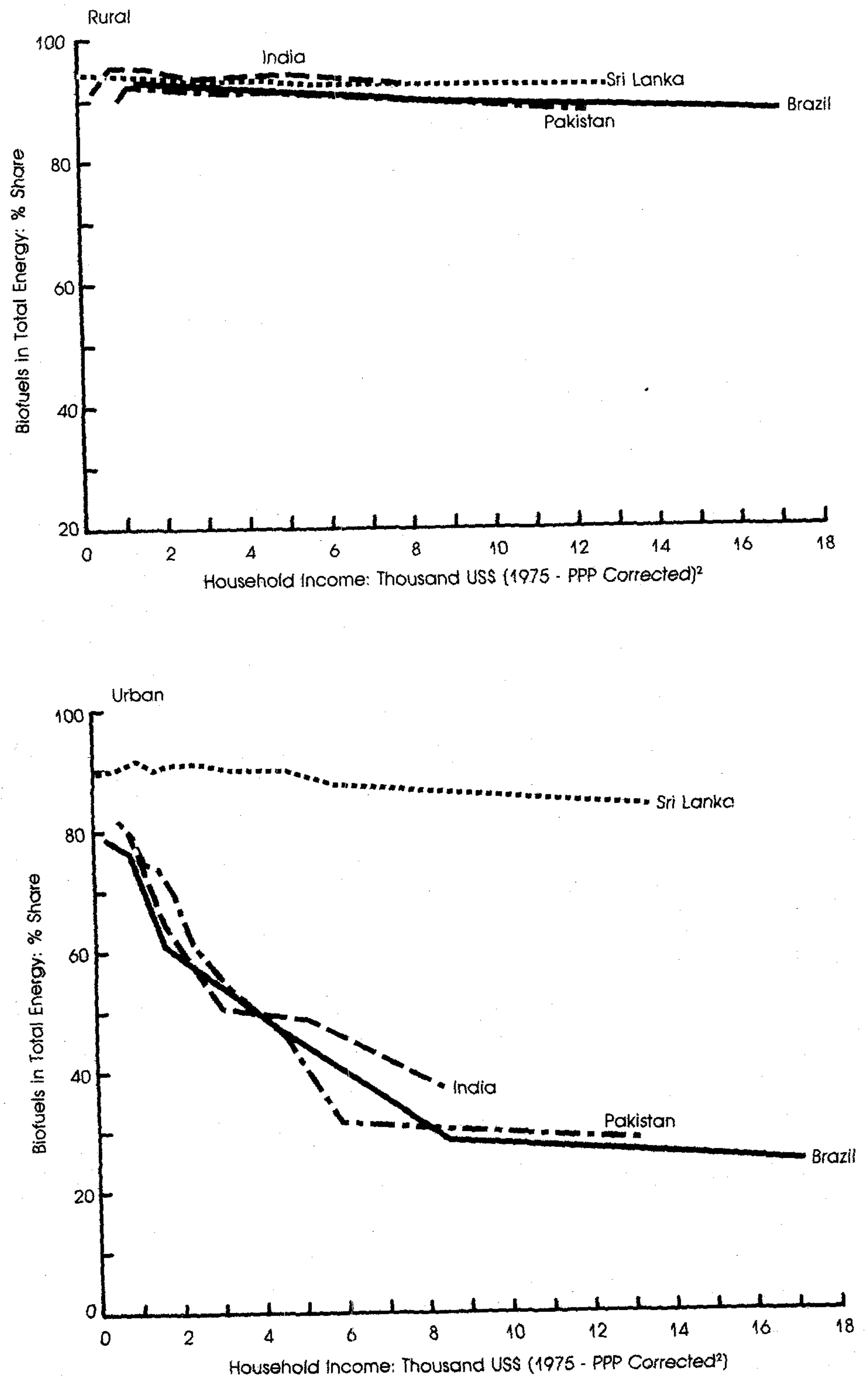
FIGURE 2.1: Household Energy Consumption against Household Income, Rural and Urban Areas, in Brazil (1979), India (1979), Pakistan (1979) and Sri Lanka (1982)



Note: [1] PPP = Purchasing Power Parity

World Bank—30736:1

FIGURE 2.2: Share of Biomass Fuels in Total Energy against Household Income, Rural and Urban Areas, in Brazil (1979), Pakistan (1979) and Sri Lanka (1982)



Notes: ¹ Includes energy consumption by household members and servants.
² PPP = Purchasing Power Parity

World Bank—30736:2

The exceptional behaviour of Sri Lankan urban households is explained by another major variable: fuel availability (and prices). In urban Sri Lanka as much as 30% of domestic firewood comes from the household's own lands or garden, compared to an average of 2.5% in India; and when firewood is purchased, its price at the time of these surveys was close to 60% of that in urban Pakistan and 40% of that in urban India. [2/]

One also sees a strong and fairly steady relationship between total energy consumption and income; and a marked tendency for energy use to rise steeply at low incomes but to "saturate" at high incomes. Discussion of these trends is deferred to the next section on the effects of household size.

Although these trends are useful general indicators, they are less important to understanding household energy use than are their underlying causes. Five of these can be singled out as they are found in many countries and explain much of the variation in fuel mix among income groups, total energy and rural-urban locations.

With increasing income one normally sees:

a. Steady or increasing biomass consumption in rural areas but declining biomass consumption in urban areas.

   The rural trend is explained by easier access to biofuels since land or cattle ownership is greater, and by the ability to purchase biofuels. The urban trend is explained by the fuel substitutions described below and by the tendency to eat more meals outside the home, thus reducing cooking needs.

b. Substitutions between biomass fuels for cooking, especially in urban areas.

   For example, in urban Africa and Latin America, charcoal often displaces firewood as the main cooking fuel. This is partly a matter of taste, but also of convenience; charcoal is easier to transport and store, and less smokey, than firewood. The degree of substitution and the income level at which substitution begins depend on the relative prices of firewood and charcoal and the relative costs of cooking equipment as well as cultural preferences.

c. Substitutions of modern fuels for biomass cooking fuels, especially in urban areas.

[2/] Prices compared between countries by normalizing to the US$ with "Purchasing Power Parity" indices [Leach 1986].

With increasing income the progression is normally: biofuels - kerosene - gas (e.g., LPG) or electricity.

d. Greater use of modern fuels and electricity for end-uses other than cooking.

With lighting, typically there is an increase in kerosene use, followed by a decline at higher incomes as electric lighting is installed. This trend is usually strongest in urban areas, where kerosene and electricity are more widely available, and depends on equipment costs as well as relative prices. The other major trend is a rapid expansion of electricity use for refrigeration, space cooling, and other electrical appliances. This typically begins at low to middle income groups in urban areas but only at high income levels in rural areas (although this depends on the extent of rural electrification, the cost of hook-ups to the grid and the price of electricity).

e. A tendency for consumption of modern fuels to "saturate" at the highest income levels.

In many developing countries without significant space heating needs, energy consumption by urban households at the highest income levels clusters around 25-35 GJ per family, per year. This is close to 20-25% of household consumption at equivalent incomes in industrial countries, or much the same as the industrial country level when space heating is deducted.

These trends reflect two underlying forces. As spending power increases in rural areas, families can buy their way out of biomass fuel shortages and/or have sufficient land to grow their own biofuels. In both rural and urban areas, greater purchasing power pulls families toward more efficient and convenient modern fuels and the new end-uses they allow. Except at the highest incomes when space cooling is introduced, there are marked limits to the amount of energy required to satisfy these end-use needs (e.g., lighting, refrigeration, and other electrical appliances).

The progression from using biomass fuels for cooking to using kerosene, LPG and electricity as urban incomes rise is shown in Table 2.7. The large differences between the cities are due to differences in average income, degree of modernization, and energy supply infrastructures.

Household Size

With nearly every household use of energy there are large economies of scale associated with increasing household size. For example, the additional energy required to cook for four persons rather than two is small compared to the fixed "overheads" for keeping the fire alight, etc. With lighting and space heating, energy use depends on the dwelling area or number of rooms, other things being equal, and is not much greater for a family of four than for a family of two.

Table 2.7: Cooking Fuels Used in Urban Households
(percent of households in fuel grouping)

City/Household Type	Firewood	Charcoal	Kerosene	LPG	Electricity
Kuala Lumpur (1980)					
Low income	4	15	75	25	19
Middle income	7	23	57	52	35
High income	0	17	19	87	50
Manila (1979)					
Low income	9	1	35	45	11
Middle income	2	1	5	73	19
High income	1	0	1	78	19
Hyderabad (1982)					
Low income	41	(a)	70	19	(b)
Middle income	24	(b)	65	54	(b)
High income	13	(b)	57	71	(b)
Bombay (1972)					
Low income	10-30	10-30	98	9	-
Middle income	3-20	3-20	98	53	-
High income	3-10	3-10	77	94	-
Papua New Guinea (1978)					
Low income	79	-	21	-	-
Middle income	41	-	42	-	17
High income	1	-	0 - 6	0 - 7	87 - 93

Note: Data for Kuala Lumpur and Hyderabad reflect use of more than one fuel. Manila data refer to "usual" source of energy. Bombay data refer to ownership of cooking devices. The percent of Bombay households owning a hearth for burning firewood or a stove for burning coal was 40, 23 and 13 for the respective income groups.

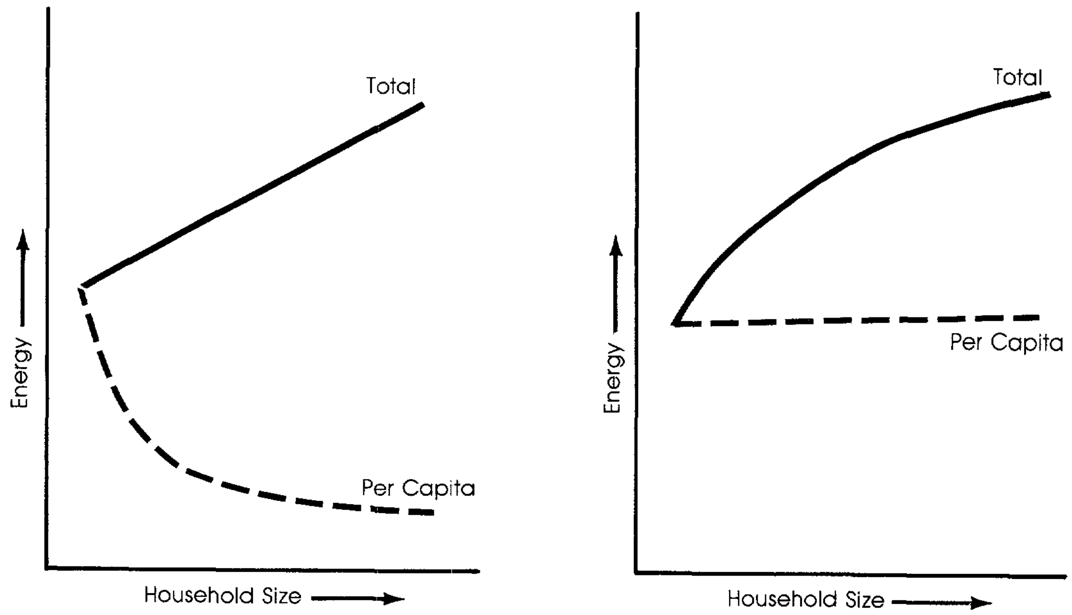
(a) Small amounts of charcoal are used at all income levels.

(b) Not measured.

Sources: Sathaye & Meyers [1985]; based on SERU [1981] (Kuala Lumpur), PME [1982] (Manila), Alam et al. [1983] (Hyderabad), Hernandez [1980] (Bombay), Newcombe [1980]. (Papua New Guinea).

This effect is illustrated schematically in Figure 2.3. In the left-hand figure, total energy consumption rises linearly with household size, so that per capita consumption falls steeply at first and then flattens out. In the right-hand figure, total energy rises rapidly at first and then grows more slowly, so that per capita consumption remains roughly constant.

FIGURE 2.3: Effects of Household Size on Total and Per Capita Energy Consumption

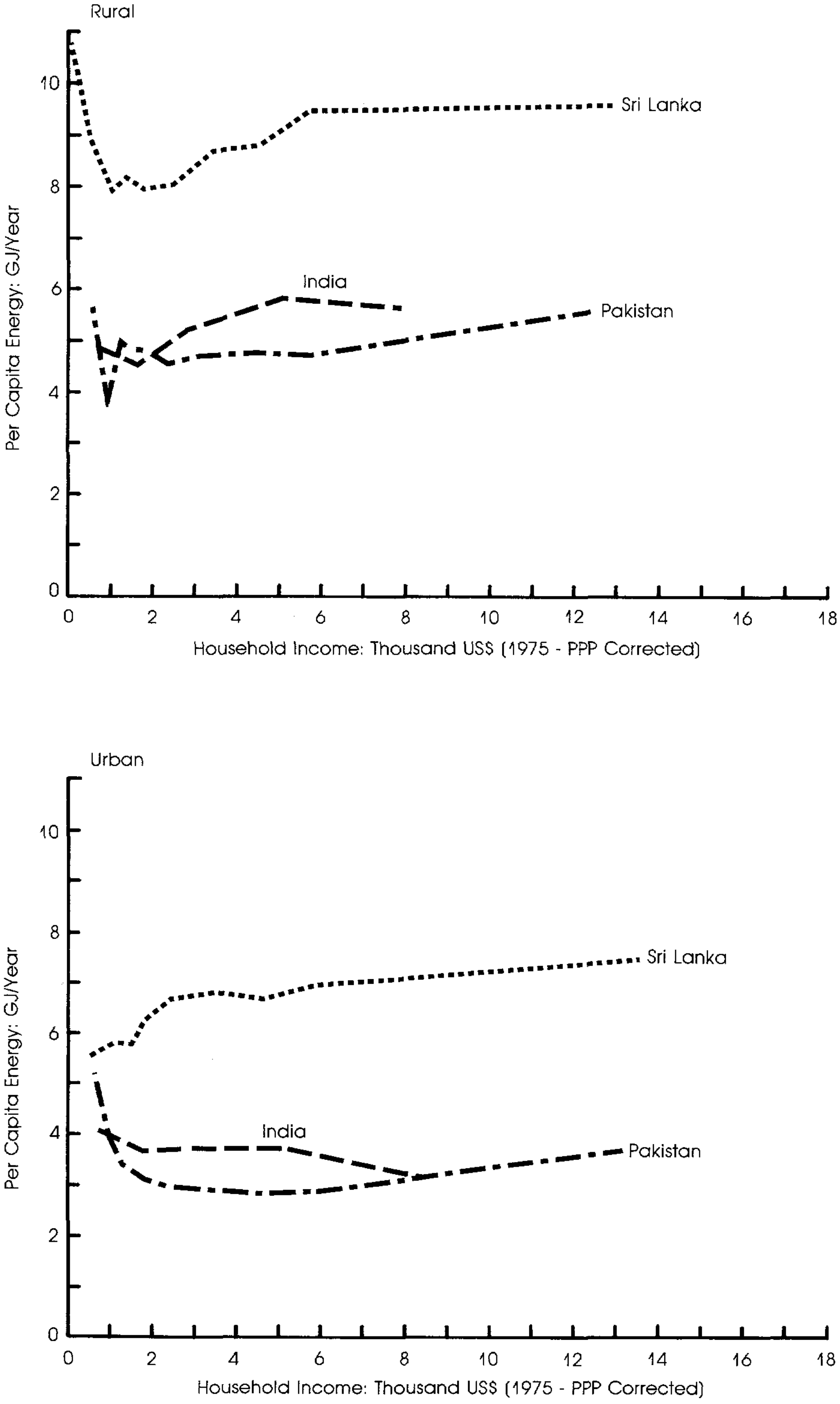


World Bank—30736:3

Household size often has as great or greater an effect on energy consumption as other major variables such as income. Furthermore, in some countries household size is strongly associated with income: on average, large families tend to have more income earners, while high income households may attract family relatives. This is certainly the case in South Asia. Consequently, when the data shown in Figure 2.1 is replotted for the South Asian countries on a per capita basis (see Figure 2.4) there is little variation in per capita energy consumption across the entire household income range. In other words, the rising curves for household energy plotted against household income (Figure 2.1) are mostly a function of increasing family size with household income.

These effects are of great importance when comparing and assessing survey data or using them to project energy consumption. First, whenever absolute levels of consumption are important (as opposed to fuel shares, etc), it is obvious that one must work either in per household or per capita terms. But since many surveys do not publish data on household size which allow conversion between these bases the range of surveys that one can use may be limited. Note, though, that the survey authors may be able to provide the missing information on household size.

FIGURE 2.4: Per Capita Energy Consumption against Household Income, Rural and Urban Areas, in Pakistan (1979), India (1979) and Sri Lanka (1982)



PPP = Purchasing Power Parity

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Second, whether per capita or household energy data are used, one has to be wary of the effects of household size. This warning applies particularly to the use of regression methods to estimate energy income elasticities. A formal description of this problem is given in Table 2.8.

Third, it is usually sufficient to base assessments on per capita data (the kind most frequently reported) and to combine these with total population and its growth rate to derive total consumption. However, if there is any cause to believe that household size is likely to change appreciably (e.g., for different income groups), then projections of household formation rates and/or average household size will also be needed.

Table 2.8: Relationships between Energy, Income, and Household Size

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Household energy frequently depends closely on household income according to a relationship such as

$$Q = a * y^{b} \qquad \text{(* denotes multiplication)}$$

where (Q) is the consumption of a fuel or total energy, (y) is household income, (a) is a constant and (b) is the energy-income elasticity. Regressions of survey data using this equation often show that income "explains" at least 90-95% (or more) of the variance in energy use.

However, energy use also depends strongly on household size, while household size may be closely linked to household income. In other words

$$N = c * y^{d}$$

and

$$Q = e * N^{f}$$

where (N) is household size, (c) and (e) are constants, and (d) and (f) are elasticities.

If these expressions are combined and manipulated it can be shown that (i) there is no simple expression linking per capita energy and per capita income, and (ii) that the only simple (two term) relationship is the one linking per capita energy and household income. It is for this reason that in Figure 2.4 per capita energy is plotted against household income rather than, say, per capita income.

The four most obvious and useful relationships are shown below:

1. Household energy to Household Income and Household Size

$$Q = a/c * y^{b-d} * N$$

2. Per Capita Energy to Per Capita Income and Household Size

$$(Q/N) = a * (Y/N)^{b} * N^{b-1}$$

3. Per Capita Energy to Per Capita Income and Household Income

$$(Q/N) = a * c^{b-1} * (Y/N)^{b} * y^{d_{*}(b-1)}$$

4. Per Capita Energy to Household Income

$$(Q/N) = a/c\ y^{b-d}$$

Purchased Fuels and Expenditure Shares

The share of income or expenditure devoted to providing energy is an important factor in assessing household fuel use. If the share is very high it indicates that families are severely stressed by their energy problems and are likely to welcome solutions. If the share is low, families may be indifferent to rising energy prices or increased fuelwood scarcity, as well as attempts to introduce energy saving measures.

In both developed and developing countries, the lowest income groups spend the largest shares of their incomes on energy. This point is demonstrated in Table 2.9, for urban households, where most fuels are purchased. Data for the U.S. and U.K. in the early 1980s are included for comparison.

Table 2.9: Household Budget Shares for Energy in Urban Areas
(percent)

	Mean	Lowest Income	Highest Income	Source
USA 1982				
oil heating	8.2	31.9	3.6	EIA [1983]
all households	4.5	20.0	2.7	EIA [1983]
UK 1982	6.2	11.9	4.3	DOE [1983]
Brazil 1979	19.0	0.9		Goldemberg et al. [1984]
Chile (Santiago) 1978	4.2	7.6	3.1	Anon [1983]
1968	4.1	4.7	3.3	ILO [1979]
Egypt 1975	3.6	4.6	3.0	ILO [1979]
India:				
Hyderabad 1981 a/	3.6	10.7	1.5	Alam et al. [1983]
Pondicherry 1979	18.4	5.2		Gupta & Rao [1980]
Lesotho 1973	4.8	8.8	3.7	ILO [1979]
Pakistan 1979	4.0	8.6	1.8	FBS [1983]
Panama 1980	20			Anon [1981a]
Sri Lanka 1981	4.7	9.7	3.2	DCS [1983]

a/ Excluding electricity.

Note: Budget shares for energy are defined as the percentage of income or expenditure devoted to household fuels and electricity, excluding motor vehicle fuels. Non-marketed gathered fuels are included using an imputed price. In urban regions this probably has little effect on actual cash expenditures on fuels.

Even higher budget shares than those shown in Table 2.9 are often cited for particular cities or regions of developing countries. Examples are 20-30% in Ougadougou, Burkina Faso [Anon 1976]; 30% in the town of Waterloo, Sierra Leone [Cline-Cole 1981]; and 25-40% in the capitals of the Sahel region of Africa [Lambert 1984]. Wherever the original sources for such widely-quoted figures can be tracked down, it usually turns out that they refer to special groups such as low income-earners with large families or even a single household with an unusually high share of income devoted to energy costs. Such figures therefore have to be used with considerable caution when considering the effects of prices, or incentives to reduce expenditures through fuel saving measures, etc. for all income groups or the whole population.

Energy Prices

Many attempts have been made to use differences in energy prices to explain variations in consumption levels and fuel choices in different countries. Unfortunately, this approach is severely hampered both by the lack of reliable data on local energy prices and also by the problem of converting prices to a standard unit such as the US dollar. To reflect true differences across countries, prices should be converted to US dollars using purchasing power equivalent exchange rates. In low income countries, these increase the "real" equivalent dollar price of goods and services by a factor of 3 to 3.5, and in middle income countries by around 1.5 to 3 times [Kravis 1982]. 3/

Alternative approaches are to compare countries using (1) shadow exchange rates, or (2) an index such as price relative to average per capita income. Table 2.10 presents estimates of fuelwood and charcoal prices and average daily wages for several countries. As a percentage of average daily wages, prices vary from less than 1% to more than 13%.

Table 2.10: Relative Prices of Woodfuels in Selected Countries

Country	Average Daily Wage	Market Price of 1.5 KG Firewood a/	Market Price of 0.5 Kg Charcoal	Percent of Daily Minimum Wage	
				Firewood	Charcoal
Ethiopia	2.00 Birr	0.27 Birr	0.22 Birr	13.5	11.0
Madagascar	1000.00 FMG	33.00 FMG	27.50 FMG	3.3	2.8
Malawi	1.00 Kw	0.06 Kw	0.08 Kw	6.0	8.0
Sudan	2.00 SL	0.08 SL	0.08 SL	4.2	3.9
Zambia	3.64 Kw	0.03 Kw	0.06 Kw	0.8	1.6

a/ Solid wood stick bundles.

Source: World Bank Mission staff measurements and observations.

3/ This reference provides equivalent (or "parity") exchange rates for a number of countries.

Within a given country, the usual method of determining the effects of prices on consumption and fuel substitution is to estimate the price elasticity of demand (see Chapter I, Section D). This estimate normally differs depending if income is constant or changing, so the income elasticity of demand must also be estimated. Both estimates require time series data on consumption, income and prices. Furthermore, data for many years is required to distinguish immediate reactions to higher prices from the more stable and usually much smaller responses over the longer term. As discussed before, this information is rarely available for the household sector in developing countries.

As a result, in most developing countries there is remarkably little information from which to judge how, even at the most aggregate level, households will respond in their fuel consumption to changes in income or fuel and power prices. Other methods of projecting energy demand, particularly for biomass fuels, are reviewed in Chapter V, which also discusses the roles of fuel prices in assessing alternative technologies such as cooking stoves.

D. ADAPTATIONS TO FUEL SCARCITY

A useful perspective on consumption differences can be gained by considering the responses that people make to the depletion of woodfuels, the major household energy source in developing countries.

Adaptations in Rural Areas

As a starting point, in some rural areas abundant fuel grows virtually "on the doorstep". Fuel collection is a relatively trivial task. Consumption is unconstrained, often abnormally high (especially in colder areas) and only preferred species of wood are used. This may be true even in areas within countries where biofuel supplies are generally scarce.

Under these conditions, an annual fuelwood consumption of up to 4 tons per person has been estimated for subsistence communities living close to the forest in the colder regions of Chile. 4/ Annual consumption levels of 2.9 and 2.6 tons woodfuel per person have been reported for fairly high altitude areas of Nicaragua and Tanzania, respectively [Jones & Otarola 1981; Fleuret & Fleuret 1978]. In warmer regions, where demand is mostly restricted to cooking and water heating, "unconstrained" consumption levels seem to fall in the range of 1.2 - 1.5 tons per person per year.

4/ This level of consumption is estimated from the following formula based on Table 2.3: $60 \text{ GJ} \times \frac{1000 \text{ t}}{15 \text{ GJ}} = 4$ tonnes.

For the majority of rural households, fuel collection is more difficult and has appreciable personal costs in terms of time and effort. With increasing scarcity, one generally finds the following broad stages in adaptation:

a. Lower quality but more accessible woodfuels are used. This expands the resource base and may postpone the need for any further adaptations. Where population densities are low, demand can often be met without depleting the standing stock of trees. Families who own sufficient land are often able to meet their demand from their own resources; others can usually collect from nearby forests, common lands, roadsides or wastelands.

b. People start to economize on fuel. This normally occurs when the time required to collect wood has become an unacceptable burden. For example, cooking fires are smaller, embers are quenched after cooking for re-use later, or greater care is taken to shelter the fire from the wind. Some least essential end-uses, such as water heating for bathing or washing clothes and dishes, may be reduced. Consumption drops considerably. Typical figures are hard to define, but from the evidence of many surveys in areas without significant space heating, consumption appears to be in the range of 350-800 kg per person per year. This level of adaptation may coincide with the first signs of interest in fuel-saving stoves.

c. Crop residues and animal wastes begin to be used. This adaptation is found right across the developing world and is often seen as an easier (i.e., less time consuming) response than tree planting. The adaptation may be most difficult for the poor and/or landless, who must depend on supplies from other people's land and animals, or common land. As biomass supplies of all kinds are depleted, traditional rights of access to fuel sources are often closed off to the poor.

d. Reductions in living standards and diet are found in conditions of acute scarcity. Income-earning tasks, hygiene, child feeding and care, or visits to health and education services may be reduced or eliminated in order to make time for fuel gathering [Cecelski 1984]. Fuel and hence time may be saved by reducing the amount and kinds of cooked foods in the diet. Staple foods which require less cooking are introduced; food may be re-heated rather than cooked a fresh; processed foods are purchased; and the number of meals may be reduced. Some examples ascribed to fuel shortages are greater consumption of raw foods in Nepal [Cecelski 1984] and reductions in staple beans in Guatemala, Mexico and Somalia [Tinker 1980, Evans 1984, Cecelski 1984]. However, it is not always clear that fuel shortages are directly responsible for these or other examples of "food deprivation." A reduction in dietary quantity and quality may reflect an attempt simultaneously to save money, time and fuel.

e. The purchasing of biomass or modern fuel substitutes by people who previously collected them "free" is another important response to scarcity--not just of fuels, but also of fuel-competing materials such as animal fodder. Essentially, the judgment is made that the benefits from alternative uses of biomass fuels (e.g., straw for fodder rather than fuel) or the time saved from fuel gathering is greater than the financial burden on often severely limited budgets for fuel purchases. Since this decision framework is complex, while there are large differences in the price and availability of commercialized fuels, the degree to which this occurs varies enormously.

These adaptations suggest that consumption levels and types of fuel can vary greatly in response to deepening fuel scarcity. They emphasize the dangers of extrapolating present consumption patterns into a future of greater woodfuel scarcity or of supposing that a shift away from woodfuels to modern fuels will occur automatically as incomes increase, as it has in developed countries. National energy plans have frequently been rooted firmly in one or the other of these notions.

Perhaps most importantly, these adaptations underline the critical distinctions between households who own land and those who do not in determining their ability or willingness to plant trees in order to alleviate their fuel shortages. Their incentives to do this are not a matter of average supply/demand balances--the "fuelwood gaps" that the outsider frequently measures. They stem from personal perceptions and balances between present costs of fuel collection and the costs and benefits of many alternatives, of which tree planting intended primarily for fuel supply is only one.

People who have little or no land often feel the effects of fuel scarcity most acutely but are, at the same time, least able to respond by planting trees or burning crop residues and animal wastes. Those who have land often may have sufficient fuel for their needs or need little help in planting a few trees to provide more fuel. If the latter are to be induced to grow more fuel than they need themselves, there must be (1) a market in which to sell it and (2) a market which provides a greater return on investment than alternative uses of their land and labor.

In many locations in developing countries, these market factors are dominated by the demands of urban areas, which can extend many hundreds of kilometers into the hinterland (see Chapter III). In these cases, urban demands for woodfuels are one of the principal causes of rural woodfuel depletion but also provide the major opportunity for increasing (commercialized) rural fuel production.

In other areas, rural traditions of gathering wood without any cash payments are increasingly giving way to commercial wood markets. As mentioned above, the extent to which rural commercialization of woodfuels has already occurred varies greatly. In Tanzania, only salaried public servants such as teachers -- or less than 2.5% of rural families -- generally purchase their firewood [Nkonoki 1983]. In Malawi 10% of rural families purchase firewood, but only 40% of their needs are met in this way [French 1985]. In other countries with higher incomes, better developed rural infrastructures or greater fuelwood scarcity, this process has gone much further. In Nicaragua, for example, some 40% of rural consumers buy some or all of their wood [Van Buren 1984], while in the arid, mountainous Ibb region of North Yemen 65% of rural households buy a quarter or more their fuel [Aulaqi 1982].

Adaptations in Urban Areas

For the urban and peri-urban poor, gathered or purchased woodfuels are the major energy source. Responses to greater scarcity (or higher prices) are much the same as those listed above: economies and lowered fuel quality standards. People buy or scavenge "trash" fuels such as small wood pieces, sawdust and mill wastes, etc. However, for many urban families living in high density apartments or small houses biomass fuels are often ruled out due to lack of space for storage and drying and, frequently, lack of a chimney or flue for the fire. Hence the most prevalent fuels are all commercialized: charcoal, and modern energy sources such as kerosene, bottled gas (LPG), and electricity.

Another major class of response for the poor is a price-driven substitution of modern cooking fuels for fuelwood (or other traditional fuels). This almost invariably means kerosene rather than the other major alternatives: LPG and electricity. Kerosene stoves are relatively cheap and portable (an important factor for shanty dwellers and itinerant laborers who may have to move homes quickly). The price of bottled gas cylinders and gas stoves, and of connection to the power grid (assuming this is possible), is normally prohibitive to the poor and lower-middle income families.

Urban consumption patterns are also strongly driven by income-related substitutions of modern fuels for biofuels. Since the former are generally available in large towns and cities, as incomes increase families can afford to attain the higher living standards offered by modern cooking fuels, such as greater cleanliness, convenience and efficiency. At the same time families benefit from new end-uses offered by electrification, such as better lighting, refrigeration and, for the highest income groups, space cooling. Urban energy behavior thus is much more like that of developed countries and depends largely on income, the price of energy, and the cost of energy-using equipment. In developing countries, the availability of fuels (especially LPG and electricity) is an important additional factor: large cities tend to have a more modernized pattern of fuel consumption than medium or small towns because electricity and LPG (and piped gas in some countries) are more widely distributed.

The strength of these urban substitutions and hence the possibility for rapid changes in energy demand patterns are illustrated in Tables 2.11 and 2.12, using data for India [Natarajan 1985, 1986].

Table 2.11 shows the effects of settlement size in India on the fuel mix for cooking and heating. In towns with populations of less than 20,000, modern fuels provide about 39% of utilized energy for these end-uses, but in cities with more than 500,000 residents the share is close to 75%. With LPG the share increases tenfold across the urban size range. The table provides a sharp reminder that the usual simple division of households into "rural" and "urban" may be wholly inadequate: urban size, as well as the proximity of rural areas to neighboring cities and transport routes, may be critical factors because of their effects on the availability of modern fuels.

Table 2.11: Household Energy Patterns and City Size: India 1979

City Size (thousand residents)	Per Capita Energy a/	Percentage Shares of Modern Fuels a/				
		All	Electricity	Kerosene	LPG	Coke
Over - 500	294	75.4	13.5	28.9	15.6	17.3
200 - 500	275	66.2	9.4	28.6	13.0	14.2
100 - 200	269	57.5	9.2	19.8	7.2	21.3
50 - 100	266	56.2	8.0	18.7	6.4	22.5
20 - 50	234	37.6	6.3	9.5	2.9	18.8
Under 20	244	39.0	6.7	16.6	1.5	14.3
All	266	57.0	9.3	21.2	8.5	17.7

a/ Energy totals and shares are given in terms of kilograms coal replacement, an approximation to useful energy. Small amounts of town gas are omitted.

Source: Natarajan [1985].

Table 2.12 shows how very rapid transitions from traditional to modern fuels can occur in urban areas. During 1979-84 firewood prices rose quite steeply in most Indian cities, while the prices of kerosene and LPG fell in real terms [Leach 1986]. During the same short period, as shown in the table, the share of firewood in cooking and heating dropped from 42% to 27% on a utilized heat basis. The shares of kerosene and LPG almost doubled. The greatest reductions in firewood use took place in the middle income groups, but the poorest households also reduced their shares (from 60% to 53.5%). This table highlights both the possibility for "fuel modernization" as a solution to increasing

Table 2.12: Fuel Shares for Cooking and Heating by Income:
India, 1979 and 1984
(percentage shares)

		Income					
Fuel Type	Year	L	LM	M	HM	H	ALL
Firewood	1979	60.0	40.9	25.1	17.4	12.1	42.4
	1984	53.5	30.8	17.9	9.9	9.6	27.4
Soft Coke	1979	12.8	20.2	23.6	16.7	17.3	18.4
	1984	6.4	18.0	17.9	15.2	8.3	15.3
Kerosene	1979	13.2	21.3	21.5	22.0	18.9	18.7
	1984	23.8	36.9	40.2	38.2	32.8	35.7
LPG	1979	0.8	4.6	14.2	26.9	32.9	6.6
	1984	15.2	9.7	8.3	8.8	10.1	10.1
Other	1979	13.3	13.1	15.6	17.0	18.8	13.9
	1984	15.2	9.7	8.3	8.8	10.1	10.1
Percentage	1979	(31.5)	(42.8)	(20.7)	(2.6)	(2.4)	(100)
of households	1984	(17.6)	(33.6)	(35.1)	(9.4)	(4.3)	(100)

Incomes (Thousand Rupees [Rs. 1978-79] a year):
L = Low (under 3); LM = Low-middle (3-6); M = Middle (6-12);
HM = High-middle (12-18)l; H = High (over 18).

Shares are on a coal replacement basis for cooking and heating.

Source: Natarajan [1986].

scarcities of traditional fuels and the need for developing countries to conduct regular, large-scale household energy surveys to track consumption trends over time.

E. ENERGY END-USES

A household's total energy consumption and mix of fuels is the result of the family's attempt to provide for its various needs by employing its labor or cash and specific technologies that use a certain type of energy. The micro-perspective of each consumer is therefore the driving force behind the sector's use of energy and opportunities for change in demand and supply patterns. In this section we examine briefly the relative importance of the major energy end-uses. Chapter III goes into them in greater detail and includes discussions on the efficiencies and costs of end-use equipment.

Among the poorest families in most developing countries, cooking (and heating) accounts for 90-100% of fuel consumption, the remainder being for lighting by the cooking fire, kerosene lamps, candles or electric torches. At higher incomes, better lighting is one of the first priorities in order to improve living standards and, frequently, to extend the working day. At still higher incomes, water heating, refrigeration and cooling begin to play an important role. The need for space heating may well decline since dwellings are generally better constructed.

A classic pattern of this kind can be seen in Table 2.13, which is based on a large rural survey in Mexico taken in 1975 [Guzman 1982]. In each of three regions, as incomes rise the shares for cooking decline, the shares for water heating increase sharply, and the shares for space heating first increase and then decline. Energy for lighting is not included.

Table 2.13: End-Use of Energy for Cooking and Heating in Rural Mexico
(Percentage Shares)

	Zone 1 Income			Zone 2 Income			Zone 3 Income		
End Use	Low	Med	High	Low	Med	High	Low	Med	High
Cooking	82.6	58.5	50.3	85.4	79.7	57.6	83.3	82.6	48.9
Water heating	2.0	9.1	34.0		10.5	36.7	-	4.3	42.2
Space heating	6.53	32.4	15.7	9.1	9.8	5.7	7.0	13.1	8.9
TOTAL ENERGY (GJ/capita)	11.5	10.2	8.3	9.1	7.9	5.9	9.5	7.6	8.2

Source: Guzman (1982).

As one would expect, substantial national and local variations can be found. For example, in rural East Africa, Openshaw [1978] has suggested a general pattern for the use of biomass fuels in which cooking accounts for 55%, water heating 20%, space heating 15%, and ironing, protection from animals, and other minor uses 10%. A recent national survey in Kenya [CBS 1980] supports this breakdown but also reveals large regional differences, especially for space heating. Shares for cooking and water heating range from 79-92%. Space heating shares are as low as

4% in Nairobi and the coastal region and as high as 20% in the cooler Rift Valley.

In six low income villages of South India, where space heating needs are negligible, there was little variation in end-use shares: the cooking share was 76-81%, water heating 14-19%, and lighting by kerosene and some electricity 2-3% [Reddy et al. 1980]. In contrast, in the much cooler climate of Chile, a survey of eight subsistence villages found that the cooking share was 42-55% and space heating 23-52% [Diaz and del Valle 1984]. Water heating absorbed 14-22% (except for one village with 6%).

Several points related to estimates of this kind are worth noting:

a. Most survey information on end-uses is not given in terms of energy shares but of the proportions of households which use certain fuels to satisfy different end uses. Data of this kind cannot be used to accurately estimate actual consumption for each fuel or end-use. This is especially true where many households use multiple fuels for specific end-uses, such as firewood and kerosene for cooking.

b. End-use consumption is often difficult to define because one end-use device frequently provides several end-use services. As discussed in Chapter I, the cooking fire often serves as the only source of space heating, water heating and, in many cases, lighting.

c. The use of energy for income-earning activities is often great and may not be distinguished from pure household demand, or may simply not be measured. Examples include beer or spirit making, boiling sugar from cane, pottery, tobacco and copra drying, blacksmithing and baking. Often these goods are produced for own-consumption and for sale. The scale of errors that can arise if these energy uses are not measured or allocated correctly is well illustrated by a rural survey in Bangladesh [Quader & Omar 1982]. For landless families, annual consumption for all kinds of cooking and food preparation was 6.9 GJ/year, of which 6.6 GJ was for domestic cooking. The small remainder was for parboiling rice and making "ghur", or sugar syrup. For the largest farmers the equivalent figures were 16.3 and 8.3 GJ/year. The latter used more than twice as much fuel in total, but little more than the landless poor for domestic cooking.

d. Religious festivals, celebrations, burials and other occasional functions may consume large amounts of fuel but be missed by energy consumption surveys.

F. SUMMARY

This chapter has reviewed many aspects of household energy consumption, including data sources that might be utilized for national assessments, ranges of energy consumption according to major variables, energy use for specific tasks, and methodologies for using these data in national assessments.

The chapter purposefully avoided presenting typical consumption data that might be adopted in countries or locations where this information is needed but is lacking because household energy supplies and uses are almost invariably location-specific. This is true of total consumption, the mix of fuels employed, and end-uses. Within countries, these differences are normally very large. While the chapter has presented a number of examples of the range of data found in surveys, there is no substitute for collecting or searching for household energy data that apply to the specific location in question.

CHAPTER III

ENERGY END-USES AND TECHNOLOGIES

A. OBJECTIVES AND STRUCTURE

This chapter examines household energy from the viewpoint of specific end-uses and the technologies which provide services such as cooking heat, space heating, lighting and refrigeration. Its principal objective is to present technical and economic data on end-use technologies, such as the efficiencies, costs, and possible energy savings from using improved cooking stoves and lighting equipment.

Section B examines energy for cooking and Section C discusses cooking stoves. These are the largest sections of the chapter due to the importance of cooking energy in most developing country households.

Sections D, E and F examine lighting, refrigeration, and space heating, respectively. Although some of these services consume significant amounts of energy only in middle to high income households, they are important to examine because they consume electricity, are growing very rapidly in many developing countries, and have a large potential for energy savings at relatively low cost.

B. COOKING

The amount of energy used for cooking depends on many factors: the type of food cooked, the number of meals cooked; household size; the specific combination of fuel and cooking equipment employed (type of stove, cooking pans), and the way in which cooking devices are used.

Consumption Ranges

Staples and other foods vary greatly in the amount of cooking time required and the rate of heat input. For example, rice is usually boiled or steamed for 20-30 minutes, while kidney beans may be boiled for four hours or more. Other foods are baked, grilled or fried, etc. Table 3.1 presents some data from field measurements on the specific fuel consumption (SFC) to cook various staple foods. The range of SFCs is about 7-225 MJ/kg even though woodfuel was used in all cases.

Table 3.1: Specific Fuel Consumption for Cooking Staple Foods (MJ/kg cooked food)

	Mean	Range of Averages	Source
Rice			
Thailand: 10 villages	15.8	12.2 - 22.9	Arnold & de Lucia [1982]
N. India: low incomes	21.4	16 - 27	NCAER [1959]
high incomes a/	41.7	32 - 49	NCAER [1959]
India: Ungra village	24.8		Reddy [1980]
India: 6 villages	28.0	21.5 - 33.6	Reddy [1980]
Bangladesh: Sakoa village	30.7	26.6 - 37.7	Quader & Omar [1982]
Bangladesh: 4 villages	33.7		Quader & Omar [1982]
Sri Lanka: 1 village b/	38		Bialy [1979]
(par-boiling rice)	(11.4)		Bialy [1979]
Other			
"To": Upper Volta	7		Sepp et al [1983]
Beer: Upper Volta	21		Cecelski [1984]
Tortilla: Mexico	38		Evans [1984]
Kidney beans: Mexico	225		Evans [1984]

a/ Range is for averages for six sites, including cooking other than for staple foods; hence greater consumption at high incomes.

b/ Abundant firewood close to village.

Since diets include food other than staples, another useful indicator is cooking energy consumption per person-meal or per person-day. Table 3.2 compares cooking fuel consumption per capita on a daily basis, and is also based on field measurements. Despite a wide range of locations and conditions, the range of consumption is quite small. In all cases food is cooked predominantly by open wood fire: lower figures apply to efficient wood (or charcoal) stoves and modern fuels. 1/

Table 3.2: Specific Fuel Consumption for Cooking
(MJ/capita/day)

Location	Household Size	MJ/cap/day	Percent Biomass	Source
Fiji: 14 villages		11.6 - 16.9	100	Siwatibau [1981]
Indonesia: Lombok	6.9 - 7.1	12.3 - 15.3	84 - 96	Weatherly [1980]
Bangladesh: rural		13.7	95	Mahmud & Islam [1982]
Indonesia: Klaten	5.4 - 5.5	14.8 - 21.4	57 - 100	Weatherly [1980]
S. Africa: Mondoro		15.1	100	Furness [1981]
India: Tamil Nadu		15.9 - 24.1	97 - 99	Aiyasamy [1982]
Indonesia: Luwu	5.8 - 6.3	17.0 - 24.4	99 - 100	Weatherly [1980]
Bangladesh: Sakoa	4.1 - 11.0	17.0 - 28.8	100	Quader & Omar [1982]
S. Africa: Chiwundra		17.5	100	Furness [1981]
Fiji: atolls		18.1	100	Anon [1982]
Bangladesh: Ulipur		18.6	100	Briscoe [1979]
India: Karnataka		19.5 - 23.8	100	Reddy [1980]
India: 2 villages		20.8 - 49.3	96 - 97	Bowonder & Ravishankar [1984]
Bangladesh: 4 villages		22.2	100	Briscoe [1979]
Mexico: 2 villages		24.8		Evans [1984]
India: Pondicherry		27.1 - 29.3	97 - 91	Gupta & Rao [1980]

1/ In the industrialized countries, where modern cooking fuels and equipment, eating away from home, and the use of partially cooked, processed foods are almost universal, specific fuel consumption for cooking in the late 1970s ranged from a low of 0.9 MJ/capita/day in Canada to 2.9 MJ/capita/day in the United Kingdom [Schipper 1982]. These low figures may also be found in developing countries among single, professional people.

The effect of different cooking technologies and variations in the type of meal cooked can be seen in Table 3.3, which is based on field tests in Fiji [Siwatibau 1981]. Using as a point of reference the energy used for the second type of Indian meal using a kerosene primus stove, some appliances have a consumption range of about 2:1 for different meals. With other appliances there is little variation according to meal type. The largest variations are for the type of appliance, with a range of 14:1.

Table 3.3: Fuel Consumption, Relative Efficiencies, and Cooking Times for Different Meals and Types of Cooking Appliances

Type of Cooking Appliance	Type of Meal				
	Fijian	Indian 1	Indian 2	Chinese 1	Chinese 2
Energy Consumption (MJ)					
Kerosene:					
primus	3.6	3.5	2.5	5.0	5.6
wick	12.1	6.1	8.2	5.2	6.9
Charcoal:					
stove	13.3	14.0	13.1	15.1	19.9
Wood:					
open fire	23.6	24.4	18.0	19.3	13.3
chulah	35.0	42.6	35.0	40.9	63.9
chanalan	21.0	25.0	19.5	19.9	--
Relative Energy Consumption					
Kerosene:					
primus	.69	.71	1.0	.50	.45
wick	.21	.41	.30	.48	.36
Charcoal:					
stove	.19	.18	.19	.17	.25
Wood:					
open fire	.11	.10	.14	.13	.19
chulah	.07	.06	.07	.06	.04
chanalan	.12	.10	.13	.13	--
Cooking Times (minutes)					
Kerosene:					
primus	58	57	70	57	130
wick	59	55	63	60	147
Charcoal:					
stove	63	70	75	75	65
Wood:					
open fire	63	61	70	73	30
chulah	90	87	95	81	100
chanalan	75	67	88	81	--

Source: Siwatibau [1981].

Fuel Preferences

Cooking is an end-use in which one finds strong and often highly specific fuel preferences. The reasons for choosing particular fuels and cooking appliances include ease of handling and lighting, flame quality and temperature, ability to secure fire from young children, smokiness and the taste imparted to food, as well as relative prices and availability of fuels. These same factors may lead households to reject "improvements" such as more efficient stoves which do not satisfy their customs and preferences. Some examples of these preferences and their weight in decisions regarding fuel choices are given below.

In the town of Waterloo, Sierra Leone, although the average family spent 30% of its income on firewood, two thirds of them would not switch from it "for any reason whatsoever." The other third were prepared to change to charcoal or, at worst, kerosene. The reasons for preferring woodfuels included food tastes, safety, and the wider range of cooking methods that are possible with an open fire. The cost of woodfuels relative to that of fossil fuels was the least important consideration [Cline-Cole 1981].

Protection against shortages of modern fuels is another key factor, often expressed by the ownership of more than one type of fuel/cooking device. In urban areas of the Philippines, for example, wood and charcoal are kept as emergency fuels in case gas and electricity supplies fail [PME 1982]. Multiple fuel use is also common for different cooking tasks. Many surveys have found that woodfuels are used primarily for cooking staples which may take on an oily taste on a kerosene stove; while kerosene is strongly preferred for quick snacks or boiling small amounts of water for hot drinks, as in Indonesia [Weatherly 1980].

In summary, it is difficult to generalize about consumption levels or fuel and equipment choices for cooking. Where interventions are being considered, local quantitative and attitudinal information must be used as a basis.

C. COOKING STOVES AND EQUIPMENT

Since much already has been written on the problems and successes of improved cook stove (ICS) programs [Foley & Moss 1983, Joseph & Hassrick 1984, Manibog 1984], this section will not review these programs. Nevertheless it is worthwhile to note the important questions which these programs indicate should be asked in considering any improved stove program: (1) What improvements do consumers want? (2) Does the improved stove provide them, in the consumers' judgement? (3) Will the stove save fuel? and (4) What does it cost?

It is critical that stoves be designed and disseminated around social preferences as well as technical factors. Stove users, producers, disseminators, developers and evaluators should all be involved in any stove development and dissemination project, since each group has its own set of objectives, priorities and measures of success. Successful stove design is largely a matter of striking the right compromise between these values, particularly those of the users. The active participation of women, extension groups and stove producers has proved to be essential to the success of stove programs [Joseph & Hassrick 1984].

Before discussing stoves, we must note that they are only one part of the cooking "system." Other factors such as the type of cooking pot, how well pots fit the stove openings, whether lids are used, and management of the fire and fuel, are important to fuel and cost savings and social acceptability. Table 3.4 lists these factors and describes how they affect energy efficiencies and fuel savings.

Table 3.4: Factors Affecting Cooking Efficiencies

Giving Higher Efficiencies	Giving Lower Efficiencies
Fuel	
dry wood, dry climate	- wet wood, moist climate
small wood pieces (even air to fuel ratio)	- large wood pieces (uneven and sometimes inadequate air to fuel ratio) dung and crop residues (usually higher moisture content)
Fuel Use and Cooking Site	
careful fire tending (burning rate to match required power output for cooking task; fire alight for minimum periods before and after cooking)	- poor fire tending (e.g. attention to other domestic tasks)
indoor cooking (protection from drafts)	- exposed outdoor site (but see text on smoke and health effects)
Stove and Equipment	
aluminium pots (good heat transfer)	- clay pots
use of pot lids (reduced heat losses)	- no pot lids
large pot, small fire/stove	- small pot, large fire/stove
pot embedded into stove opening (large heat transfer area)	- non-embedded pot
well-fitted pot(s), with small gap between pot and stove body (increased heat transfer)	- poorly fitted pot(s)
new stove, good condition (e.g. reduced heat loss through cracks)	- old stove, poor condition
metal ceramic-lined stove	- clay or mud stove, open fire
Cooking Methods	
stove well adapted to or allows improvements in methods	- stove ill-adapted to customary methods
food preparation to reduce cooking times (e.g. pre-soaking of cereals, beans)	- no initial preparation
use of ancilliary equipment (e.g. hay box for extended, slow cooking, thus reducing need for stove)	

Stove Types

A summary of stove types and their advantages and disadvantages is presented in Annex 5 [Prasad et al. 1983]. 2/ This section presents only general comments and ranges of technical data.

Improved Cook Stove programs initially focused on rural mud and clay stoves, usually to be built by the intended user. They generally had poor performance and acceptance (see Annex 5 for their main disadvantages). More recently, attention has turned to urban and peri-urban consumers, to ceramic and metal stoves for burning wood or charcoal, and to construction by artisans with distribution through the market, perhaps with government subsidies. Acceptance has improved, in some cases dramatically. Quite rapid increases in stove production and sales are now being seen in several countries.

For example, in Kenya some 84,000 improved "Jiko" stoves costing $4-6 have been sold in a period of 24 months [Hyman 1986]. In Niger, about 40,000 scrap metal woodburning stoves costing less than $6 have been sold in 24 months [UNDP/The World Bank 1987]. And in Nepal, a concerted effort is being made to introduce improved woodstoves as part of a World Bank Community Forestry Development and Training Project. Over 10,000 stoves (mainly ceramic-insert and double-wall design) had been installed by 1985.

Stove Efficiencies and Fuel Savings

Stoves are usually rated and compared to traditional cooking methods in terms of efficiency (see Chapter I for definitions). Other important user criteria are the maximum and minimum power output, i.e., output range and "turn-down" ratio; the type of fuel, including the size and uniformity of firewood pieces; equipment lifetime; and cost.

Early emphasis on achieving high efficiencies often ignored the other technical aspects which are equally important for designing acceptable and convenient stoves [Prasad et al. 1983, Manibog 1984]. However, some compromise between the various technical factors is inevitable in designing a new stove. For example, efficiencies are often extremely low at low power outputs, but to correct for this (by altering the air flow to the combustion chamber) may upset the power range and efficiencies at higher power outputs.

2/ Information on basic construction designs and technical details such as efficiencies, power ranges, and labor and material needs for specific improved clay, mud, ceramic and metal stoves can be found in: de Lepeliere et al. [1981], de Lepeliere [1982], Prasad [1982], Prasad & Sangren [1983], Sulitlatu, Krist-Spit & Bussman [1983], Strasfogel [1983 a,b], Baldwin & Strasfogel [1983], Prasad & Verhaart [1983], and Foley & Moss [1983].

As a result, stoves with high efficiencies in laboratory tests have failed to produce the expected fuel savings under practical conditions. This is usually because cooks prefer (or are "forced") to operate the stove in ways that are sub-optimal for maximum efficiency in order to make up for various technical deficiencies. Alternatively, cooks may simply be wasteful in their use of fuel. For example, a stove may be filled to the brim with fuel which is allowed to burn out completely, long after the cooking pot has been removed.

On the other hand, improved stoves which have been designed taking into consideration users' habits have been shown to save substantial amounts of fuel under real life conditions. For example, in Senegal metal stoves consistently achieved fuel savings of about 30% compared to open fires when used for the same meals and cooking environment, as predicted by laboratory tests. [Ban 1985].

As this example suggests, it is essential to compare like with like when assessing stove performance. The failure to do this underlies much of the controversy and conflicting evidence on whether an improved stove is more efficient or needs less fuel than a traditional stove. Much of this controversy can be ascribed to: (1) comparing different products, e.g., a one-pot and two-pot stove [Bialy 1983]; (2) using different cooking utensils, e.g., aluminium versus clay pots; (3) using different test procedures; and (4) poor definitions of test procedures. Given these disparities, it is no wonder that widely different efficiencies are reported in the literature even for the same type of stove [Gill 1983].

To clear up this confusion, standard efficiency tests have been devised and are being used more and more [VITA 1984]. See Annex 6 on Stove Performance Testing Procedures. These tests do not measure efficiency in the narrow technical sense (i.e., utilized heat output/fuel energy input) but rather the Specific Fuel Consumption (SFC) for a defined cooking cycle, such as preparing a standard meal (see Table 3.2).

The wide diversity in efficiency values is depicted in Table 3.5, which provides a set of cooking efficiencies that can be used as reasonably reliable, broad guidelines. Nevertheless, actual measurements of fuel use per cooking cycle yield superior values and should be used in place of these guidelines whenever they are available. The efficiencies provided in Table 3.5 are based on a variety of sources. Before applying these values, one should be aware of the factors which influence cooking efficiencies and SFCs, shown in Table 3.4.

Table 3.5: Average Cooking Efficiencies for Various Stoves and Fuels a/
(Percent)

Fuel/Stove Type	Lab b/	Field c/	Acceptable d/ Value
Wood			
Open fire (clay pots)		5 - 10	7
Open fire ("3 stone"; aluminum pot)	18 - 24	13 - 15	15
Ground oven (e.g. Ethiopian "altad"	-	3 - 6	5
Mud/clay	11 - 23	8 - 14	10
Brick	15 - 25	13 - 16	15
Portable Metal Stove	25 - 35	20 - 30	25
Charcoal			
Clay/mud	20 - 36	15 - 25	15
Metal (lined)	18 - 30	20 - 35	25
Kerosene			
Wick:			
Multiple wick	28 - 32	25 - 45	3
Wick Single wick	20 - 40	20 - 35	30
Pressurized	23 - 65	25 - 55	40
Gas (LPG)			
Butane	38 - 65	40 - 60	45
Electricity			
Single element	55 - 80	55 - 75	65
Rice cooker		85	
"Electric jug/pot"		80 - 90+	85

a/ Assuming aluminum cooking pots unless otherwise indicated.
b/ Mostly from water boiling tests.
c/ Generally reflects cooking cycle tests.
d/ Acceptable: *assuming that the dominant stove types are higher quality* examples of the type; i.e. excluding stoves demonstrated as having inferior efficiencies.

Other Technical Aspects

Reliability and longevity are also important design aspects. In measuring longevity, the "half-life" concept is often used in the ICS literature [Wood 1981]. This refers to the number of years after which half the stoves that were originally disseminated are no longer in use.

Smokiness and its relationship to eye irritations, eye disease, chest complaints and other afflictions among women (or other family members) has often been neglected by stove designers and analysts. Nevertheless it is an important criterion in stove acceptance. Recent work by Smith et al. [1984] in different areas of India suggests that smoke from cooking fires can be highly carcinogenic and that carcinogen levels greatly exceed acceptable exposure rates in developed countries. Evidence of correspondingly high carcinoma incidence in housewives is still slim, however. On the other hand, smokiness is sometimes seen as a benefit since it repels insects, and the smoke has creosotes which preserve thatch and timber roofs from premature deterioration.

Stove Costs

Although serious work on stove programs has been going on for five years, there still is very little economic data available for different types of stoves. It is not always clear in this data whether costs apply to the stove only, the fuel only, or the stove and fuel. Initial costs and/or lifetimes also may not be given, so that payback periods cannot be calculated. Furthermore, costs to the stove user may be estimated but costs for other essential groups in the design, production and dissemination chain are frequently neglected. To the producer (artisan or stove owner) the important economic factors are profits or the return to labor; to the stove developer, the development and testing costs; and to the disseminating agency, the margins after accounting for the costs of marketing, distribution, training, monitoring and, possibly, subsidizing the improved stove. All these costs and margins should be considered, since an improved stove program can fail if the economics are poor for any one link in the chain.

The costs of stoves vary widely by type, technical specification (size, quality of materials and workmanship, etc.), and country. The costs of woodburning stoves can range from less than $1.00 for a simple scrap metal type in some developing countries to as much as $60 for a modern, heavy metal oven. Experience in a number of countries indicates that improved wood and charcoal burning stoves can be produced and sold for anywhere from US$1 to US$15. For example, in Kenya, the very successful improved Jiko -- a charcoal stove of metal ceramic construction -- presently sells for US$4-8 while in Ghana local scrap metal woodburning stoves cost about US$1 and heavy metal stoves sell for about US$5-8. In Peru, an improved ceramic stove costs about US$1-2.

While prices may vary considerably from country to country, within a country there tends to be a relationship between the prices of the different types of stoves. This relationship is summarized in Table 3.6.

Table 3.6: Generalized Stove Cost Index
(mud stoves = base)

Woodburning Stoves	
Mud	1.0
Clay	1.5 - 2.0
Metal	0.60 - 6.00
Charcoal	1.0 - 2.5
Kerosene	2 - 8
Gas	12.0
Electric	14.0

To the user, the amortized cost of an improved stove would normally be a minor factor in the total lifetime of the stove. But the investment to purchase the stove occuring at one point in time may be a major deterrent to poor families. For the user, the economics of an improved stove is determined by the amount of fuel saved and, if adoption demands a switch in fuel, relative fuel costs.

This point is clearly illustrated by the recent cost comparisons of eleven stove/fuel combinations in Thailand, presented in Table 3.7. The amortized cost of the stove ranges from about 13% to as little as 0.5% of the total monthly costs, including fuel. The total monthly costs are dominated by the unit costs of the fuel and by the efficiencies.

For this reason, the most useful cost indicator for stove users is the payback period; i.e., the time required to pay back the investment on the stove (plus any repair costs) through reduced fuel costs. Methods for estimating payback times are presented in Annex 7.

Payback periods as short as 13 days have been reported for an improved charcoal stove plus a change to aluminium pots at current market prices in Ethiopia [UNDP/World Bank 1984b]. Payback periods of one and three months have been estimated respectively for metal stoves in Burkina Faso [Sepp et al. 1983] and ceramic stoves in Nepal [Bhattarai et al. 1984]. In contrast, heavy mud stoves built *in situ* by artisans have had payback periods of as long as 12-30 months.

Table 3.7: Efficiencies and Total Costs of Various Fuel/Stove Combinations in Thailand

Fuel	Stove Type	Efficiency	Fuel Cost per Kg	Fuel Cost per Month	Stove Cost per Month	Total Cost per Month
		%	baht	baht	baht	baht
Rubber Wood	Bucket	24	.16	1.14	.16	1.30
Rice husk	Bucket	23	.16	1.19	.16	1.35
Rice husk	Rangsit	16	.19	2.04	.30	2.34
Rice husk	2-hole mud	12	.19	2.61	.22	2.66
Sawdust	1-gal.can	16	.76	5.76	.03	5.64
Charcoal	Bucket	18	1.70	6.46	.16	6.62
Charcoal	Bucket	14	1.70	8.84	.16	9.00
Corn cob	Bucket	21	1.45	8.93	.16	9.09
Corn cob	Bucket	17	1.45	11.24	.16	11.40
Rice husk log	Bucket	25	1.85	12.67	.16	12.83
Sawdust log	Bucket	18	2.03	18.92	.16	19.08

Source: Islam et al. [1984].

Dissemination and Impact

In addition to stove costs and payback periods, any stove program must also allow for regional fuel constraints, user preferences, and institutional requirements. Manibog [1984] discusses thoroughly the problems of carrying out ICS projects. There are six essential conditions for getting operational stoves into widespread use. These include: (1) active participation of women (stove users), artisans, and the marketing or disseminating (e.g. extension) workers in developing or adapting a stove design; (2) proof that long-run market, production, delivery, and maintenance systems exist or can be established; (3) establishment of training programs for local artisans or extension workers; (4) development of and strong financial support for a strategy to market the chosen stoves and appliances based on comprehensive acceptance surveys, and, possibly, incentive pricing systems to stimulate early adoption of the new technology; (5) continued support for research and monitoring of stove development; and (6) market conditions which allow competitive models to be developed and reach the market.

The potential gains from improved woodstove programs are enormous. Many of them do not relate directly to "energy" but involve, for example, better health and hygiene, safety for young childern, and improvements to the general cooking environment. At the same time reductions of 30-50% in fuel use can be achieved and should be easier to deliver and manage, and in less time than supply-side developments such as fuel plantations.

The cumulative impact of an improved stoves program on national fuel savings can be significant. As explained in "Tropical Forests: A Call for Action," [WRI 1985] this impact "will depend on the number of households that use the stove, the amount of time the stove is used, and the actual gains in efficiency obtained from the stove." For example, if 50% of households in a region use improved stoves for cooking 80% of their meals, and the stoves double the cooking efficiency, a 20% decrease in fuelwood consumption would be achieved. However, if only 10% of the households in a region use the stove, and cook only 50% of their meals on it, the decrease in fuelwood use for cooking is only 2.5% for the region.

A recent study in the Kathmandu Valley, Nepal -- a region containing some 800,000 people -- estimated that improved stoves could save up to 92,000 tons a year of fuelwood valued at US$6 million. This is equivalent to the annual yield from a 14,000-hectare fuelwood plantation in local conditions.

D. LIGHTING

Although lighting uses relatively little energy, it has an important place in household energy for three reasons. First, lighting usually involves the use of commercial energy and often is the only use for such energy by poor households. Second, low and middle income families view improved lighting as a high priority in the achievement of better living standards. Third, for poor families improved lighting usually involves substantial equipment costs whether they be for a kerosene pressure lamp or electric light fittings and connection charges.

As a result, energy consumption for lighting normally increases quite rapidly with income above a certain threshold level, but at the same time may be a critical component in the energy budgets of the poor. Consumption is also highly dependent on energy prices and technologies, which have a very large range of end-use efficiencies and hence a large potential for energy savings without sacrificing lighting standards.

Although information on energy use for lighting has improved with recent surveys, in general it has been poor. Household surveys often fail to separate consumption of electricity and liquid fuels (e.g. kerosene) into lighting and other end-uses; and very few studies have followed the energy used for lighting through to the ultimate level of service provided, such as levels of illumination and daily hours of lighting.

Measurement Units and Standards

The basic unit of light intensity is the lumen (lm), which combines a physical measure of the light level with the response to this by the human eye. Another unit is the lumen/Watt (lm/W), which introduces measures both of efficiency and the rate of light output over time. For instance, a 100-W incandescent bulb typically provides 15-18 lm/W, or a "luminous flux" of 1800 lumen. Illuminance refers to the effective light level per unit area and is the measure on which lighting standards are set. An illuminance of 1 lumen/ft is equal to one footcandle. Table 3.8 provides international lighting standards which were devised for developed countries. They suggest that some working conditions require a lighting intensity seven times greater than normal background lighting. However, these standards are often too high to be considered practical for developing country applications where incomes are low and/or electricity costs are high; e.g., for home or village street lighting.

Table 3.8: Lighting Standards for Various Household Activities

Activity	IES Standard (footcandles lumen/ft^2)
Passageways, relaxation, and recreation	10
Reading (book, magazines, and newspapers)	30
Working (kitchen sink handwriting, study)	70

Source: Leckie, J., ed. [1975].

Lighting Energy, Fuels, and Technologies

Many poor families in developing countries rely on the cooking fire and possibly candles and sparing use of an electric torch to meet all their lighting needs. For others, electricity and kerosene are the main energy sources for lighting. Of these, electricity is usually preferred (although it may not be available, or is too expensive) because of its cleanliness, convenience and better spectral light "quality". Kerosene or benzine lamps, on the other hand, have a high glare factor, are hot, and in the case of pressure lamps, are very noisy. Many electrified households, however, consume significant amounts of kerosene as a supplementary lighting source and/or during power shutdowns. Benzine is often used instead of kerosene by higher income households in non-electrified villages. Gas lighting is a rarity.

Table 3.9 indicates the range of kerosene consumption for lighting, based on the few surveys where this end-use was distinguished and where 90-100% of lighting needs were met by kerosene. For low to middle income groups, consumption is roughly 25 liters (1.8 - 3.6 GJ) per household per year, or about 0.07 - 0.28 liters per night, although much

Table 3.9: Household Kerosene Consumption for Lighting
(liters per year)

	Kerosene		
	Mean	Range	Source
Rural			
Bangladesh: Sakoa			
low income	28		Quader & Omar [1982]
high income	143	-	" "
India: Balagere	35		Bowonder &
Bhogapuram	42		Ravishankar [1984]
6 villages	52	45-61	Reddy [1980]
all rural/low income	25	-	Natarajan [1985]
all rural/high income	51		
Indonesia: 3 villages		70-500	Weatherly [1980]
Sumatra	254		Down [1983]
all rural 1976	148		Strout [1978]
Pakistan:			
all rural/low income	34		FBS [1983]
Sri Lanka	104	96-140	Wijesinghe [1984]
Thailand		55-91	Arnold & deLucia [1982]
Urban			
India:			
all urban/low income	31		Natarajan [1985]
all urban/high income	86		" "
Indonesia 1976	570		Strout [1978]

higher figures have been reported for Indonesia, possibly because of exceptionally low kerosene prices at the time. Lighting periods in these surveyed households were typically about 2-4 hours per night.

Table 3.10 presents data for India on the consumption of lighting kerosene and electricity by income level, urban-rural differences, and whether houses are electrified or not [Natarajan 1985]. Notable points are that consumption increases significantly with income only above annual incomes of around 6,000 rupees (approx. US$600), and kerosene is used rather extensively in electrified households, especially in rural areas. The substitution ratios shown in the final column are discussed below.

Kerosene and benzine are burned either in open wick lamps (typically with a naked flame from a wick protruding from a simple jar or bottle of fuel); enclosed wick lamps, in which the wick is surrounded by a glass chimney that creates an updraft past the wick and promotes a

Table 3.10: Energy Use for Lighting in Electrified and Non-Electrified Households, India 1979 (by Income and Urban-Rural Location)

Annual Income (thousand Rupees)	Non-Electrified		Electrified			Substitution
	Kerosene (litres)	GJ	Kerosene (litres)	Elec. (kWh)	Total GJ	Ratio a/ (litres/kWh)
Rural						
<3	25	0.87	9.0	156	0.88	0.10
3- 6	29	1.02	8.4	163	0.88	0.13
6-12	41	1.44	10.4	205	1.10	0.15
12-18	46	1.60	10.1	283	1.37	0.13
18	51	1.79	10.6	322	1.53	0.13
ALL	28	0.97	9.1	178	0.96	0.11
Urban						
<3	29	1.03	4.5	164	0.75	0.15
3-6	31	1.07	6.1	189	0.89	0.13
6-12	31	1.07	4.8	243	1.04	0.11
12-18	50	1.74	3.9	324	1.30	0.14
18	86	3.02	3.9	425	1.67	0.19
ALL	31	1.08	5.3	217	0.96	0.12

a/ Substitution ratio is the difference in kerosene use between non-electrified and electrified households divided by electricity use in the latter (litres kerosene/kWh electricity, per year).

Source: Natarajan [1985].

hotter, brighter flame; or pressurized lamps which normally employ a coated mantle to provide an intense white light.

Table 3.11 provides data on light intensities and the specific fuel consumption of kerosene lamps. Comparing this with Table 3.7, it can be seen that most kerosene lamps provide very low lighting intensities, far below those required to meet the illumination standards accepted in developed countries. Indeed, in a survey of low income Indonesian households, Weatherly [1980] found that the simplest, small wick bottle lamps, although burning only 10 millilitres of fuel hourly, gave out a light equivalent to only a 2-Watt electric torch bulb.

Table 3.11: Technical Characteristics of Lighting Fuel/Lamp Combinations

Fuel and Lamp Type	Light Intensity (Foot candles at 30 cm)		Fuel Use (millilitre/hour)	Consumption Index a/
Kerosene	Mean	Range		
Fishcan and wick	0.5		9.8	127
Standing	1.5	up to 4	12.0	52
Hurricane	3	1 - 35	12.1	26
Pressure ("Tilly")	32	20 - 70	47.8	10
Benzine				
Pressure ("Coleman")				
badly pumped	20	8 - 25	48.6	15
well pumped	25	20 - 45		
Electricity				
60-W incandescent	40		(60 Wh)	1

a/ Consumption index is measured as power input per unit lighting intensity, normalized to 1 for the 60-W bulb. Calorific values used are: kerosene 35 MJ/liter; benzine 33 MJ/liter; electricity 3.6 MJ/kWh.

Source: Siwatibau [1981].

The costs of various lighting technologies are given in Table 3.13. For the poorest families these costs are a major deterrent to adopting lighting standards which improve on simple wick lamps. However, for families who own or are choosing between relatively advanced lighting equipment, initial costs are a small part of total life-cycle costs.

Relative efficiencies and energy prices are therefore critical components in the economics of lighting. Here it is worth noting that in the Indonesian case just cited, the respective power inputs were 0.01 liter/hour x 35 MJ/liter = .35 MJ/hour for the kerosene lamps and 0.002 kW x 3.6 MJ/kWh = .0072 MJ/hour for the 2-W electric bulb with the same lighting intensity. Thus, the wick lamps were roughly 50 times less efficient than incandescent electric lighting. Few kerosene lamps have an efficiency better than 1/10th that of electric lighting, as can be seen in the final column of Table 3.11 which gives an index of power input per unit lighting intensity. As a result, one frequently finds that the running costs of electric lighting are less--or much less--than lighting by kerosene for an equivalent light output.

Table 3.12: Lamp Costs

Country	Type of Lamp	Cost 1984 (US$)
Fiji	Large Kerosene	45
	Large Benzine	43
	Small Benzine	29
Liberia	Small kerosene (Chinese)	5.50
	Medium " "	7.50
	Large " "	11.75

This point is of great importance for fuel substitution. Since electricity almost invariably replaces kerosene for lighting, and not vice versa, one might expect energy consumption to fall after the switch due to the much greater efficiency of electric lighting. However, most consumers increase their lighting standards (intensities) at the same time.

The important quantity for analysts therefore is the actual energy substitution ratio. This can be established only by comparative surveys of electricity and kerosene users at similar socio-economic levels or, preferably, by consumption surveys before and after the substitution is made. The results from the few analyses of this kind that have been made are given below.

In Klaten, Indonesia, Weatherly [1980] found that one kWh of electricity for lighting replaced 0.51 liters of kerosene: an electricity/kerosene energy ratio of 3.6:18 MJ, or 1:5. In six South Indian villages [Reddy 1980], electrified households used one kWh for every 0.15-0.28 litres of kerosene in non-electrified households: an energy ratio of 1:1.5 to 1:2.7. In the Indian survey reported in Table 3.9, the ratio for the bulk of rural and urban households was a bit lower at 0.13 - 0.15 litres per kWh, an energy ratio of 1:1.3 to 1:1.5.

Table 3.13 presents the costs and specific consumption of electric luminaires which include incandescent bulbs, standard fluorescent lamps, and "advanced" technologies available in the early 1980s. The costs are for retail markets in Brazil in 1983, converted to US dollars. One notable point is the large range in lighting efficiencies, expressed here in lumen output per Watt input. The range is from 12 to 63 lumen/watt, a ratio of 5:1. The second point is the much higher cost of the fluorescent and "advanced" devices, although these are offset by their much longer lifetimes.

For consumers, the economics of these lighting methods depend on the tradeoff between the high costs of efficient equipment and the lower running costs of this equipment. The economics can best be compared by estimating payback times, as with stoves (see Annex 7). A payback calculation to compare the 40 W incandescent bulb to the 16 W fluorescent light, normalized to an output of 1,000 lumen, is presented in Table 3.14. Despite the 18-fold difference in equipment cost, the total costs over the first 5,000 hours, when the fluorescent light has to be replaced, are very similar at around $17 for an electricity price of 3 USc/kWh. For any higher electricity charge, the fluorescent light would be the most economic on a life-cycle basis.

Table 3.13: Technical Characteristics and Costs of Electric Lighting Technologies
(Market Prices in Brazil, 1983)

Technology & Power Input	Light Output (lumens)	Specific Consumption (lumen/watt)	Life (hours)	Equipment Cost (US$ 1983)
Incandescent				
40 W bulb	480	12.0	1,000	0.5
60 W bulb	850	14.3	1,000	0.5
100 W bulb	1,500	14.9	1,000	0.6
Fluorescent tubes				
11 W tube	400	35.7	5,000	13.0 a/
16 W tube	900	55.6	5,000	13.0 a/
Advanced fluorescent bulbs				
9 W bulb	425	47.6	5,000	13.0
13 W bulb	500	38.5	6,000	9.2
18 W bulb	1,100	62.5	7,500	25.0
High intensity discharge				
55 W bulb	2,250	41.7	5000	12.0

a/ Including ballast, costing US$4 with life of 20,000 hours.

Source: Goldemberg et al. [1984].

Table 3.14: Payback Analysis for 16 W Fluorescent Lighting
Compared to 40 W Incandescent Bulbs
(data from Table 3.12)

For light output of 1,000 lumen and lighting for 5,000 hours:

	40 W bulbs	16 W fluorescent
Lumen per unit	480	900
No. of units required	2.1	1.1
Lifetime per unit (hours)	1,000	5,000
Unit cost (US$)	0.5	13.0 a/
Equipment costs for 5,000 hours		
Units purchased	10.2	1.1
Equipment costs (US$)	5.1	14.3
Energy costs: general		
Watts per 1000 lumen output	83	18
kWh for 5000 hours lighting	415	90
Total costs at 3¢/kWh		
Equipment	5.1	14.3
Electricity	12.45	2.7
TOTAL	17.55	17.0
Payback period: approx. infinite		
Total costs at 5¢/kWh		
Equipment	5.1	14.3
Electricity	20.75	4.5
TOTAL	25.85	18.8
Payback period: approx. 5,000 hours x 18.8/25.85 = 3,636 hours 727 days (2 years) if 5 hours lighting per night		

a/ Includes ballast at US$4. Replacement required only after 20,000 hours.

Photovoltaic Lighting

Photovoltaic lighting in some instances can be a viable alternative to the more traditional lighting systems and therefore should be examined also. A typical household solar lighting system consists of a solar panel or "array" with an output capacity of 20-30 Watts for a solar input of 1 kW/m^2 (i.e. 20-30 peak Watts, or Wp), a deep-charge battery, and 2-3 fluorescent lights which are run for about four hours per night. Outputs for TV and radio are often provided as well. Total kit costs (i.e. panel, lights, battery and wiring) average US$250-350, while total installed costs are about US$300-400 (or about $12-15 per Wp). Panel costs were approximately US$6-9 per peak Watt in 1984 for small-scale household systems but are expected to fall steadily. These costs reflect favorable situations where good market, transportation and installation conditions exist, i.e., mostly in urban areas where grid electricity usually is available. Although running costs are close to zero, actual financial life-time costs cannot be generalized since they depend on the average level of solar radiation, its seasonal as well as day-to-day variability, and the amount of lighting demanded from the system. However, some estimates can be made, as in the example below.

<u>Example</u>

Assume: interest (discount) rate = 10%
10-year kit life; i.e., amortization factor = 0.162
total daily insolation equivalent to 1 kW for 5 hours.

Then 30 W kit costing $300 installed,
will produce 30 x 5 x 365 = 54750 kWh/year

Annualized cost of installed kit will be:
0.163 x $300 = $50

And thus, elecric power cost produced with such a kit would be $50/54,750 = $0.91/kWh

Studies which have compared the economics of kerosene, diesel-electric and solar lighting in remote rural areas tend to find that solar and diesel costs are fairly close, and generally lower than kerosene, assuming the same quantity of lighting for each method [Wade 1983]. Although this is likely to be the case in sunny regions where no electric grid exists and diesel fuel is expensive or hard to obtain, where these limitations do not exist photovoltaic lighting is unlikely to be economic -- at least at present costs. In the absence of subsidies, the high initial cost is bound to be an insurmountable barrier for most households.

One should also recognize that the economics of all decentralized energy sources compared to those of centralized systems (e.g. grid distribution of electricity) depend on energy consumption levels. Once the capital costs of grid extension have been met, any increases in consumption are related only to generation costs, while the costs of the distribution system per unit of consumption actually fall. In contrast, with a decentralized system each increment of energy use (or power) requires a complete additional supply unit. For this reason, it can often be shown that decentralized (e.g. solar) energy is competitive with grid power at low consumption levels, but compares poorly at higher levels.

E. REFRIGERATION AND OTHER ELECTRICAL END-USES

Higher income households normally consume substantial amounts of electricity for uses other than lighting. The major demands are for refrigeration and air conditioning, with minor amounts for TV, radio and hi-fi, ironing, and electric power tools, etc.

The key parameters in assessing consumption are: (1) ownership levels (and acquisition rates) of the major items of equipment; (2) period of use (i.e., hours per day); and (3) specific consumption (i.e., kW per appliance). Since these factors can be estimated only by detailed measurements over long periods of time, more practical indicators are given by typical ranges of consumption according to equipment ownership.

Two examples of the way in which consumption increases as equipment is purchased are shown in Table 3.15, for Fiji and Sri Lanka. In both cases the large increments in consumption occur when refrigerators and air conditioning are acquired.

Table 3.15: Electricity Consumption by Appliance Ownership: Fiji and Sri Lanka

Location	Equipment Owned	Electricity Use (kWh/month)
Fiji:	Lighting	0 - 15
	+ iron & radio	15 - 35
	+ refrigerator	35 - 150
	+ hot water & washing machine	150 - 300
	+ cooker & air conditioning	above 300
Sri Lanka:	Lighting, fan, iron	27
	+ hot plate & kettle	190
	+ hot water & washing machine	280
	+ air conditioning	700

Sources: Siwatibau [1981]; Munasinghe [1983].

To assess the economics and potential energy savings of conservation programs and other kinds of technology substitution, the technical characteristics and patterns of using the existing equipment stock and possible replacements must be determined. Very little information of this kind has been recorded for developing countries. However, the potential for improving energy efficiencies is undoubtedly large. For example, the specific consumption (i.e. Watts per liter capacity under standardized operating conditions) of Japanese model refrigerators fell by a factor of 3.7 between 1971-73 and 1980; from 0.618 W/litre to 0.166 W/litre [IEE 1980]. With air conditioning one also finds a range of about 3:1 between the most and least efficient technologies in current use.

A number of attempts have been made to induce consumers to adopt some of the more energy efficient equipment that has been tried in developing countries. These include labeling appliances for energy use and setting efficiency standards on domestic producers and imported equipment, as well as controlling electricity pricing and tariff structures.

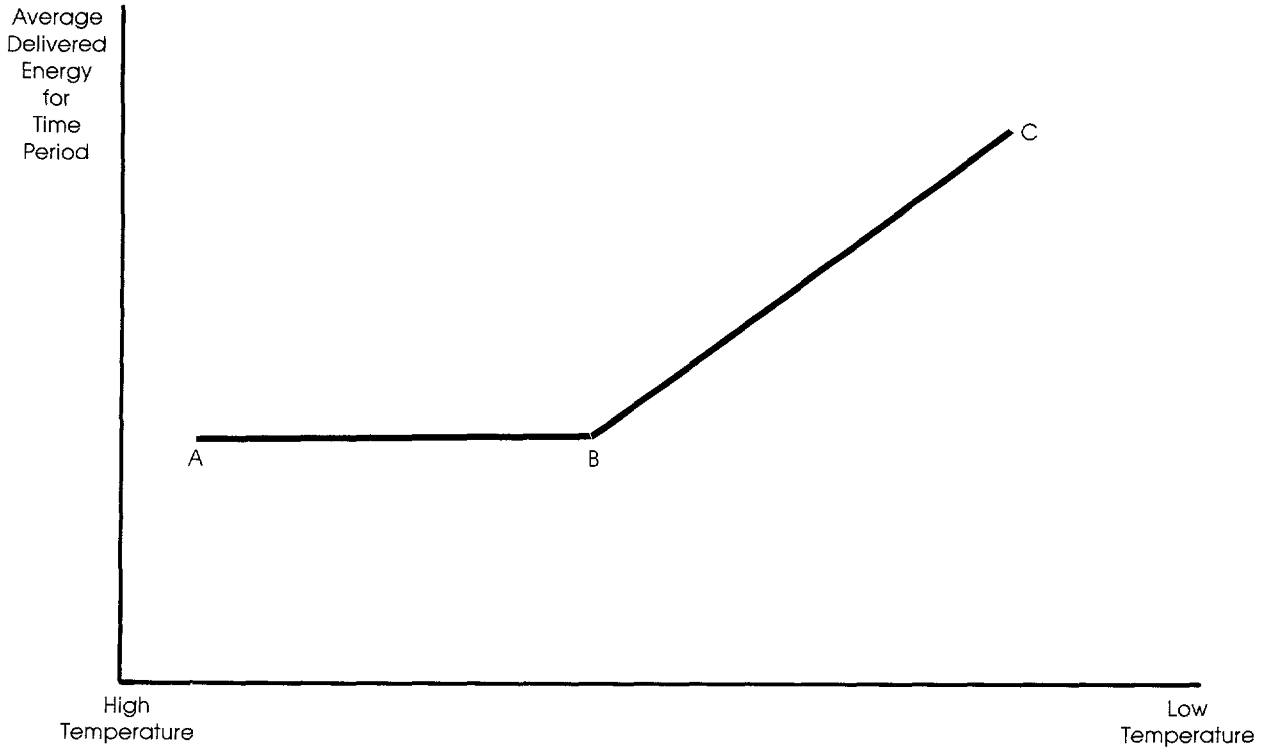
F. SPACE HEATING

The importance of space heating in some areas of developing countries has already been stressed. Several surveys, for example in Lesotho [Best 1979] and Tanzania [Skutsch 1984], have shown that it may as much as double the amount of energy used in winter as compared to summer. The main impact of space heating is not only that it raises total fuel needs but also that it raises them during seasons when it is more difficult to collect, store and dry biofuels.

Despite this, there is little information from which to determine where and when heating is a significant end-use, what levels of consumption to expect, or what might be done to reduce these needs. Two reasons for this dearth of information stand out. First, as discussed before, space heating is provided by any heat source in a dwelling and cannot easily be distinguished from other end-uses. So there is little reliable information on specific consumption levels. Second, ambient temperatures are rarely reported in household surveys. This means that there is little information on which to correlate space heating needs with easily measured or available quantities such as local weather data.

A simple method for assessing space heating needs which is adequate for most analyses is provided in Figure 3.1. The promotion and economic analysis of methods to reduce space heating loads are much more difficult in developing countries than in industrialized countries. This is primarily because the majority of dwellings are poorly constructed, so that heat is lost by the infiltration of cold air through innumerable gaps in the structure and around doors and windows, etc. These are not so easily prevented as in well-constructed houses by weather stripping remedies. Reducing conduction losses through the fabric of the dwelling by applying thermal insulation has considerable potential for saving energy in many areas, but the idea is novel and there is usually no tradition of using these techniques.

FIGURE 3.1 Method of Estimating Space Heating Consumption from Total Energy Use and Ambient Temperature



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The graph plots total delivered energy consumption, averaged over periods such as a day or week, occurring within the living space. The portion from A to B is for non-space heating end-uses. At Point B, heat is generated from these uses at the same rate that it escapes from the dwelling to the cooler external surroundings. To the right of B, as the external temperature falls, the temperature inside the dwelling would drop unless extra heat is generated. To maintain the internal temperature, the occupants must therefore burn fuel at a higher rate. The line B-C records this effect and allows for adjustments of internal temperature during colder weather. For example, if the occupants maintain a (roughly) constant average internal temperature--e.g. using a thermostat and central heating system the slope of B-C would be steeper than if temperatures were allowed to fall as the weather gets colder. A few measurements of daily or weekly fuel use at different external temperatures can establish the position and slopes of the lines A-B and B-C. Annual fuel consumption can then be estimated using temperature data for the whole year, assuming that the dwelling is occupied. More sophisticated methods can be found in many texts on heating and energy conservation in buildings.

CHAPTER IV

HOUSEHOLD ENERGY SUPPLIES

A. OBJECTIVES AND STRUCTURE

This chapter discusses household energy resources and supplies, focusing on firewood, charcoal, and other traditional fuels used by households in developing countries. The chapter does not discuss supplies of petroleum, gas or electricity since there is much literature already available on these topics.

As with consumption, household fuel supply issues can be subtle and complex. Where woodfuels are scarce and forests depleted the obvious answer would appear to be to plant more "trees for fuel." However, the many failures to do just this over the past decade underline the fact that there are rarely simple answers to the problems of woodfuel scarcity and indeed, that people frequently have been misled by trying to answer the wrong questions.

Experience to date suggests that fundamental questions must be asked before any effort to increase biofuel supplies is undertaken. For example: Is fuel scarcity really the problem? For whom? Is tree growing the solution? Who wants to and can grow trees? Are the main issues technical and economic, or do they relate to management and social structures?

Section B reviews some of the issues involved in household fuel use decisions and presents observations of behavioral patterns and characteristics of fuel users under various circumstances.

Section C discusses fuelwood supplies, providing data on yields, characteristics of species, and methods of analyzing production in physical and economic terms.

Section D looks at transport and other marketing costs which strongly affect the incentives for producing fuelwood and the retail prices of wood in urban areas. If producer prices are low, farmers are unlikely to grow fuelwood, and continued deforestation by low-cost cutting of natural woodlands may be inevitable. Transport and other marketing costs also play an important role in the relative economics of wood, charcoal and densified crop residues for urban commercial fuels. These costs are also significant in determining the "command area" of urban woodfuel supplies.

Sections E, F and G discuss the key issues in supplying charcoal, crop residues, and animal wastes, respectively. For charcoal these issues include access to and rights over the primary wood resources and the costs and efficiencies of converting them to charcoal. For crop residues the issues involve the amount of residues that can be safely removed from the soil, the costs of collection, and competition with non-fuel uses. The section on animal wastes includes a brief discussion on biogas.

B. BACKGROUND PERSPECTIVES

The African Sahel has experienced widespread deforestation and fuelwood depletion over the past decade and has become a priority target for attempts by governments and aid agencies to plant trees for fuel. Yet by 1982, despite expenditures of about US$160 million only 25,000 hectares of fuelwood plantations had been established, and most of them were growing poorly [Weber 1982].

Similar disappointments have been experienced in other regions. Although there have been a few successes, it is still not clear why those who appear to face acute fuel scarcity are so often reluctant to take steps to increase their traditional fuel supplies. Questions such as this which relate to the socio-economic background of traditional fuel supplies are fundamental to understanding the remainder of this chapter. They are addressed here briefly, before the technical and economic aspects of traditional fuel supplies are discussed. There the focus is on production at the farm and village level rather than on large-scale, managed plantations, since the former is most frequently misunderstood.

Village Biomass Systems

Rural inhabitants produce and depend on biomass materials of all kinds: food, fibre, grass and crop residues for animal fodder, timber for sale or construction materials, crop residues for thatching and making artifacts such as baskets, and biofuels. Most of these resources and the land devoted to their production have alternative uses (or an opportunity cost for any one use) while the materials are frequently exchanged within the village biomass economy in complex and subtle ways.

At the same time, it is reasonable to generalize that, where household fuels are in such short supply that they amount to a "problem" requiring intervention or significant adaptations, there will be shortages of one or more types of biomass material. This is so because scarcities of traditional fuels are generally most severe in areas of high population density (with strong pressures to produce more from each unit of land) and in arid or semi-arid regions where the productivity of all kinds of biomass is low. These biomass shortages may be general, or they may be confined to critical sub-groups such as the landless poor and the small farmer.

Whether general or localized, biomass shortages usually call for an integrated approach to restoring supplies. Particularly where agricultural residues and animal wastes are used as fuels and are in scarce supply (at least for some classes and/or in some seasons) supply-demand balances and remedial actions cannot look only at the fuel aspect of biomass products. If they do, they are likely to produce sub-optimal answers or lead to projects which are rejected, fail once implemented, or actually damage some parts of the community. For example, if animal fodder is scarce, planting trees for woodfuels on grazing land--or planting with species such as *Eucalyptus* which have inedible leaves--could deny essential fodder resources to some people. Conversely, a fodder and dairy development scheme might not only improve nutritional standards and incomes but also "solve the fuel problem" by freeing up biomass resources which can be burned without harm to other production or consumption activities. This latter approach has been shown to be an effective remedy for traditional fuel shortages in semi-arid areas of India, for example [Bowonder et al. 1986]. It is unlikely that this would have been recognized in the more narrow scope of analysis commonly taken in an energy assessment.

Access to Resources

Differential access to resources is another reason why integrated approaches are usually essential. In most village societies there are not only large differences among sub-groups in obvious biomass-related assets such as land and cattle ownership (both of which may provide fuels) but also subtler rights and dependencies concerning fuel collection. These may include rights to graze on or collect fuel from common lands; customs about scavenging crop residues after the harvest or crop processing (e.g., rice straws and husks); and traditions over part-payment for labor in fuel materials instead of cash. Generally, as fuel shortages develop, these traditions, dependencies and "rights" are altered to the disadvantage of the weakest sections of the community.

Similar arguments apply to one of the most common approaches to biofuel shortages: the promotion of small-scale tree growing for fuel and other purposes; e.g., "social and community forestry." Those with the most serious fuel problems are generally the people who are least able to grow trees: landless laborers, small farmers who lack labor and other inputs required for tree care, and pastoralists who lack the traditions of crop and tree planting. In many places, land tenure constraints are fundamental barriers to growing trees. Farm tenancy, often with precarious rights to the land, periodic reallocations of land ownership (as in Burkina Faso), and creeping land enclosure, effectively destroy incentives that do exist for farmers to invest in the long-term enterprise of tree growing (or in soil and water conservation efforts). [Foley & Barnard 1984].

In most of these situations, changes in community attitudes to land holding and access rights are required before the majority of people can either grow trees themselves or benefit from tree growing by others. Quite fundamental changes also usually are required in village power and control structures, or in leadership and the trust that people put on the village elite. Planting communal trees along roadsides, canal embankments and on waste ground, as well as in village woodlots, has taken root in many places and with considerable success. But this success requires a consensus in the community about the need to grow trees, how to distribute the work of tree care, and how to divide the benefits.

Involving the People

The need for integrated appoaches to inherently complex and socially stratified systems leads to a critical question. How are the systems to be understood? The discussion above suggests that before any actions can safely be taken food, fuel, fodder, and fertilizer balances need to be constructed; furthermore, that these balances must differentiate between groups such as large, medium and poor farmers, landless laborers, the landless non-farm population, and so on. Some analysts believe that identifying the critical constraints or scarcest resources requires the use of approaches such as farming systems analysis which look at the linkages and conflicts around all the key resources: land, labor, water, food and feedstuffs, fuel and fiber. Remedies, which may not be primarily directed to "energy", are then based on findings about the operation of the system.

However, this "ideal" approach, if conducted mainly by outside experts, is extremely time-consuming, requiring much more than a rapid, sectoral survey. Furthermore, "outsiders" almost inevitably try to separate and compartmentalize what they think are the relevant factors in order to find and impose pattern and structure in the search for "solutions." These dichotomies may bear no relation to the holistic view of the people on the ground--the "insiders"--who may well see different overlaps, interrelationships, constraints, and opportunities.

The close involvement of local residents therefore is not only necessary to avoid sub-optimal--or rejected or damaging--solutions, it may also be the best way of finding shortcuts to successful remedies. Local residents, better than any outside visitors, know how their system operates, where it fails and needs improvement, and usually what needs to be done if extra resources are made available to work with. Local "grassroots" voluntary organizations frequently share this knowledge, are trusted by the village community, and have the social commitment and motivation to effect change as well as the knowledge and ability to invent new approaches. In short, close liaison with local residents and voluntary organizations is a much better guarantee of success than any amount of data collected for desk analysis.

Tree Loss and Tree Growing

The massive loss of forest and woodland that is occurring across the developing world [WRI 1985] requires broad, integrative thinking if its true causes are to be recognized and effective remedies developed. In most places, the main causes of tree and forest depletion are clearances for arable and grazing lands due to population growth, migration and resettlement schemes; "slash and burn" farming with over-rapid rotation cycles due to population pressures; overgrazing of young trees and supportive grasslands; uncontrolled bush fires; and commercial logging for timber in some areas.

Demand for fuel may play a major part in deforestation in two broad cases. The first is when tree loss has gone a long way and the local rural population must cut fuel from the few remaining trees. Fuelwood cutting thus may play a part in the final stages of tree depletion [Barnard 1985, Newcombe 1984b]. The second case is where the demands of urban markets for woodfuels (firewood or charcoal) are sufficiently large and/or concentrated in particular areas.

In some cases, tree clearance for agriculture can produce a temporary glut of woodfuels, thus lowering prices and encouraging greater consumption and the substitution of woodfuels for fossil fuels. When the glut comes to an end, there may be a sudden onset of woodfuel shortages and a rapid rise in prices. Woodfuel gluts have occurred recently in Sri Lanka, due to the large scale forest clearances of the Mahaweli Development Project; and in Nicaragua, where vast numbers of diseased coffee bushes have been replaced and land reform measures have allocated forest land to peasant farmers.

Tree planting or more productive management of existing forest resources is obviously necessary if these trends are to be decelerated or reversed. But it may not be sufficient if other causes of deforestation that have nothing to do with fuel demand are not also tackled. If woodfuel consumption were to drop to zero overnight, deforestation in many countries would still continue on a significant scale because of factors such as land clearing and overgrazing [Barnard 1985].

In particular, urban pressures on woodfuels can rarely be halted merely by growing trees. The entire structure of woodfuel markets, fees and permits to cut wood, and access rights to forests, must almost invariably be adjusted as well. A full discussion of the issues involved is beyond the scope of this section but a concise description of the impact of urban fuel demands is included in Annex 8 [Barnard 1985].

One also needs to consider the incentives for growing trees, especially where the aim is to provide woodfuels. Planting, weeding, watering, protecting and caring for trees takes time and effort and conflicts with other priorities. This is particularly the case in arid areas, where fuelwood scarcity generally is most acute, because the planting season for both crops and trees is short. Farmers may be able to plant a few trees each year, but if tree growing in any larger volumes interferes directly with food production or off farm wage earning activities, it is unlikely to be undertaken [Hoskins 1982].

Where private farmers do plant trees in large volumes, fuelwood supply beyond their immediate needs usually has a low priority--even in regions of considerable fuel scarcity. This is so because often no well established market and transport systems exist for fuelwood to make private farmers able to profit financially from fuelwood production. In most areas of the developing world, trees are grown for some combination of timber, pulpwood, building poles, fencing material, animal fodder, fruit or nuts, shade, live fencing and hedging, windbreaks or aesthetic reasons. Firewood is seen as a useful by-product rather than a major justification for planting. There have been numerous attempts to promote quick-growing firewood species which have failed almost completely and may well have hampered the growing of other species which would have produced firewood as a by-product [Barnard 1985, French 1981, Weber 1982].

Table 4.1 provides a checklist of the potential benefits from rural tree growing. The range of benefits, which includes both private as well as social benefits, suggests that programs based on narrowly defined objectives, such as woodfuel supply, may greatly understate the real value of trees to rural dwellers.

It is this discrepancy between private benefits and social benefits which creates the divergence between private and social incentives for tree growing. From the farmers' perspective, the social costs (externalities) of not growing trees while continuing to deplete the already thinning forestry reserves, or burning biomass wastes which could otherwise be returned to the land, are not perceived. Similarly, the costs of "consuming" the forests are not incurred by the individual, since the burden of replenishing the forests usually falls on the state. Putting all these factors together, it is not uncommon to find that social incentives to grow trees greatly exceed individual incentives in many areas, and when properly accounted for in economic analysis will indicate that forestry activities are economically justified, even though no single individual farmer will find it profitable to do so.

The incentive to grow trees for woodfuel is obviously stronger where there is a commercial market offering financially attractive returns to tree growers. This may be in local towns or more distant cities. However, the returns to the farmer must generally not only be sufficient to justify his investments in wood production, but greater than those from other potentially competing crops. Where wood is grown on hilly lands, farm borders, etc., that are not suitable for food crops, the incentive to grow trees could be sufficient to make this effort worthwhile. In these cases, reductions in grazing land for animals or forage production as a result of tree growing may need to be considered carefully.

When estimating these incentives, it is essential to compare the prices received by the farmer and not final market prices. Because of transport costs, profit-taking by distributors, and the costs of splitting firewood, the producer may receive as little as 5-10%--and, exceptionally, only 1%--of the urban retail price. For example, in the early 1980s the ratio of the retail price in Blantyre (Malawi) to the typical rural producer price was around 20:1 [French 1985]; and in Managua (Nicaragua) about 15:1 [Van Buren 1984]. In Niger, the license

Table 4.1: Potential Benefits of Rural Tree Growing

	Benefit	Type
Basic Resource Base		
Soil protection	Reduce wind and water erosion - sustain or enhance crop production	social/private
Watershed protection	Reduce siltation of upland rivers and regulate stream flows - reduce frequency and severity of flooding - promote more even water flows, reduce irrigation requirements downstream - reduce siltation of irrigation and hydropower systems	social
Agricultural Resources		
Moisture retention (field trees)	Preserve soil moisture - increase crop yields/reduce irrigation needs	private
Mineral nutrients (field trees)	Increase nutrient recycling and pumping from deeper soil layers Provide nitrogen with N-fixing species - increase crop yields/reduce needs for manure or chemical fertilizers	private
Forage from leaves	- increase animal production - release crop residues and land for other uses than feed supply	private/social
Fruit, nuts, etc.,	- improve diet quantity and quality - income from sales	private
Timber	- provide materials for construction, basic tools, craftwork, etc for local use - income from sales	private
Windbreaks	- reduce soil erosion, shelter for animals in extreme climatic conditions	social/private
Energy and Other		
Woodfuels	- improve local household/artisanal supplies of firewood and/or charcoal - income from sales if commercial markets exist and are profitable	private private
Employment and "development"	- provide employment, broaden horizons and range of activities, increase participation in local decision-making, etc., [FAO 1978]	social
Ornament and shade	- enhance environment	social

fee for cutting one stacked cubic meter of wood from the forest ("stumpage" fee) was recently about US8¢, or less than 1% of the market selling price [Timberlake 1985]. Transport and other marketing costs are discussed further in Section D.

C. FUELWOOD RESOURCES AND PRODUCTION

This section provides some basic data on and methodologies for assessing fuelwood supplies, both from natural and managed resources. It also discusses transport costs and other factors which play an important part in evaluating the economics of biomass fuels.

Measurement Units and Concepts

Chapter I discussed the basic units for measuring the energy content of fuels and the moisture content, density and volume of biomass fuels. These concepts are not repeated here. Basic data on the energy content of fuels are provided in Annex 1. For the biofuels, these data should be used only for "first cut" estimates because of the substantial variation that is likely to occur with different tree species and moisture content levels.

For estimating wood resources and actual or potential wood supplies one must first make a clear distinction between (1) standing stocks and (2) resource flows; i.e., the rate of wood growth, or "yield." Other important distinctions for energy assessments are:

a. Competing uses of the wood for timber, construction poles, etc. These can be allowed for by estimating the fraction of the wood resource or yield that is available as a fuel resource under current conditions of collection or market costs and prices.

b. The fraction of the standing stock and yield that is accessible for exploitation due to physical, economic or environmental reasons. This quantity applies to natural forests and plantations for purposes such as watershed protection rather than to managed plantations, village woodlots or single tree resources. For example, parts of a natural forest/plantation may be on inaccessible, hilly terrain or too remote for access except at prohibitive cost. A study by FAO [de Montalembert and Clement 1983] estimated that physical accessibility of fuelwood from natural forests varied from 5-100%, with 40-50% as a range that was often used in estimates. Environmental accessibility is often related to the minimum standing stock that can be left in situ without permanent degradation of soil or other resources.

c. The fraction of the total yield that can be cut on a sustainable basis. Total yield is usually referred to as the Mean Annual Increment (MAI) of stem wood, normally in terms of solid volume per unit area (i.e., solid m^3/hectare/year). The sustainable yield might be lower than the MAI to protect the soil structure and nutrient recycling function served in part by dead and fallen wood in the soil.

d. The fraction of the cut wood that is actually recovered (harvested), i.e., allowing for collection and cutting losses which usually exceed 5% and may be much higher.

Estimating Stock Inventories

The standing stock of trees is normally estimated by aerial surveys or satellite remote sensing to establish the areas of tree cover by categories such as closed forest, open forest, plantations and hedgerow trees, etc. Data must normally be checked by observations on the ground ("ground truth"). These observations are also needed to estimate tree volumes, species type, and perhaps growth rates (e.g. MAI). Inventory data is normally held by national Forestry Departments and reported, on a regional basis, either as a volume (m^3) in a given area or as a mean density (m^3/ha).

Inevitably, estimates of tree stocks are approximate. Furthermore, most inventory data are for the commercial timber volumes which are a small proportion of total standing biomass. The quality of fuelwood biomass may greatly exceed the commercial timber volume. The most serious data deficiency in most countries is the lack of time series information to show where, at what rate, and due to what causes, tree loss has been occurring.

Estimating Supplies: Stock and Yield Models

Incorporating the concepts outlined above, Table 4.2 estimates the amount of wood that can be obtained from a natural forest by (1) depleting the stock and (2) by sustainable harvesting. Essentially, the method involves simple multiplication to adjust stock and yield quantities by the accessibility and loss factors mentioned above (Gowen 1985). The table also uses the concepts discussed in Chapter I to convert the volume yield of wood to an energy value.

This model could apply equally well to a managed plantation or village woodlot, although with different numbers; to estimating the effects of forest clearance for agriculture (partial or complete stock loss); and to evaluating the impact of fuel gathering on forest stocks. Furthermore, the method is easily adapted to a time series model, in which standing stocks are augmented (or depleted) each year by the difference between Mean Annual Increment and wood removals. Finally, the same model can be disaggregated to allow for different tree species and selective cutting methods. Each major species will normally have

Table 4.2: Example of Stock and Yield Estimation Method: Natural Forest/Plantation (Hypothetical Data)

Assumptions	Stock Data		Yield Data	
Supply Factors:				
A. Forest Area			1,000	ha
B. Stock Density			200	m^3/ha
C. Stock Volume			200,000	m^3
D. Mean Increment			0.4	m^3/ha/yr
F. Sustainable Yield			3.8	m^3/ha/yr
G. Gross Sustainable Yield (A x F)			3,800	m^3/yr
H. Fraction Available for Fuelwood	0.4		0.4	
I. Fraction Accessible	0.9		0.9	
J. Harvest/Cutting Fraction	0.9		0.9	
K. Gross Sustainable Harvest (G x I x J)			3,078	m^3/yr
L. Fuelwood Sustainable Harvest (K x H)			1,231 1.23	m^3/yr m^3/ha/yr
Clear Felling:				
M. Gross Harvest (C x I x J)	162,000	m^3		
N. Fuelwood Harvest (M x H)	64,800	m^3		
O. Wet Density (0.8 tons/m^3)				
P. Net Heating Value (15 GJ/ton or MJ/kg)				
Q. Energy Harvest: Clear Felling (N x O x P)	777	TJ a/		
R. Energy Harvest: Sustainable (L x O x P)			14.6 14.6	TJ/yr a/ GJ/ha/yr
S. Other Wood: Clear Felling (M - N) x O	77,700	tons		
T. Other Wood: Sustainable Harvest (K - L) x O			1,477 1.47	tons/yr tons/ha/yr

a/ TJ = terajoule = 1,000 GJ.

different stock volumes, MAIs, and suitabilities for fuel or other wood resources. In addition, different cutting techniques for the same stock will imply different MAIs.

Estimating Financial Returns: Plantation Models

When assessing the economics of managed plantations and wood lots, normally one must estimate costs and benefits through time. There are obvious analytical reasons why this is so: for example, to estimate annual cash flows, compare net present values or rates of return on various projects, or to estimate the loans and/or subsidies needed to tide the producer over during the period between establishing the plantation and harvesting the first wood crop.

There are two further reasons, almost unique to tree growing, why life cycle cost models are needed. First, with the exception of regular coppicing or pruning, wood is harvested in different quantities at intervals of several years. The supply is therefore "lumpy" and irregular, and to provide a continual supply trees must be planted at phased intervals. Second, as trees mature and their diameter increases, the value of wood also increases (in real terms) and may well exceed the value at which it would be sold as a fuel. In other words, while trimmings and thinnings at an early stage in the growth cycle ("rotation") may be used locally or sold as woodfuel, at later stages--and especially after the final clear felling--much of the wood will probably be used or sold as timber and not fuel.

Table 4.3 provides an illustration of a life cycle cost analysis, in which annual costs and benefits are recorded from plantation establishment to final felling on a 20-year cycle. It is based on Pakistan Forestry Department data for plantations of "shisham" trees for timber and fuelwood. Returns from forage leaves and other byproducts are ignored. The method can easily be adapted to rotations of any length and to the assumption of constant wood prices (in real terms).

Table 4.3: Example of Financial Discounted Cash Flow Method: Plantation (Data Based on Irrigated Shisham Plantation, Pakistan)

	Per Hectare Costs		Per Hectare Production			Cash
Year	Non-harvest ($)	Harvest ($)	Volume (m^3)	Value ($\$/m^3$)	Revenue ($)	Flow ($)
1	330					- 330
2	165					- 165
3	130					- 130
4-5	60					- 60
6	60	37	20.9	35.3	738	+ 641
7-10	60					- 60
11	60	81	45.6	53.0	2,417	+2,276
12-15	60					- 60
16	60	73	34.3	70.6	2,422	+2,289
17-19	60					- 60
20	60	375	151.5	88.2	13,362	+12,927
TOTALS	1645	566	252.3		18,939	+16,728
Net Present Value (10% interest) a/: (Costs & revenues fall in mid-year)						+ 3,037

General data

454 ha irrigated plantation, initial spacing 3 x 2 m (1793 seedlings/ha). Land rent of $75/ha excluded. Costs converted from Rupees at Rs 10/$.

Cost data per hectare

All years:	irrigation $30, maintenance (including watercourses) $30.
Year 1:	establish plantation (site preparation, layout, digging water channels, plant costs, plant transportation, planting) $200
Year 2:	restocking $35.
Years 1-3:	weeding $70.

Harvest data and costs

Year 6:	1st thinning at	$\$1.77/m^3$
Year 11:	2nd thinning at	$\$1.77/m^3$
Year 16:	3rd thinning at	$\$2.12/m^3$
Year 20:	final felling at	$\$2.47/m^3$

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a/ NPV calculation: For each year net costs or revenues are multiplied by a discount factor. For a 10% discount rate and mid-year costs & revenues, the factor is 1/1.1 raised to the power of (N - 0.5) where N is the Year Number. The annual values are then summed.

Source: PFI [1981].

Fuelwood Production Data

Table 4.4 provides data on typical fuelwood tree species, by climatic zone. The table also gives the basic densities of the woods in kg/m^3, since these densities are needed to convert volumes to weights. In general, densities are lowest (400-600 kg/m^3) for young trees and for fast-growing species. They may be much lower still (200-400 kg/m^3) for eucalyptus and other fast-growing fuelwood species on very short 1-3 year rotations, since the harvest is mostly in the form of small branches, twigs or "shoots" and leaves. In contrast, mature trees of slow-growing species have much higher densities, in the 500-1,000 kg/m^3 range.

Table 4.4: Characteristics of Various Fuelwood Species

Fuelwood Species	Average Rotation	Average Production	Basic Density
	(yrs.)	(m^3/ha/yr)	(kg/m^3)
Humid Tropics			
Acacia a/ auriculiformis			
good soils	10 - 12	17 - 20	0.6 - 0.8
poor soils	4 - 8	10 - 15	0.6 - 0.8
Calliandra calothyrsus a/			
1st year	1	5 - 20	0.5 - 0.8
2nd year	1	35 - 60	0.5 - 0.8
Casuarina b/ equisetifolia	7 - 10	10 - 20	0.8 - 1.2
Leucaena b/ leucocephala	8 - 10	25 - 60	
Sesbania bispinosa	6 ms.	15 odt/ha/yr	0.3
S. grandiflora	2 - 5	20 - 25	0.4
Tropical Highlands			
Eucalyptus globulus	5 - 15	10 - 30	0.8 - 1.0
E. grandis irrigated	5 - 10	40	0.4 - 0.5
Good soils	5 - 10	17 - 45	0.4 - 0.5
Poor soils	10	5 - 7	0.4 - 0.5
Arid/Semi-Arid			
Acacia saligna	4 - 5	1.5 - 10	(light)
A. Senegal			
Gum plantations	25 - 30	0.5 - 1.0	(heavy)
Wood plantations	15 - 20	5 - 10	(heavy)
Albizia lebbek a/	10 - 15	5	0.5 - 0.60
Azadiarachta indica a/	8	10	0.6 - 0.9
Cassia siamea	5 - 7	10 - 15	0.6 - 0.8
Eucalyptus camaldulensis			
good soils	7 - 10	20 - 30	0.6
poor soils	14 - 15	2 - 11	0.6
E. citriodesra b/	8	15	0.8 - 1.1
Prosopis juliflora			
good soils	10	7 - 10	0.7-1.0
poor soils	15	5 - 6	0.7-1.0

a/ Preferred fuelwood species.
b/ Preferred fuelwood and charcoal species.

Source: NAS [1980].

Fuelwood: Market Prices

Fuelwood prices are generally reported as retail or wholesale market prices, usually for urban locations. These are important to fuelwood users and producers, but they largely ignore the benefits of tree cover (and costs of forest depletion), which include protection from soil erosion, watershed protection, and avoided costs of afforestation. Economic prices therefore should be used in project analysis. (See Section C for discussion of methodology.)

Table 4.5 presents urban retail fuelwood prices in several developing countries. As one might expect, they vary widely: from $10-140/ton across countries and by as much as 3:1 within some countries. The inter-country variation is partly explained by the use of market exchange rates to convert local currencies to dollars. The rest of the variance is explained by: (1) the cost of competing fuels; 1/ (2) the cost of transport and fuelwood preparation (e.g., splitting logs into firewood pieces); (3) quantities purchased (small bundles normally cost more per kg than bulk purchases); (4) quality (species, size and size uniformity of split pieces); (5) locale within the city; and (6) the sale value by producers. The final item includes producer profit and the costs of producing and harvesting the wood resource. The (market) production cost may be very small, or zero, when wood comes from land cleared for agriculture, or is taken from public forests, whether illegally or with a permit.

Fuelwood: Relative Prices

In some countries, firewood and charcoal prices have been rising rapidly both in real terms and relative to alternative fuels such as kerosene and LPG. In others they have fallen in real terms and have become progressively cheaper than fossil cooking fuels. The addition or removal of subsidies, particularly on kerosene, complicates these relative prices. Nevertheless, in some places woodfuels are becoming so costly that there are strong incentives for consumers to switch away from them for cooking. In these cases one needs to examine carefully the assumptions about projected demand on which woodfuel supply projects are based.

The wide range in relative prices is indicated by data from 17 countries which show that the ratio of kerosene to firewood prices (per unit of delivered energy) varied from 0.3 in parts of Nigeria to 16 in a rural area in South Africa between 1980 and 1983. The ratio of charcoal to firewood prices varied much less, as one would expect, with the lowest ratio at 1.1:1 (Bangalore, India) and the highest at 3.0:1 (Freetown, Sierra Leone).

1/ There is some evidence that in several countries woodfuel prices have risen in line with jumps in the prices of kerosene, the main competitor to woodfuels.

Table 4.5: Retail Fuelwood Prices in Various Developing Countries

Region/Country	Year	US$/ton	Cost of delivered energy a/ ¢/MJ	Cost of utilized energy b/ ¢/MJ	Source
Africa					
Ethiopia	1983	80-90	0.52 - 0.58	4.0-4.5	b
Gambia	1982	140	0.90	6.9	b
Gambia (Banjul)	1982	53	0.34	2.6	a
Kenya	1981	10	0.06	0.46	b
Liberia	1984	50 - 130	0.32 - 0.84	2.5 - 6.5	b
Madagascar	1985	20 - 25	0.13 - 0.16	1.0 - 1.2	b
Malawi (Blantyre)	1981	37	0.24	1.8	a
Morocco	1983	20 - 60	0.13 - 0.39	1.0 - 3.0	b
Niger	1982	60	0.39	3.0	b
Sudan (Khartoum)	1982	72	0.46	3.5	a
Asia					
Bangladesh (Dacca)	1982	38	0.25	1.9	a
Burma (Rangoon)	1982	60	0.39	3.0	a
India (Bombay)	1982	87	0.56	4.3	a
Nepal	1981	20 - 60	0.13 - 0.39	1.0 - 3.0	b
Pakistan (Karachi)	1982	20 - 40	0.13 - 0.26	1.0 - 2.0	b
Sri Lanka (Colombo)	1982	61	0.39	3.0	a
Thailand	1984	17	0.11	0.85	a
Latin America					
Guatemala (Guatemala City)	1982	34	0.22	1.7	a
Peru	1983	20-60	0.13 - 0.39	1.0 - 3.0	b

Note: Prices vary considerably by quantity purchased.
a/ Cost of delivered energy assumes heating value of 15,500 MJ/ton.
b/ Cost of utilized energy assumes end-use efficiency of 13%.

Sources: a. FAO [1983a].
b. UNDP/World Bank Energy Sector Assessment Reports, Washington, D.C., The World Bank.

Normally, relative prices are compared for utilized energy (sometimes called the "effective" price) since this is the relevant measure for the consumer and for questions of fuel substitution: a switch in fuel normally requires a corresponding switch in cooking appliance, end-use efficiency, and effective price. The latter is calculated simply by dividing the delivered energy price (e.g. in $/MJ) by the end-use efficiency of the appropriate end-use appliance. Appliance costs (amortized so that they can be added to fuel costs) are frequently included in these comparisons.

Table 4.6: Relative Costs of Cooking in African Countries, 1982-83

	Cameroon	Senegal	N.Nigeria	Niger	Ethiopia
Relative Costs a/					
Fuelwood	1.0	1.0	1.0	1.0	1.0
Charcoal	3.4	0.9	2.4	1.4	1.6
Kerosene	10.0	1.7	0.6	1.7	0.7
LPG	n.a.	1.3 - 1.9	2.0	2.0	1.1
Electricity	11.1	3.3	1.1	2.8	2.0
Fuelwood Costs Cents per MJ of "utilized" heat b/	1.1	2.5	3.1	2.5	7.2

a/ Assuming thermal efficiencies of 13% and 22%, respectively, for cooking with fuelwood and charcoal using metal pots. The fuelwood prices used in the calculations correspond to those found in urban centers, and include the costs of appliances.

b/ That is, per MJ of heat output by the stove and absorbed by the pot. The nature of the trial on which the data are based is not described in some sources, so it is not possible to provide a confidence interval for the estimates.

Source: Anderson & Fishwick [1984]; using data from UNDP/World Bank Energy Assessment Reports.

Table 4.6 compares the effective (utilized energy) costs of cooking with fuelwood, charcoal, kerosene, LPG and electricity, including equipment costs, in five African countries in the 1982-83 period. While in Cameroon woodfuels are the cheapest option, in Ethiopia cooking with woodfuel is as expensive or more expensive than using most of the modern fuels.

Table 4.7 presents a more detailed analysis of cooking fuel prices in Nigeria in order to show the methodology applied. According to this table wood and charcoal are much more expensive than kerosene, LPG or electricity for cooking even though LPG and kerosene are often difficult to obtain.

Table 4.7: Comparative Prices of Household Cooking Fuels in Nigeria

Fuel	(1) Delivered Price (k/unit)	(2) Net HV (MJ/unit)	(3) End-Use Efficiency (%)	(4) Effective Price (k/MJ utilized)	Appliance Cost (N=100k)
Wood (air dried)	17/kg	14.7/kg	8-13	8.9 - 14.5	n.a.
Charcoal	22/kg	25.1/kg	20-25	4.4 - 5.8	n.a
Kerosene	10/l	34.8/l	30-40	0.7 - 1.0	3 a/
	28/l	34.8/l	30-40	0.2 - 2.7	38 b/
LPG	34/kg	49.0/kg	45-55	1.3 - 1.5	40 - 45
Electricity	6/kWh	3.6/kWh	60-70	2.4 - 2.7	40

$$\text{Effective price (Col. 4)} = \frac{\text{(Col. 1)}}{\text{(Col. 2)} \times \text{(Col. 3)}/100}$$

a/ Small one burner wick stove.
b/ Two burner pumped stove.
N = Naira, k = kobo (1 Naira = 100 kobo)
Source: UNDP/World Bank [1983c].

Fuelwood: Economic Values

Several methods have been used to depict the economic [social] value of fuelwood production, in contrast to market (financial) costs and returns. This can be done whether or not fuels have a commercial market price by establishing proxy values which reflect either the economic costs of alternative fuels that would be used if the fuelwood was not produced, or the total benefits and avoided costs of tree planting. It is important to note that the market prices are usually a poor guide to economic values; in general they are likely to be much lower than economic values owing to the divergence between the individual and social costs of fuelwood cutting discussed before. Also, while there are several methods of calculating economic values, limited data and other uncertainties usually make this task very difficult.

Nevertheless, one method of calculating economic values for fuelwood is to evaluate the opportunity cost of using the alternative fuel most likely to be used if wood were not available; e.g., kerosene or crop residues and animal dung. With residues or dung the method could involve estimating the economic cost due to the increase in soil erosion or loss in crop production that results from diverting the material to energy uses. For example, in a World Bank/FAO community forestry appraisal in Nepal it was estimated that 1 m^3 of air-dried fuelwood was equivalent in energy terms to 5.68 tons of wet animal manure; and that if the latter was used as manure rather than being burned it would increase maize yields by about 160 kg/ha/yr. Given the market price of maize, the economic value of fuelwood was estimated at Nepal Rupees 520/m^3 [SAR 1980].

A second method is to evaluate the non-wood benefits, such as savings in fuelwood collection time, fodder values in terms of increased milk yields and their prices, the value of shelterbelts in increasing crop yields, or benefits in preventing soil erosion and desertification. For example, the same Nepal appraisal estimated the value of fodder using the following methodology: (1) calculate the net quantity of leaf fodder and grass produced; (2) from this, estimate the fraction that would be fed to animals; (3) estimate the increased milk yield due to this additional feeding; and (4) calculate the value of the additional milk produced. Over the 30-year project life the value of the leaf fodder was estimated to be US$11 million.

Plantation Costs

The cost of establishing fuelwood plantations varies considerably depending on the terrain and amount of land preparation needed, irrigation works (if any), labor costs and the like. Table 4.8 presents data on 12 fuelwood projects financed by the World Bank during the early 1980s. The range of investment costs varies from US$212/ha to 2000/ha (1984 dollars), although there are substantial economies of scale associated with plantation area. If the two projects of 5,000 hectares and below are excluded, the range narrows to $212-934/ha.

Smaller scale social and community forestry schemes should cost less than fuelwood plantations since much of the labor is provided by the recipients of the scheme. In the Karnataka Social Forestry Project, India, plantation costs ranged from only US$51/ha for bamboo in tribal areas to US$464 for plantings on public waste lands (1983 dollars). Administrative and equipment overheads for the whole scheme, ignoring contingency estimates, averaged about $100/ha [SAR 1983].

Apart from initial investments, the important cost with plantations is the final harvest cost per unit of wood. This varies widely by climate, species, irrigation and other input costs--and above all, tree survival rates. The cost of harvesting and transport generally amounts to $15-20/m^3--at least twice that of establishment. Most available sample figures are based on pre-project estimates and therefore may bear little relation to actual results. Suffice it to say that some appraisals have suggested that plantation fuelwood can be produced at less than current market prices and with even lower economic costs. As a general rule, these tend to include a high level of participation by local people. In contrast, large scale plantations in unfavorable climatic zones can prove to be prohibitively costly. For example, World Bank assessments of fuelwood plantations in the arid regions of Northern Nigeria gave costs of US$74-108/m^3. By comparison, the price at which fuelwood, delivered to urban markets, became uncompetitive against kerosene and LPG was about US$70/m^3.

Table 4.8: Selected Fuelwood Projects Financed by the World Bank Since 1980

Country and Project	Year of Loan or Credit	Afforestation Area (ha)	Main Species	End Products Other Than Fuelwood a/	Approximate Investment Cost per ha 1984 US$ b/
Upper Volta: Forestry	1980	3,500	Euc., Gmelina	Sawlogs	1,867 c/
India: Gujarat	1980	205,000	Albizia, Acacia, bamboo, Casuarina, Prosopis, Morus	Poles	672
Malawi NRDP II/Wood Energy	1980	28,000	Euc., Gmelina		467
Nepal: Community Forestry	1980	11,000	Alnus, Prunus, Betula, Pinus	Fodder, poles	840
Rwanda: Integrated Forestry & Land	1980	8,000	Euc., pine	Sawlogs	934
Bangladesh: Mangrove Afforestation	1980	40,000	Mangrove spp.	Pulpwood, sawlogs	373
Thailand: Northern Agriculture	1980	11,000	Euc., pine	Poles	212
Senegal: Forestry	1981	5,000	Euc., neem	Poles	2,000
India: West Bengal	1982	93,000	Euc., indig, spp., bamboo	Poles, fodder, fruit	312
Niger: Forestry II	1982	8,650	Euc., Ac., neem	Poles	784
India: Jammnu, Kashmir, Haryana	1983	111,500	May, incl. indig.	Small timber	502
Zimbabwe: Rural Afforestation	1983	5,200	To be determined	Poles	616
			Unweighted mean:		798
			Weighted mean:		559

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a/ In this column "poles" refers to building poles, mainly for traditional construction.

b/ The US$ amounts were converted from current to 1984 values by means of the Manufacturing Unit Value (MUV) Index which is published periodically by the Economic Analysis and Projections Department of the World Bank; this index reflects both international inflation and changes in the US$ exchange rate, and the latter changes in turn reflect (i.a.) differences between local and US inflation rates. The investment costs include not only the immediate afforestation costs including weeding and after-care until the trees are firmly established, but also some related investments in studies, training and institution-building. They also include physical contingencies.

c/ The often very high cost of afforestation in the Sahel countries is generally due to a combination of difficult ecological conditions and overvalued exchange rates.

D. TRANSPORT COSTS AND MARKET STRUCTURES

Urban woodfuels are sometimes trucked or brought by rail over long distances. Transport costs thus may be a critical component not only of urban woodfuel prices but of the area from which woodfuels can be supplied at competitive prices. Potential resources which are otherwise economically attractive may be ruled out due to transport distances and costs, thus limiting supply possibilities as urban demands for woodfuels expand unless fuel prices increase substantially. Because fuels with the highest energy densities (MJ/m^3 or MJ/kg) are the cheapest to carry, transport costs (other factors being equal) reduce the relative prices--and increase the availability--of urban fuels such as charcoal and densified biomass compared to firewood.

Examples of transport costs and their impact on retail prices are presented below, and examples comparing costs and maximum economic transport distances for firewood and charcoal are provided in Table 4.9. Before turning to these, some general points about transport costs may be in order:

a. Transport costs are often quoted per ton-kilometer. But stacked firewood and, to a larger extent, charcoal have such low densities that the load which a truck can carry may be limited by volume and not weight.

b. In many areas (e.g., the Sahel) woodfuel is trucked by small, informal owner-operators in 15-20 year old vehicles which have very low overhead costs, such as depreciation, maintenance, spares, and insurance. Their costs may be one third to one half of those charged by large, commercial enterprises. For example, in Nigeria about 65% of trucking costs are attributed to depreciation, maintenance, spare parts and overheads, 14% to wages, 10% to tires, and only 11% to fuel and lubricants [FMT 1983].

c. Woodfuels are sometimes carried as partial loads and on "empty return" trips and so have very low or zero opportunity cost. This applies especially to small urban markets in parts of Africa.

These factors help to explain the considerable variance in fuelwood transport costs that have been found in surveys. The results of several World Bank [Schramm & Jirhad 1984] assessments and those done by others illustrate this point:

In Zaire, woodfuel transport costs US$0.11-0.24 per ton-km over unpaved roads but only US$.07-.14 per ton-km over paved roads.

In Nigeria (1983), firewood transport in 10-ton trucks typically costs only US$.055 per ton-km, but for comparative short trips of 100 km can account for as much as 50% of the ex-woodlot price.

In Ghana (1980), charcoal transport costs were much lower still at US$.0065 per ton-km for the 350-km trip from Accra to Nima. Nevertheless, transport accounted for about 50% of the wholesale market price [Schramm & Jhirad 1984].

In Ethiopia (1983), the financial costs of carrying briquetted cotton residues in 22-ton trucks over 300 km were estimated at US$14/ton plus US$2/ton for handling charges, giving a total transport charge (less bagging at US$3.8/ton) of US$.024/ton-km. This was 36% of the delivered cost to the urban market [Newcombe 1985].

In Nicaragua (1981), fuelwood transport in 5-ton trucks cost about US$.01/ton-km for the 150 km trip to Managua, where it accounted for 27% of the retail price [Van Buren 1984].

Table 4.9 provides a formula for estimating woodfuel transport costs. It shows that, for any but the shortest trips when handling charges are significant, costs are inversely proportional to the load and the energy density of the fuel (GJ/ton). Since charcoal has roughly twice the energy content per unit weight (MJ/kg) of firewood, it costs approximately half as much to carry. Costs are also directly proportional to the load carried and cost per vehicle-km, as one would expect.

Table 4.9 also gives an example comparing the maximum transport distance for firewood and charcoal, using hypothetical but realistic values. This shows that the maximum distance is extremely sensitive to the difference between the "producer price" - (at the point of loading) and the maximum "delivered price" at the market (the price at which the fuel remains competitive). Some fixed costs, such as for bagging charcoal and splitting firewood, have been ignored although they obviously affect the producer and delivered prices. The delivered price of charcoal has been set at just over twice the firewood price to allow for its greater end-use efficiency.

The example shows that (with these data) the maximum distances for firewood and charcoal are about 170 km and 990 km respectively, a ratio of roughly 1:6. However, the area from which fuels can be transported competitively is in the ratio of 1:36. This example helps to explain why charcoal is sometimes trucked over distances of 600-900 km to urban centers and can lead to tree loss over vast areas. It also emphasizes the importance of drying biofuels before transport and densifying them to briquettes or pellets if this is logistically possible.

Table 4.9: Woodfuel Transport Costs: General Formula and Example

General Formula for a Single Trip (weight basis)

F	$	Loading/unloading cost ("fixed cost"). May be calculated from load (tons) x cost/ton.
L	tons	Weight of load carried (assumed all woodfuel).
C	$/km	Trucking cost per vehicle - km.
T	km	Trip length
E	GJ/ton	Energy density of fuel as transported.
P	$/GJ	Cost or price to point of loading ("producer energy price"). May be calculated from other units such as $/ton and GJ/ton.
D	$/GJ	Cost or price at point of delivery ("delivered energy price"). Note: $D = P +$ transport cost in $/GJ

Trip cost:	$F + C \times T$
Trip cost/ton load:	$(F + C \times T)/L$
Trip cost/GJ	$(F + C \times T)/(L \times E)$

To estimate the maximum competitive trip length (Tmax), we can set the delivered energy price to a maximum value that the market will bear (Dmax). Then:

$$P + (F + C \times Tmax)/(L \times E) < Dmax$$

which gives:

$$Tmax \leq (Dmax - P) \times L \times E - F/C.$$

(Volume basis):
If the load is limited by maximum volume rather than weight, the values L and E can be converted to volume units (m^3, GJ/m^3)
Note that stacked or packed volumes, and not solid volumes, must be used.

Worked Example for Firewood and Charcoal

Basic parameters			Firewood	Charcoal	Both
Producer price:	$/m^3		20	40	
Bulk density:	tons/m^3		0.6	0.25	
Producer price:	$/ton		33.3	160	
Energy content:	GJ/ton	E	15.5	30.0	
Producer price:	$/GJ	P	2.15	5.33	
Delivered price	$/GJ (max)	D	3.0	7.0	
Load:	tons	L			10
Load/unload cost:	$	F			10
Trucking cost:	$/vehicle-km	C			1
Applying the formula for max distance:					
Max trip length for given conditions:		km	168	989	
Supply area:		km^2	89,000	3,072,000	

The difference in supply area can be very much greater than this. In some parts of Africa charcoal can be transported economically over a direct distance of 600 km, giving a potential (under straight road conditions) concentric supply area of up to 1.1 million km^2 (110 million ha) around a city. Even with a mean annual yield from farm and forest areas of only 0.25 m^3/ha/yr, this area would yield 28 million m^3 of fuelwood annually, enough to supply around 25-30 million people. Assuming that in the same area firewood can be economically transported over a direct distance of 70-100 km--as estimated in some World Bank assessments--the firewood supply area would be only 1% of the charcoal supply area.

E. CHARCOAL

In many cities of Africa and Asia, charcoal is fast becoming the dominant fuel where wood resources are scarce or located far from urban centers. One major reason for this trend is the lower transport cost and greater supply area of charcoal, as outlined above. Other advantages are that charcoal is easier for the consumer to carry from the market due to its greater energy density (MJ/kg), is easier to handle and store, gives a more even cooking temperature than wood and, with suitable equipment, has a higher end-use efficiency. Also, charcoal is smokeless and can be used indoors, offering greater convenience. This is especially favorable in urban areas. For many consumers these advantages outweigh the fact that (typically) it costs more per kg than firewood. However, charcoal may require more wood resources than the direct burning of fuelwood. A good recent review of charcoal issues appears in Foley [1986].

Production Processes and Yields

Charcoal can be produced in batch or continuous kilns, retorts, or furnaces, but the basic principles are the same for all technologies. Combustion is initiated in a wood pile within the conversion device and proceeds with a very limited supply of air until the wood is reduced to charcoal. This process is often called carbonization.

Most charcoal is made from wood, although other sources may include coconut shell, coffee husks (e.g. Ethiopia), cotton stalks (e.g., Sudan), and timber wastes. Excess bark in the wood results in charcoal that is friable and dusty. However, charcoal fines, dust and small fragments can be briquetted. The type of equipment, density and moisture content of wood govern the charcoal yields from a kiln or retort. Dry and dense wood yield the highest proportion of charcoal as a percentage of the orginal wood weight (oven dry). (See Table 4.10 below.) Yields also tend to be greater with larger kiln size and also depend on the amount of charcoal dust or "fines" produced. Fines arise both in the charcoaling process and from vibration and shaking of finished charcoal pieces during handling, bagging and transport. Up to 30% of charcoal may be fines on removal from the kiln/retort, although fines typically are much less than this; a further 20-30% of lump charcoal may be broken down to fines during transport over poor roads. Bagged charcoal in the market may contain from 5-20% fines. Although fines can be briquetted and sold, often simply by hand, losses and increased unit costs are inevitable.

The effects of wood density, moisture content and conversion technology on charcoal yields are shown in Table 4.10, adapted from Openshaw [1983]. Apart from inherent differences in conversion technology, the effects of greater density and the use of drier wood on charcoal yields are clear. If one includes the technological variations, the complete range of yields (and energy conversion efficiencies) is a factor of six to one.

Table 4.10: Yields and Conversion Factors for Charcoal Produced from Wood

Effect of Wood Density/Species

	Pines	Average Tropical Hardwood	Preferred Tropical Hardwoods	Mangrove (Rhizophora)
Charcoal yields:				
kg per m^3 wood, 13% moisture, wet basis	115	170	180	185
kg per m^3 wood, oven dry basis	132	195	207	327

Effects of Technology and Moisture Content

For typical preferred tropical hardwoods:

Oven dry weight of wood (tons) to produce one ton of charcoal, including fines (approximate data):

Moisture %: dry basis	15	20	40	60	80	100
wet basis	13	16.7	28.6	37.5	44.4	50
Kiln type:						
Earth kiln	6.2	8.1	9.9	13.0	14.9	16.8
Portable steel kiln	3.7	4.4	5.6	8.1	9.3	9.9
Brick kiln	3.7	3.9	4.4	6.2	6.8	7.5
Retort	2.8	2.9	3.1	4.4	5.0	5.6
Energy Conversion Efficiency: percent a/						
Earth kiln	25	19	16	12	10	9
Portable steel kiln	43	36	28	19	17	16
Brick kiln	43	40	36	25	23	21
Retort	56	54	51	36	32	28

a/ Assuming wood at 20 MJ/kg, oven dry: charcoal at 31.5 MJ/kg, 5% moisture (wet basis), including fines.

Source: Adapted from Openshaw [1983].

This brings us to the much-debated point whether charcoal is more wasteful of wood resources for cooking than direct wood burning. Many authors have asserted that it is; and they are obviously correct if one assumes that charcoal is made from wet, green wood in "primitive" earth kilns where the wood-charcoal conversion efficiency is only about 9-12% in terms of energy as opposed to weight. (See Table 4.10). The greater energy efficiency of cooking by charcoal rather than wood fires or stoves cannot generally make up for this difference. However, as shown in Table 3.5 of Chapter III, end-use efficiency of a metal charcoal stove with aluminium cooking pots is 20-35% and that of an open fire with clay pots is about 5-10%, or 3.5-4 times less. Thus, if consumers switch from an open wood fire using clay pots to a charcoal stove with aluminium pots, and wood-charcoal conversion efficiencies are better than 25-28%, wood consumption will fall when charcoal is used instead of firewood. This efficiency rate or better is achieved with all the technologies except for earth kilns as long as fairly dry wood is used.

Nevertheless, these arguments underline the importance of using high quality data, preferably from large sample surveys, in carrying out any assessment of woodfuel resources, charcoal conversion technologies, and cooking fuel/device substitutions. Sensitivity analyses should also be made to check the effects of errors in the basic data and it should be recognized that this is one area of energy analysis where 'rules of thumb' are frequently inaccurate.

Charcoal Prices and Other Data

Since charcoal is almost pure carbon, its heating value varies little by wood species. Gross heating values, oven dry, are about 32-34 MJ/kg. When air dried the moisture content (wet basis) is typically about 5% and the net heating value is close to 30 MJ/kg. In damp weather charcoal easily absorbs water and its moisture content may rise to 10-15%. For this reason lower net heating values of about 27 MJ/kg are often reported in the literature.

Table 4.11 provides a list of wood characteristics and their advantages and disadvantages for charcoal making. Just as there are strong preferences for types of firewood, so too with charcoal. Many consumers are very selective about its hardness, friability, density, the size of pieces, and burning quality.

Table 4.11: Preferred Wood Feedstock Characteristics for Charcoal Production

Wood Characteristics		Reason
Mature Tree not too young or too old	-	Very young trees are rich in sap and thus have high moisture content; trees that are too old have longitudinal fibers that separate, creating a friable charcoal product or fines.
Thin Bark	-	Bark can be very rich in ash, which makes a poor quality charcoal.
Compact, Heavy	-	Light or loose woods often result in charcoal with low compressive strength so that it breaks easily and produces fines.
Correct Dimensions	-	Wood that is too thick (diameters over 25 cm) (length, diameter) or too long (longer than 1.80 or 2.00 m) slows down the carbonization process, leaving semi-carbonized pieces of wood in the final product.
Healthy	-	Wood that has been attacked by fungus, or other depredations gives lower yields. It also makes low quality charcoal, which is friable and fragile.
Low Moisture	-	Moisture levels above 15% to 20% slow the carbonization process and lower the conversion efficiency.

Source: Osse [1974].

Table 4.12 shows retail charcoal prices in a number of countries. Once again, the ranges are large and are explained by factors similar to those for wood prices: producer and transport costs, wholesale versus retail costs, charcoal quality, and the size of the sacks or bags in which charcoal is sold. Typically, charcoal production costs account for 50-65% of the retail price, while transport makes up 15-30% of the final price [UNDP/World Bank 1984c]. For simple charcoal production technologies such as earth kilns, the wood feedstock cost dominates the costs of production, though the significance of feedstock costs in financial terms depends greatly on whether wood is purchased or freely collected.

Table 4.12: Retail Prices of Charcoal in Selected Developing Countries (per 30 kg bag sold at markets)

Region/ Country	Charcoal Price	Net Heating Value	Cost of Delivered Energy a/	System Efficiency	Cost of Utilized Energy b/
	($/kg) c/	(MJ/kg)	(¢/MJ)	(%)	(¢/MJ)
Africa					
Ethiopia (1983)	0.44	29	0.7-1.7	23	3.0 - 7.4
Kenya (1981)	0.06	29	0.2	23	0.9
Liberia (1984)	0.14 - 0.22	29	0.5 - 0.8	23	2.2 - 3.5
Madagascar (1984)	0.09 - 0.17	29	0.3	23	1.3
Niger (1982)	0.15	29	0.5	23	2.2
Asia					
Thailand (1984)	0.09 - 0.21	29	0.3 - 0.7	23	1.3 - 3.0
Latin America					
Peru (1983)	0.38	29	1.3	23	5.7

a/ Cost of delivered energy assumes a heating value of 29 MJ/kg at 5% mcwb.

b/ Cost of utilized energy assumes an end-use efficiency of 23%, equivalent to most efficient traditional charcoal stoves as measured in World Bank sector work in Ethiopia and Liberia. Efficiency range is 15 - 23% for traditional and 25 - 40% for improved stoves.

c/ Converted at official exchange rate.

Sources: UNDP/World Bank Energy Sector Assessment Reports.

F. AGRICULTURAL RESIDUES

In wood-scarce areas, raw agricultural residues are often the major cooking fuels for rural households. The greatest concentration of residue burning is in the densely populated plains of Northern India, Pakistan, Bangladesh and China, where they may provide as much as 90% of household energy in many villages, and a substantial portion in urban areas too. For many people in these areas--some of which were deforested centuries ago--the "woodfuel crisis" is essentially over. The evolution of fuel scarcity has entered a new phase where the struggle is not to find wood, but to obtain enough straws (and animal dung) to burn [Barnard & Kristoffersen 1985], while knowingly risking the threats of--or causing--soil erosion, nutrient loss and reduced agricultural productivity that result from excessive residue removal. Hughart [1979] has estimated that 800 million people now rely on residues or animal dung as fuel, although reliable figures are scarce.

Residue Supplies and Energy Content

Most farming systems produce large amounts of residues. With most cereal crops, at least 1.5 tons of straws and husks are produced for each ton of grain [Newcombe 1985]. With other crops such as cotton, pigeon pea and coconuts, the residue to crop ratio can be as high as 5:1. This means that in the rural areas of many countries, average residue production exceeds one ton per person [Barnard & Kristoffersen 1985]. Table 4.13 provides some data on residue to crop ratios, and Table 4.14 gives heating values for some major types of residue.

Table 4.13: Residue-to-Crop Ratios for Selected Crops

Crop	Residue	Residue Production (tonnes per tonne of crop)
Rice	straw	1.1 - 2.9
Deep water rice	straw	14.3
Wheat	straw	1.0 - 1.8
Maize	stalk + cob	1.2 - 2.5
Grain sorghum	stalk	0.9 - 4.9
Millet	stalk	2.0
Barley	straw	1.5 - 1.8
Rye	straw	1.8 - 2.0
Oats	straw	1.8
Groundnuts	shell	0.5
	straw	2.3
Pigeon Pea	stalk	5.0
Cotton	stalk	3.5 - 5.0
Jute	sticks	2.0
coconut (copra)	shell	0.7 - 1.1
	husk	1.6 - 4.5

Source: Barnard & Kristofferson [1985].
(See also Newcombe [1985].

Table 4.14: Calorific Values of Selected Agricultural Residues (MJ/kg oven dry weight)

Material	Source	Ash Content	Gross Heating Value (oven dry weight)
		(%)	(MJ/kg)
Alfalfa straw	(1)	6.0%	18.4
			17.3
Almond shell	(1)	4.8%	19.4
Cassava stem	(2)		18.3
Coconut shell	(3)	0.8%	20.1
Coconut husk	(3)	6.0%	18.1
Cotton stalks	(1)	17.2%	15.8
	(4)	3.3%	17.4
Groundnut shells	(1)		19.7
	(4)	4.4%	20.0
Maize stalks	(1)	6.4%	18.2
	(4)	3.4%	16.7
Maize cobs	(1)	1.5%	18.9
	(4)	1.8%	17.4
Olive pits	(1)	3.2%	21.4
Pigeon pea stalks	(4)	2.0%	18.6
Rice straw	(5)		15.2
	(4)	19.2%	15.0
Rice husks	(5)		15.3
	(4)	16.5%	15.5
	(1)	14.9%	16.8
Soybean stalks	(2)		19.4
Sunflower straw	(1)		21.0
Walnut shells	(1)	1.1%	21.1
Wheat straw	(1)		18.9
	(4)	8.5%	17.2

Sources: (1) Kaupp and Goss [1981], (2) Saunier et al. [1983], (3) Kjellstrom [1980], (4) Pathak and Jain [1984], and (5) OTA [1980].

Viewed purely as a fuel, residues can be a large resource. However, as discussed in Section B, most residues have important or vital alternative uses quite apart from the need to leave some of them in the field to retain moisture, reduce soil erosion by wind and rain, maintain or enhance soil nutrients, and preserve the physical structure of the soil. Their use as fuel has to compete with these alternatives, although in many places the cooking fire has to take precedence. The supply of crop residues for fuel can be estimated by a formula which allows for these alternative uses and is based on a method [Gowen 1985] very similar to the one used in Table 4.2 to determine wood yields from forests:

Potential Residue Supply		(1) Crop Area Ratio		(2) Crop Yield		(3) Residue to Crop		(4) Fraction available allowing for sustained soil fertility		(5) Fraction available allowing for non-energy uses
(t/yr)	=	(ha)	x	(t/ha/yr)	x	(x/x)	x	(x/x)	x	(x/x)

Items 4 and 5 can be expressed as weights and subtracted from the product of Items 1, 2 and 3.

Given the large range of residue to crop ratios--varying significantly within the same crop species by cultivar--and crop yields, there is little point in providing typical figures of residue production per hectare or the availability of this residue as fuel. Local data on residue availability must be used instead.

With residue analysis, a clear distinction must be made between (1) material that is left in the field after harvesting but which can be collected later (e.g., wheat straws and stubble), and (2) crop husks and shells that are harvested with the main crop product and separated during processing (e.g., rice and coffee bean husks, wheat chaff, coconut husks and fiber). Collection costs for the first type are often prohibitive. With the second type, residues are frequently collected with the main crop product and brought to a central processing point.

A further distinction must be made between distributed and concentrated collection due to the differences in volumes flowing into the collection point. Distributed production refers mostly to family-scale crop processing which produces small volume flows at a multiplicity of locations. Residues may be used by the family or in the village but the costs of transporting them to a central depot for further processing are likely to be prohibitively high. Moreover, these 'small farm' residues often have higher value uses as animal feed, roughage, and soil conditioner. Concentrated production produces large volumes at just a few locations. Examples are the processing plant of a large cash crop farm, a village rice de-husking plant, and sawmill wastes. In these conditions it may well be economic to process residues into briquettes or pellets, or convert them to other forms of energy, such as biogas, producer gas, or electricity via the boiler and steam cycle.

Availability and Economic Costs

A central question emerges whenever crop residues and animal wastes are considered as possible fuel sources. How much safely can be harvested? The question is the source of vitriolic argument and a large literature, reinforced by data that is confusing, conflicting, or absent entirely. This section will not attempt to resolve this dispute but instead will provide some guidelines to the main issues.

In some arid and semi-arid areas, where biological productivity is already low, there is no question that after the trees have been cleared and people have begun to burn residues and dung from the fields in large quantities, severe soil degradation and reductions of crop yields begin. As productivity falls and local people press harder on the remaining resources, the biological system can slide down into a terminal stage of almost total collapse. This transition is occurring across Ethiopia and in some areas has reached the terminal phase, although the burning of crop residues may not be the sole cause of this collapse. The same transition can be seen in other parts of Africa. A graphic account of the stages of this transition is included in Annex 9, taken from Newcombe [1984b].

At the opposite extreme, it has been argued that in moist, temperate zones all residues can be removed from the field without any serious effects on soil health, provided sound agronomic practices are followed [Ho 1983], including crop rotations and sequencing, strip cropping, contouring or terracing, and use of chemical fertilizers. Much of the required organic matter is provided by the sub-surface root systems of crop plants, which are not considered here as removable residues.

There are three main issues involved in removing residues from tropical and semi-tropical farming systems.

> Depleting Organic Matter. Under steady state conditions, additions and losses of organic matter in the soil are in approximate equilibrium. If less residue or dung is returned to the soil, the organic matter content will decline slowly until a new equilibrium is reached. However, there are virtually no data on tropical farming systems to establish the rate of decline, or how far it will go, under different crop and management conditions [Barnard & Kristofferson 1985]. Losses of 30-60% over a few years have been recorded when forest land is converted to agriculture, but this has little relevance to land under continual farming.
>
> Reduced Nutrient Balances. The effects on crop productivity vary greatly according to the crop and farming system. With low input dryland agriculture, as in the poorest parts of the developing world, chemical fertilizer use is low and organic matter breakdown is the principal source of nitrogen and sulphur, and a major source of phosphorous. If reserves of these nutrients fall sufficiently, crop yields will be reduced--although the degree and rate of reduction depend on many factors, including the initial nutrient levels and the amount of nitrogen fixing by plants (e.g., legumes and some tree species). With low input wetland or irrigated farming (e.g., rice cultures), significant amounts of nutrient are provided by the irrigation water and nitrogen fixing organisms. Even substantial reductions in organic matter levels may be possible without serious effects on crop yields.
>
> In wet and rainfed systems, the enormous range of effects is well illustrated by the results of 12-year trials to increase residue

levels in many crops and locations in India [ICAR 1984]. When 10-15 tons/ha of farmyard manure were added to crops along with standard doses of chemical fertilizer, the average yield for most crops increased. However, with rice, wheat and maize there were many cases where yields did not change, or else fell. This may have been due to changes for the worse in farming practices, but the results do indicate that the response to increased manure--and by implication, to residue removal--are extremely variable. The results from some of these tests are presented in Table 4.15.

Table 4.15: Results of Long-Term Manuring Trials in India

	Extra Grain Yield Using Manure (kg/ha)		
Crop	Lowest	Highest	Average
Rice	- 100	+ 800	+ 430
Wheat	0	+ 600	+ 290
Maize	+ 100	+1300	+ 480
Millet	0	+ 500	+ 250

Source: ICAR [1984].

These and related studies for India have shown that the financial cost to the farmer in lost crop production through burning animal wastes (and by analogy, crop residues) is often less than the cost of using alternative fuels such as firewood [Aggarwal & Singh 1984].

Prevention of Rain and Wind Erosion. In the humid tropics, rainstorms on bare, sloping ground can remove very large amounts of soil. Covering the ground with a layer of residue can reduce this loss by factors of 100-1000. For example, trials in Nigeria established that on field slopes of 10%, leaving 6 ton/ha of residue on the ground in periods when it would normally be ploughed bare would reduce annual soil loss from 232 ton/ha to only 0.2 ton/ha. Water run-off was reduced by 94% because the residues both absorbed and retained the rainfall [Lal 1976]. Where water is a limiting factor in plant growth, residue mulches thus can increase crop yields by reducing moisture stress. However, the worst effects of water and wind erosion can be be mitigated without the need for residue mulches by terracing, providing tree shelter belts, and inter-planting and sequencing crops (and trees) so that the ground is nearly always covered by standing plants.

The economic costs of using residues instead of returning them to the land thus may be very high indeed, or close to zero. The costs depend critically on how much residue is removed and on the crop and farming system that is either practised now or could be practised if farming systems were to be adjusted to allow for greater volumes of residue removal. Added to these issues are the various economic and opportunity costs of using residues as fuel rather than as animal feed or building material, etc.

Pellets and Briquettes

Densification of agricultural and forestry residues to briquettes or pellets is a method of expanding the use of these resources. Densification increases the energy content per unit volume and thus reduces transport and handling costs. The densities of residue briquettes are in the upper range for woods--namely 800-1,100 kg/m^3 solid--with a bulk density (i.e. for a sack or truck load) of around 600-800 kg/m^3. Densification also produces a fuel with more uniform and predictable characteristics: an important factor with medium to large scale energy conversion devices such as furnaces and boilers.

For small-scale uses such as cooking, the burning qualities of the fuel may be better than raw residues, but this is not always so. Some residue briquettes are smokey and hard to light or keep burning evenly--a factor which varies more with the briquetting process and briquette dimensions than with particular ligno-cellulosic residues. Special designs of cooking stoves are sometimes needed to make the fuels acceptable. Alternatively, briquettes can be carbonized to produce a form of charcoal, thus further reducing transport costs, improving storage characteristics, and providing a more easily adaptable cooking fuel.

Since the processing costs are quite considerable, densified residue fuels are normally intended for rural or urban industrial use and middle to higher income households in countries where either woodfuel prices are very high or residues are concentrated very close to demand centers. Similarly, since these residue fuels also show economies of scale, densification is normally economic only at sites where raw residues are produced in substantial quantities: e.g., centralized crop and food processing plant, large cash crop estates, saw mills, logging centers, and the like. Supply estimates therefore are based simply on the volume flows through such plants.

Densification Processes and Feedstock Characteristics

A variety of processing methods are available to make pellets or briquettes but they fall into two main categories: low pressure systems such as manual or mechanical baling presses, and high pressure systems which use rollers, pistons, or screw extrusion to produce relatively dense products. Tandler and Mendis [1984] provide a thorough treatment of densification processes, feedstocks, and comparative costs.

The attributes of several densified residue feedstocks are summarized in Table 4.16. Table 4.17 presents the costs and other data on densification processes. The most important characteristics for producing good quality pellets or briquettes are high lignin content, low ash content, and low to medium moisture content. Lignin helps to bind the material together to make a durable product that will not crumble or powder during transport and handling. If low lignin material is used, higher pressures are needed to achieve binding. Moisture contents below about 15% (wet basis) are essential to densification. However, more difficult residue feedstocks can be densified satisfactorily provided they are prepared and processed adequately. For example, more chopping or grinding may be needed before pressurization, or higher pressures may be needed in order to plasticize small amounts of lignin into a binding agent. Thus straw and rice husks, which appear in Table 4.16 as "poor" feedstock materials, can be densified satisfactorily with suitable processes.

Table 4.16: Characteristics of Various Residue Feedstocks for Densification

	Feedstocks	Reason
Good		
	coffee husks	high lignin
	wood (not sawdust)	high lignin, low ash
	bark	high lignin
	cornstalks	high lignin
	peanut shells	
	coconut shells	high lignin
	bagasse (sugar cane)	
Poor		
	straw	low lignin, high ash
	rice husks	low lignin, high ash
	cotton gin trash	low lignin
	peat	high ash

Source: Tandler and Mendis [1984].

Table 4.17: Characteristics of Densification Processes and Products

Densification Process	Energy Consumption of Equipment a/	Product Density	Pellet/Briquette Production Rate	Range of System Costs	Cost per Unit Produced	Product Characteristics
	(KWh/t)	(te/m^3)	(te/hour)	(US$'000/te h)	(US$'000/te h)	
Piston Extrusion Briquetting	30 - 60	NA NA	0.15 - 0.8 1.00 - 1.5	20 - 60 25 - 110	40 - 75 30 - 40	- durable, but breaks if over 25 mm long. - any length, preferrably less than 25 mm long
Screw Extrusion Briquetting	50 - 180	NA	0.60 - 1.0	50 - 60	70 - 100	- feedstock moisture content may need to be low.
Roll Briquetting	12 - 25	NA	1.0 - 4.5	75 - 170	40 - 75	- 25-50 mm size low density
			4.5 - 9.0	170 - 300	30 - 40	- durable ability poor unless used binders
						- pillow-shaped
Pelletizing (Pellet Mill)	20 - 35	NA	2.0 - 6.0	130 - 300	30 - 60	- less than 30 mm - high bulk density - durable, smooth - easy storage, handling conveying, fuel
Cuber	15 - 30	NA	4.0 - 8.0	130	15 - 30	- lower density and durability than other extruder pellets
Bailing	5 - 10	160 - 240	NA	NA	NA	- less durable low density
Manual Presse	NA	NA	0.30 - 0.80	NA	NA	- village-level production - poor quality pellets - binder is needed for durability

NA = not available.

a/ System energy requirements for the shredder, dryer, feeder, and densifier generally range from 75 to 120 KWh/te product.

Source: Tandler and Mendis [1984].

Energy Content and Costs

Table 4.18 provides heating values and some indicative costs for the major residue briquettes, based on studies in Ethiopia [Newcombe 1985]. At typical moisture contents of 10%, most briquettes contain 16-18 MJ/kg net heating value (17.5 MJ/kg on average), or some 10-20% more than firewood at its typical air-dried moisture content. This compares to an average 14 MJ/kg for the same residues in non-briquetted forms.

Table 4.18: Average Net Heating Values and Costs of Briquetted Residues

Feedstock	Net Heating Value a/ (MJ/kg)	Cost of Delivered Energy (US¢/MJ)
Coffee Residue	17.6 MJ/kg	0.42
Bagasse	17.3 MJ/kg	0.52
Cotton Residue	17.8 MJ/kg	0.52
Cereal Straw	17.1 MJ/kg	0.53
Sawdust	17.7 MJ/kg	0.55
Cereal Stover	18.7 MJ/kg	0.68

a/ Net heating values assume 10% mcwb.

Source: UNDP/World Bank [1984b].

Briquette/pellet costs will vary considerably according to the densification process, the scale of processing, and the original biomass feedstock. Collection costs for harvesting feedstocks such as cotton stalks and cereal straws may be considerable, but with residues that arise as by-products in crop processing plants (e.g., coffee bean husks) the feedstock costs are negligible unless there is an opportunity cost for alternative uses.

Table 4.19 gives some costs for harvesting, densifying, storing and packing various residues in Ethiopia [Newcombe 1985]. The economic costs range from US$25-32/ton unbagged at the processing plant, and US$2.6-3.4 per GJ energy content, bagged and delivered 300 km to the market. These costs are low compared to fossil fuel alternatives. The "ready to burn" costs at the market are equivalent to unprocessed crude oil (5.8 GJ/barrel) of only US$15-20 per barrel. Transport and bagging in the Ethiopian case studies make up 38-44% of the economic cost, delivered to the market.

Table 4.19: Production Cost Estimates for Commercial Scale Crop Residue Briquetting in Ethiopia (US$ (1983)/ton of product)

	Residue		
Stage of Production	(1) Cotton Stalks	(2) Corn & Sorgum Stover	(3) Wheat & Barley Straw
Harvesting	7.23	19.03	10.85
Capital charges	(4.22)	(10.40)	(2.39)
Energy & lube	(1.35)	(4.11)	(1.64)
Maintenance & other	(1.50)	(4.32)	(6.40)
Labor	(0.16)	(0.20)	(0.42)
Grinding	-	1.44	1.44
Briquetting	11.80	8.54	8.54
Capital charges	(5.56)	(2.37)	(2.37)
Energy & lube	(1.76)	(5.25)	(5.25)
Maintenance & other	(4.37)	(0.80)	(0.80)
Labor	(0.11)	(0.12)	(0.12)
Storage etc.	1.0	0.88	0.88
Financial cost ex-plant	20.05	29.89	21.71
Economic cost ex-plant	25.02	32.15	27.35
Economic costs of transport and bagging, etc.	19.41	19.41	19.41
Bagging (40 kg sacks)	(3.38)	(3.38)	(3.38)
Transport a/	(14.03)	(14.03)	(14.03)
Handling at each end	(2.01)	(2.01)	(2.01)
Economic cost delivered to market	44.43	51.56	46.76
Net heating value: MJ/kg	17.3	15.0	17.4
Moisture content: % (wb)	(12)	(15)	(15)
Economic cost per energy unit delivered to market: US$/GJ	22.57	3.44	2.69

a/ Transport: 22 ton trucks over 300 km of deteriorated paved roads to Addis Ababa.

Source: Newcombe [1985].

G. ANIMAL WASTES

Direct Combustion

Animal wastes are either burned directly as dried fuel or processed in a digestor to produce biogas and a fertilizer slurry. Like crop residues, animal wastes are vital fuel resources in many wood-scarce areas of developing countries for rural and urban low-income groups. In India an estimated 72 million tons of cattle dung were burned as fuel in 1978-79 [Natarajan 1985].

Since a mature bovine produces roughly 5-7 tons of fresh dung annually, with an oven dry weight of 1.3-1.7 tons and an energy content of 16-22 GJ (or up to half a ton oil equivalent), the potential fuel supply can be large wherever animals are kept for draft power as well as meat, milk and hides, etc. But the availability of this material as fuel is a much more pertinent factor. Apart from questions of whether animal wastes should be removed from the land, dung availability will be high only when (1) animals are stalled or corralled for substantial periods of time, or (2) when people are prepared to spend time collecting it from the fields and pastures, etc. Only the poor women who collect dung for sale, and the servants of the rich, are normally prepared to do the latter. In village level studies it is also of vital importance to allow for the distribution of animal ownership by household, and customs of dung barter and collection rights on common land, etc., since these factors have a profound bearing on who can and cannot burn dung as a fuel (or benefit from its conversion in a biogas plant). Supplies may also vary greatly by season, since dung cannot be collected from the fields during prolonged wet weather.

Table 4.20 presents some data on annual dung production, wet and dry, for a range of "average" animals, as well as the nitrogen content of animal dung. These values could be used for rough order of magnitude estimates, but always should be checked against local data. The need to use local information is underscored by the enormous range of production figures that has been found in detailed Indian surveys which attempt to establish the availability and costs of dung for the country's biogas program. For example, although the all-India mean figure for wet dung production by cattle is 11.3 kg/day (4.1 ton/yr), the mean figure for different states ranges from 3.6 kg/day (Kerala) to 18.6 kg/day (Punjab) [Neelakantan 1975].

Table 4.20: Manure Production on a Fresh and Dry Basis for Animals in Developing Countries

	Fresh Manure Basis				Dry Manure Basis		
						Nitrogen Content Percentage of Dry Matter	
Animal	Fresh Manure per 1,000 kg Liveweight (kg/yr)	Assumed Average Liveweight (kg)	Fresh Manure Production Assumed per Head (kg/yr)	Assumed Moisture Content of Fresh Manure (percent)	Dry Manure Production per Head (kg/head/yr)	Solid and Liquid Wastes	Solid Wastes Only
Cattle	27,000	200	5400	80	1,000	2.4	1.2
Horses, mules donkeys	18,000	150	2700	80	750	1.7	1.1
Pigs	30,000	50	1500	80	300	3.75	1.8
Sheep and goats	13,000	40	500	70	150	4.1	2.0
Poultry	9,000	1.5	13	60	5	6.3	6.3
Human feces without urine	-	40 to 80	50 to 100	66 to 80	-	5 to 7	-
Human urine dry solids/yr (urine only)	-	40 to 80	to 25 kg	-	-	15 to 19	-

Sources: Bene et al. [1978] and Hughart [1979].

The heating value of dung is usually lower than crop residues because it contains more inorganic material. Fresh dung is often contaminated with earth or grit, while it is often mixed with straw and other residues when it is dried and patted into "dungcakes". One set of detailed measurements from Thailand put the gross heating value of fresh dung, oven dry basis, at 11.8 MJ/kg for buffaloes, 12.8 MJ/kg for cows, and 14.9 MJ/kg for pigs [Arnold & deLucia 1982]. When air-dried to 15% moisture content (wet basis), the respective net heating values are 8.6 MJ/kg, 9.4 MJ/kg, and 11.2 MJ/kg, using the formula for firewood presented in Chapter I. Other estimates in the literature range from 10-17 MJ/kg, although it usually is not clear whether these refer to air dried or oven dry material.

Biogas

The biodigestion of dung and residues to gas appears to offer an enormous potential for bringing cooking heat, light, and electric power to the villages of the Third World. Yet it is discussed here only briefly, for three reasons. First, the technology is peculiarly dependent on many specific local circumstances which favor or work against its success and therefore can be assessed only by site-specific studies. Second, there is a vast literature on the topic which can assist in such studies, especially in India, China, Thailand and a few other countries which have pioneered the biogas digestor (see, for example the recent major study by Stuckey [1983]). Third, due to very high failure rates--among small "family size" digestors--it is not yet a technology that appears suitable for household energy use. The main successes have been with village-scale plants that run irrigation pumps and other machinery, as well as provide household fuel; and large-scale digestors attached to agro- and food-processing plant and animal feedlots.

There are serveral key points to note about the technology as it applies to household use:

a. Small family-size systems of 3-4 m^3 capacity have experienced extremely high failure rates. Of the 300,000 units installed in India, almost half are routinely out of order [FAO 1985b]. A 1978 survey in Thailand found that 60% of the family-size installations were non-operational [UNDP/World Bank 1985b], and experience has been equally discouraging in other ASEAN countries. One of the main reasons for these high failure and abandonment rates is that biogas digestors are labor intensive and require a high level of management and experience to operate successfully.

b. Costs are either high for materials, as in the Indian-style steel drum systems, or in skilled labor, as in the buried masonry systems pioneered in China. Recent data for Indian systems give investment costs of US$230 and US$335 ($1981) for 2 m^3 and 4 m^3 family-size units respectively, while dung from

2-3 and 4-6 animals is needed to keep them operating. Families who could afford these investments and own as many cattle are often in the income group which is shifting towards fossil fuels for convenience or the sake of modernity. They are likely to invest in biogas only if there are clear advantages outside the area of household energy, such as using the gas for power generation and/or irrigation pumping.

c. Perhaps more than for any other topic discussed in this handbook, there is a dearth of reliable and comparable information on biogas systems, except in a few specific locations from which generalizations cannot be made. This point has been noted in many studies, including the UNDP/World Bank assessment by Stuckey [1983] cited above. The Stuckey assessment calls for a comprehensive and systematic global biogas program to provide reliable technical, economic, and social data to use in unravelling the uncertainties surrounding biogas use in developing countries.

CHAPTER V

ASSESSMENT METHODS AND CASE STUDIES

A. OBJECTIVES AND STRUCTURE

Project analysts and planners concerned with household energy need to identify the key issues and options for the sector as a first step in identifying policy and project goals. To do so they must draw on a wide variety of information not only about patterns of energy resources, supplies and demand but also, wherever biofuels are important, about related areas such as agriculture, forestry, the commercial wood trade, transport costs, and manufacturing capabilities. The socio-economic conditions and attitudes of families are also critical components of many types of energy assessments. However, the main requirement is to keep a clear eye on the main principles, which can so easily be overlooked in the welter of details.

This chapter presents some broad methods of analysis and the principles that underlie them. The emphasis is on biofuels since these raise questions which may be unfamiliar to many readers. The emphasis is also on first-order appraisals from available information which aim to identify the main issues and opportunities for change through policies, projects or other types of intervention. Preliminary appraisal methods must be employed in all analyses and so are worth discussing here. The chapter does not consider in any depth the great variety of other assessment methods and analytical approaches that are required to turn preliminary "scoping studies" into well formulated policies and projects. The focus therefore is on ways to identify major policy and technical issues and select options for further study, rather than detailed project assessment.

With this aim in mind, the chapter begins with a brief review of data sources. The limitations of the information available about energy resources and supply and demand for the household sector have a great bearing on the types of methods that can be used. The simplest and most aggregate approaches to projecting biofuel resources, supplies and demand therefore are presented as a means of identifying policy priorities. These approaches are then refined in order to provide greater reliability and value.

B. DATA SOURCES

Demand Data and Data Sources

As we saw in Chapter II, there are four main sources of household energy data on the demand side:

a. National Energy Balances: Usually developed annually, although household data is limited, highly aggregated, and often unreliable for biofuels. Regional differences such as in fuel abundance or scarcity are rarely noted.

b. National Household Expenditure Surveys: Usually large, nationally representative surveys, with a reasonable degree of disaggregation such as for type of fuel used and main categories of household including income, household size, rural-urban location and, sometimes, region. Data are often based on recollection and so may be unreliable and are given in terms of cash expenditure rather than physical quantities (although the latter can usually be obtained from the survey source).

c. National Household Energy Surveys: Where they exist, these are usually by far the richest source of disaggregated data. As well as breakdowns provided in (b), they may also give data on attitudes, preferences, and technologies used.

d. Local "Micro" Surveys: These can provide excellent data on energy use and supplies, as well as the diversity of demand/supply patterns, attitudes, and behavior. They may also provide information on the total system of biomass resources, flows, and consumption (agriculture, livestock, etc.); critical inputs to the system; and differences in these respects between various socio-economic classes. Extrapolation to the regional or national level is rarely valid and should be avoided unless there is evidence that the survey locations are typical, or there is no other information to go on.

Table 5.1 provides a checklist of data needs, assessment methods and associated problems in the analysis of cooking energy, the major end-use in the household sector. It draws on the material presented in previous chapters.

In assembling this information at any level of aggregation some cardinal rules are worth bearing in mind. These also apply to supply data, which is discussed in the next section.

* Do not be be guided by averages: it is often the variation and the extremes that matter most since they can (1) point to the locations where fuel problems are greatest or likely to become so, and (2) give clues to how people have adapted to different conditions (e.g., burning more crop residues or purchasing non-traditional fuels where woodfuel resources are particularly scarce);

Table 5.1: Cooking Energy Demand Analysis: Data Needs, Methods, and Problems

	Data	Methods	Problems
Household & population demographics	Numbers in categories used below	National statistics; surveys	
Fuel use	Per capita & per household	Surveys	Measured rather than recall data. Uncertain heat values for biofuels (moisture content, etc.)
	By household category (rural, urban, income, household size, etc.)	Surveys	Variation by household category; culture and diet; fire/stove management; technologies used
	By fuel	Surveys	Multiple fuels & equipment; multiple uses of cooking heat (especially space heating)
Technologies & efficiencies (existing & improved)	Efficiency by equipment type, hence:	Testing & surveys	Uncertain estimates; often better to compare specific fuel use for technologies
		Equipment ownership surveys	Expense
	Useful heat for cooking or relative fuel use (RFU) for technologies	UH = fuel use x efficiency RFU observed directly	Technology changes may not give estimated fuel savings due to changes in management, multiple uses, etc.
Technologies & cultural factors	see 'Problems'	Observation, anecdotes	Fuel/technology preferences & aversions, often for "non-energy" reasons (smoke, safety, insect control, convenience, etc.)
Technologies & costs	Capital & repair costs. Lifetime. Fuel prices. Efficiencies or RFU	Relative costs of utilized heat = price/efficiency or price x RFU. Life-cycle costs	First cost may be major barrier even if low life-cycle costs. Varying time horizons for investments. Cost uncertainties; e.g., mass production v. test models

- Do not ignore it because it has not been measured (or you cannot measure it): qualitative information is often as important as quantitative data in forming assumptions;

- Your data requirements must be driven by your problem, which often means that you need less data than you think;

- Distrust the simple, single answer, as there is usually a range of interrelated solutions, some of which may lie outside the energy sector;

- Make your assumptions explicit, so that you or others can change them as the data or ideas improve;

* Rural inhabitants are the best judges of what is good for them, especially where biomass resource and consumption systems are fairly complex.

In many situations and types of assessment, the single most important rule to bear in mind is that existing demand patterns will change with time. They will be adapted, through feedback, to changes in supply and resources. This is well recognized for modern fuels, where income, prices, fuel availability, etc., are known to be key variables which affect the level and choice of fuels used. Many assessments of traditional fuels, on the other hand, assume that existing patterns of demand are immutable and will persist through every reduction in available resources.

In most cases, though, there will be no information on which to judge the type or scale of these adaptations. The lack of adequate time series data on household energy parameters (and their relation to other factors) means that one must work without any clear sense of history, of past experience; and must instead include the concept of future change as an assumption (or variety of assumptions). This has important implications for all that follows. It means that assessments must usually be based on "what if?" scenarios or projections which may also be normative in character. That is, projections are made from starting data (or assumptions) about the present by making further assumptions about "natural" rates of change (e.g. in response to rising fuel prices or firewood scarcity) or certain deliberate policy and/or technical changes (e.g., the introduction of so many improved stoves each year). Projections of this kind are particularly valuable for policy formulation and project selection since they show in a transparent way the likely (estimated) outcome of policy actions. Some illustrations are given below.

Supply Data

Information about household biofuel supplies normally must be estimated from consumption data, as described above. Actual or potential supply volumes are very rarely recorded by household consumption surveys. The same is true of modern fuels, such as kerosene and LPG except for the most aggregate, or total, data. As discussed in Chapter III, electricity and piped gas are the only energy sources for which data on the household sector is dissagregated by region or type of household.

Equally important are data on biofuel resources, potential supplies, and available or economic supplies, allowing for competing uses. There are two main kinds of resource information to consider--information on tree resources, and information on residue resources:

a. Tree resources: These include all types of tree formations, such as forests and woodlands, "single tree" resources (i.e., trees dispersed through urban and agricultural ecosystems) and managed forests (i.e., plantations and woodlots, etc). The important quantities that may be required for an assessment are (1) land areas under forests and plantations, (2) the standing stock (m^3/ha), (3) the gross sustainable yield or Mean Annual Increment ($m^3/ha/yr$), and (4) the fraction of both (2) and (3) that is or could be available as woodfuel for a given "market" allowing for physical accessibility, competing uses such as timber and poles, environmental considerations, and the costs of preparing and transporting woodfuels. This type of data usually is required for major regions within a country and with breakdowns by land type.

Many developing countries now have data on land use and land types which include estimates of the standing stocks and annual yields of trees and other woody plants. Some "typical" stock and yield data were presented in Chapter IV. This type of information is normally held by the government forestry, survey or planning departments (or appropriate academic units) and is collected by a combination of satellite imagery, aerial survey and ground observation. Data on woodland stocks and yields for most developing countries are also published in the regional volumes of the "Tropical Forest Resource Assessment Project" conducted by the UN Food and Agriculture Organization (FAO, Rome) and the UN Environment Program (UNEP, Nairobi). Although estimates are approximate in many countries, the quality and quantity of data are steadily improving as recognition of their importance to biofuel planning increases.

b. <u>Residue resources</u>: These include woodfuels, crop residues and animal wastes, which are generally flow resources rather than the stock plus flow resources discussed above. For woodfuels, the major resources are concentrated and include logging and sawmill wastes. Data may be difficult to obtain unless there has been a recent survey of commercial forestry and timber operations. For crop residues and animal wastes the main sources of data are agricultural statistics, or occasional agricultural and animal censuses. Data from these sources on crop areas, their location, and crop yields can be combined with the residue yield factors given in Chapter IV to estimate total residue production. A similar approach can be used for animal wastes, using data on the number and size of domestic animals and daily dung production (see Chapter IV). Wherever possible, local data should be used since there are considerable local variations in crop yield and crop/residue ratios. Estimating the amount of this material that is or could be available as an energy source, allowing for alternative uses, is much more difficult. Local "micro" surveys or specific studies on this point may provide some guidance.

Table 5.2 provides a checklist of data needs, assessment methods, and associated problems in assessing biofuel resources and supplies.

Table 5.2: Woodfuel Resources and Supplies: Data Needs, Methods, and Problems

	Data	Methods	Problems
Land use	Area of main land types; by region	National, international statistics	Data quality varies widely by country.
Wood resource stocks & yields (closed & open natural forest, bush/scrubland, single tree, managed forests & woodlots)	Standing stock (m^3, m^3/ha) & sustainable yield (m^3/yr, m^3/ha/yr); by resource type	As above	As above. Large variation by type (e.g., age of woodlands, species); soil/climatic region; management practices.
Physical & economic accessibility	Fraction of stock currently accessed; reasons for limited access	Gross stock & yields x accessibility = net stock & yields	Uncertain data; large local variations. Most data is for commercial timber.
	Accessibility under different conditions (population density cost, etc)	Physical & economic analysis	As above. Future estimates especially uncertain: use sensitivity analysis.
Resource availability (allowing for competing uses)	Volumes for timber, poles etc. Fraction of resource now used for woodfuels. Actual woodfuel "take"	Forestry & commercial statistics; local surveys. Deduct competing uses; multiply net stock/yield x fraction available. Use actual take	As above.
Costs, prices & economics (firewood)	Commercial: harvest costs, producer prices, transport & marketing costs & profits. Non-commercial: local practices & attitudes	Estimate market and economic costs; available resources at these costs. Repeat for future costs & prices	Uncertain data. Much fuelwood (& charcoal) is produced & marketed by the informal economy. Poor data for noncommercial collection; variable responses to abundance/scarcity.
Costs, prices & economics (charcoal)	As above; plus costs & efficiencies of kilns	As above	As above.

C. SIMPLE SUPPLY-DEMAND PROJECTIONS

Forecasts of energy demand and supply are well recognized as a valuable tool for identifying imminent problems in the sector. In this section we review the value, methods and precautions that must be considered in making the simplest "first order" projections of woodfuel demand and supply.

Constant-Trend Based Projections

A useful initial analysis for the biofuel sector is to assume that there are no feedback mechanisms at work, so that there is no change in unit consumption and demand grows in line with population growth. One also assumes that nothing is done to increase available supplies and resources through efforts such as afforestation. Projections can be made at any level of aggregation: at the national or regional levels or for a particular town or village.

The main uses of such projections are (1) to identify any resource problems and (2) to ascertain, if a problem does exist, the degree of future adaptation required to bring supply and demand into a sustainable balance. If there is a problem, the projection is merely a starting point for further work since it describes a future that is most unlikely to come about in practice.

Table 5.3 presents a sample projection. The basic data on consumption, population and resources are given below the table and are used in subsequent projections in which the methodology is refined. The calculation method is also presented with the table. Essentially, consumption grows with the population at 3% a year, and supplies are obtained from the annual wood growth and clear felling of an initially fixed stock (area) of trees. We assume at this stage that there is no use of agricultural residues or animal wastes as fuels.

The starting conditions for the projection reflect the situation in many areas of the developing world: wood consumption exceeds wood growth so that supplies are partly met by cutting down the forest stock. In the first few years the rate of resource reduction is small (only 1.8% annually for the first forecast period). It may not be noticeable to local residents or may appear less threatening than other problems of survival. Unless adaptations which slow or halt the decline have large perceived benefits and/or low costs, they are unlikely to attract much interest. However, since demand is assumed to rise exponentially, the resource stock declines at an accelerating pace and eventually falls to zero (in this case, by the year 2007).

Table 5.3: Constant Trend-Based Projection: Wood Balance

		1980	1985	1990	1995	2000	2005
Standing stock	000 m^3	17,500	16,010	13,837	10,827	6,794	1,520
Fuelwood yield	000 m^3/yr	350	320	278	217	136	30
Consumption	000 m^3/yr	600	696	806	935	1,084	1,256
Deficit	000 m^3/yr	250	376	529	718	948	1,226
(Population	000s)	(1,000)	(1,159)	(1,344)	(1,558)	(1,806)	(2,094)

Assumptions:

Fuelwood yield: 2% of standing stock. (Standing stock: 20 m^3/ha).
Population: 1 million in 1980, growth at 3% per year.
Consumption: 0.6 m^3/capita/year.
Deficit is met by felling the standing stock.

Calculation method:

Calculations are performed for each year (t, t+1, etc), taking the stock at the start of the year and consumption and yield during the year:

Consumption (t) = Reduction in stock (t, t+1) + Yield in year (t)

Stock (t) - Stock (t+1) + M/2 x [Stock (t) + Stock (t+1)]

where M = Yield/Stock expressed as a fraction (0.02 in this case).

Hence to calculate the stock in each year:

Stock (t+1) x [1 - M/2] = Stock (t) x [1 + M/2] - Consumption (t).

Such a picture of the long term is unrealistic, at best. As wood resources decline ever more rapidly, wood prices and collection times would rise and consumption would be reduced by fuel economies and substitutions of other fuels.

Projections with Adjusted Demand

A useful next step is to examine reductions in per capita demand to see how large they must be to reduce or halt the decline in wood resources. The adjustments can then be related to policy and project targets, such as improved stove programs and substitutions of other biomass fuels or petroleum-based cooking fuels for woodfuels.

An exercise of this kind is shown in Table 5.4, using the same basic assumptions used in Table 5.3. The calculation method is quite simple. The population (A) is divided into categories of fuel and equipment users, in this case for cooking (B). Estimates are made of the specific energy consumption of each category (C). Total energy for each category (D) is the product of (A) x (B)/100 x (C). Finally, total wood energy is converted to a wood volume (E). Apart from demographic information, the only data required for the projection are those shown in the first column of (A), (B) and (C), plus rough information on fuel savings that can be achieved by economies and more energy efficient equipment.

In this example three main kinds of wood saving are considered:

a. Substitution of improved stoves for open fires (B). This may result from market forces, increasing urbanization and incomes, or a proposed program for introducing improved stoves. The rate of substitution assumes a "logistic" curve for the proportion of wood users employing stoves (F). From these assumptions, the rate of stove introductions can easily be calculated (F). The implied stove "program" expands fairly steadily to 1995 and then slackens off as saturation in stove ownership is approached. Alternatively, annual targets for stove introductions can be used to derive the data in (B).

b. Substitution of wood by crop residues (in rural areas) and petroleum products (in towns) at a gradually accelerating pace. The former change is a common response to wood scarcity; the latter, to urbanization and rising incomes. Substitution into petroleum cooking fuels (and electric cooking) may also be the result of policy choices for urban areas facing woodfuel deficits, as occurs in some developing countries today.

c. Reductions in specific fuel consumption by all user categories. The largest reductions (40% over the 25-year period) apply to open fires since the scope for economies is greatest here. For the stove and residue groups the equivalent reductions are 30%, and for the petroleum product group 17%. In all cases, much of the reduction could be due to the use of more efficient cooking equipment such as aluminum pots and pressure cookers (see Chapter III). Some reductions could also be due to progressive improvements in stove efficiency and the introduction of stoves for use with crop residues, perhaps through pelleting and briquetting.

Table 5.4: Basic Projection, Adjusted for Demand

		1980	1985	1990	1995	2000	2005
(A)	Population ('000s)	1,000	1,159	1,344	1,558	1,806	2,094
(B)	Fuel & equipment use (percent)						
	Wood	80	78	72	66	56	45
	open fire	75	66.3	50.4	33	19.6	10
	stove	5	11.7	21.6	33	36.4	35
	Residues	10	11	14	17	22	25
	Petroleum products	10	11	14	17	22	30
(C)	Per capita consumption (GJ)						
	Wood	9.0	8.6	7.6	6.2	5.0	3.7
	open hearth fire	9.3	9.3	9.0	8.3	7.3	5.6
	stove	4.6	4.6	4.4	4.1	3.7	3.2
	Residues	10	9.8	9.4	8.8	8.1	7.0
	Petroleum products	3	2.9	2.8	2.7	2.6	2.5
(D)	Total consumption ('000 GJ/yr)						
	Wood	7,205	7,770	7,373	6,375	5,016	3,518
	open hearth fire	6,975	7,146	6,096	4,267	2,584	1,173
	stove	230	624	1,277	2,108	2,432	2,345
	Residues	1,000	1,249	1,769	2,331	3,218	3,665
	Petroleum products	300	370	527	715	1,033	1,570
	TOTAL	8,505	9,389	9,669	9,421	9,267	8,753
	Total/capita: GJ/yr	8.51	8.10	7.19	6.05	5.13	4.18
(E)	Wood consumption '000 m^3/yr	600	647	614	531	418	293
(F)	Supplementary data						
	Wood users with stoves (%)	6.3	15	30	50	65	78
	Increase in stoves over preceeding 5 years: '000s/yr	-	3.4	6.2	9.0	5.7	3.0

For calculation method, see text.

Assumptions:

As for Table 5.3, plus:
Fuelwood of 600 kg/m^3; 20 MJ/kg (both oven-dry basis).
Stove introduction rate assumes 5 persons per household.

These adjustments cut annual wood use in half over the projection period. The effect of this change on wood resources is shown in Table 5.5. The reduction in stock over 1980-2005 is now only 37% and, equally important, consumption and resources come close to being in balance by the end of the period. The catastrophe of total deforestation has been averted.

Table 5.5: Basic Projection, Adjusted for Demand: Wood Balance

	1980	1985	1990	1995	2000	2005
Standing stock ('000 m^3)	17,500	16,103	14,479	12,960	11,777	11,082
Wood yield ('000 m^3/yr)	350	322	290	259	236	222
Consumption ('000 m^3/yr)	600	647	614	531	418	293
Deficit ('000 m^3/yr)	250	325	324	272	182	71

Assumptions:
As in Table 5.3; consumption from Table 5.4.

The projection presented in Table 5.5 may also be considered unrealistic, since wood savings continue to accelerate at a time when demand and resources are brought into balance. However, this objection misses the point of projections of this kind. They are not intended to forecast one particular future as much as to explore alternative futures and the role of policy interventions in achieving these alternatives. Thus, their purpose is to explore the effects of given changes--to ask "what if"?--and hence to help select the policies and projects which aim to bring about those changes. The realism of a scenario lies in the likely timing, scale and successful adoption of the interventions recommended, and can only be judged after the fact. For this reason it is always valuable to make a variety of projections to illustrate the implications of different policy initiatives and outcomes.

Projections with Increased Supplies

Woodfuel deficits may also be reduced by a variety of measures which increase the supply of woodfuels or alternative biofuels. Woodfuel supplies can be increased by more productively managing existing forests, planting trees in rural areas for fuel or multiple purposes, or setting up periurban plantations. For example, logging and sawmill wastes may be utilized economically. Many agricultural changes can be made to augment supplies of crop residues or animal wastes so that they can be used more extensively as fuels without competing with other essential uses. The briquetting and pelletizing of agricultural residues often can make these fuels more widely available at economic prices.

Targets for these additional supply options can easily be set by estimating the gap between projected woodfuel demand and supplies, since the objective is to eliminate woodfuel deficits. Various mixes of supply options can be considered with different levels of demand reduction so that together they achieve a balanced projection. Examples of balances with a variety of additional supply outputs are presented in the case studies of Section E.

Projections Including Agricultural Land

A major shortcoming of the projections discussed above is that they ignore the effects of the expansion of agricultural land. In most developing countries the spread of arable and grazing land, together with commercial logging in some places, has been a much more important cause of tree loss than the demand for woodfuels (see Chapter IV).

The effects of agricultural land expansion are illustrated in Table 5.6, using the same hypothetical system as before. Assuming no increase in agricultural productivity, farm land increases by 3% annually, or the same as the growth of population. This expansion is alone responsible for a 63% decline in woodland area and wood stocks over the period of analysis. If much of the land is cleared by felling and burning--a common practice in many areas--this wood would not contribute towards meeting some of the demand, causing additional pressures on the forest stock and leading to their very rapid decline. On the other hand, if one assumes that all the wood from these clearances is used as fuel--as in Table 5.6--then the wood made available from land clearance and natural regeneration would be sufficient to meet a 2% annual growth in fuelwood demand without resorting to tree cutting for fuel in the remaining woodland areas.

This simple example underlines the critical importance of including agricultural parameters in wood resource and demand projections, and the need to establish whether trees and woodlands that are cleared for farming are burned *in situ* or are used as fuel and timber.

Projections Including Farm Trees

A particularly important source of supply often ignored in these types of projections is the fuelwood from trees growing on farm lands to produce fruit, forage, small timber, shelter, shade or fuelwood itself. These represent a major source of fuel for many rural inhabitants and provide another very important reason for including the agricultural system in projection models.

An example of the potential contribution of farm trees to fuelwood supply is provided by a number of FAO/UNDP Tropical Forest Resource Assessments for East Africa. In addition to timber and construction poles, these assessments revealed that farm trees can provide on average as much as 0.5 m^3 of fuelwood a year per hectare of total farmland in some regions (see Table 5.7) [Kamweti 1984]. This is more than the gross yields from the woodland uses in the projections above.

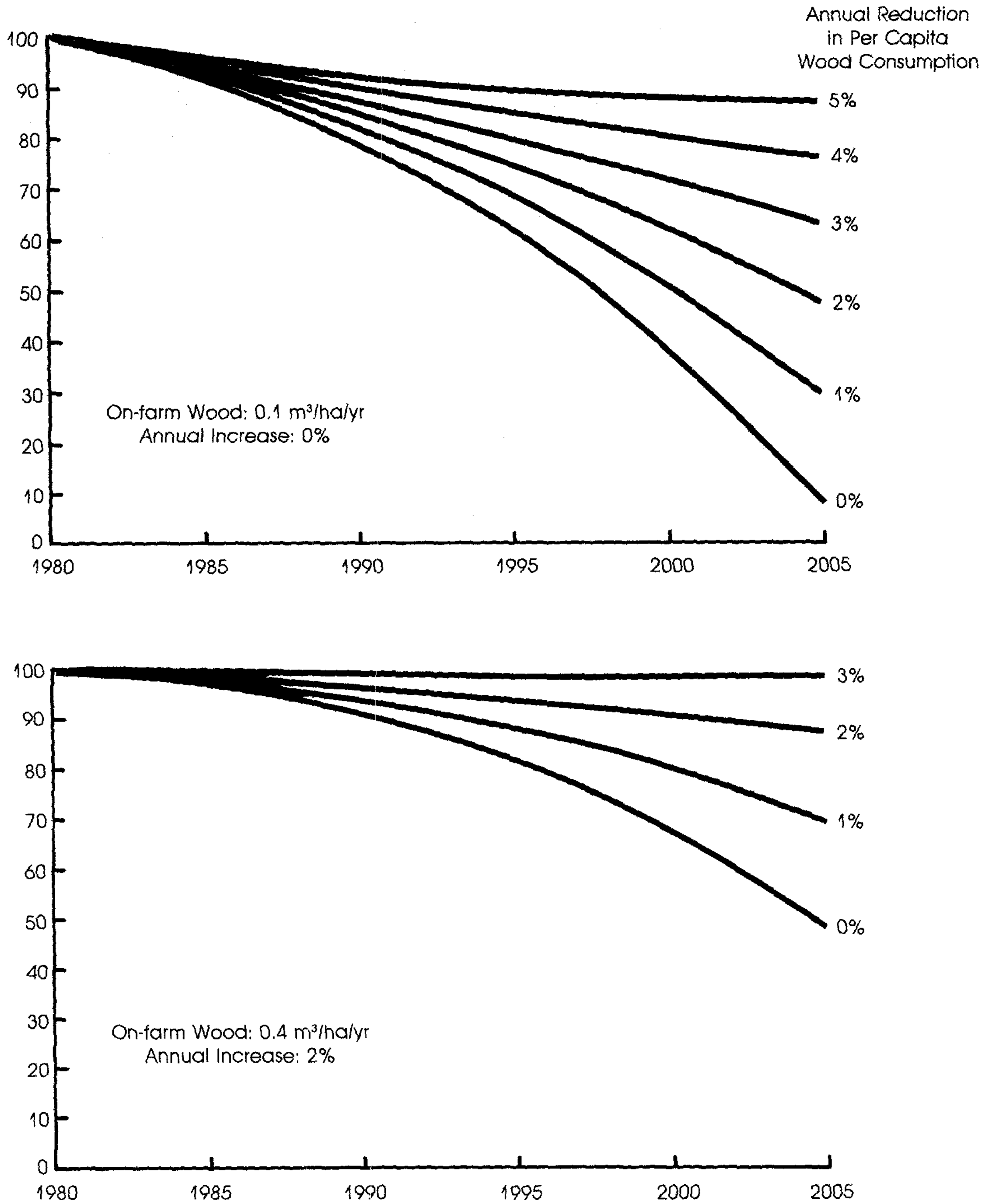
Table 5.6: Projection Based on Expansion of Agricultural Land

	1980	1985	1990	1995	2000	2005
(A) Areas and stock						
Woodland area ('000 ha)	875	795	703	596	472	328
Agric. area ('000 ha)	500	580	672	779	903	1,047
Standing stock ('000 m^3)	17,500	15,907	14,061	11,920	9,439	6,562
(B) Wood availablity ('000 m^3/yr):						
New agricultural land	300	348	403	467	542	628
Woodland yield	347	315	277	234	183	125
TOTAL	647	663	680	701	725	753
(C) Consumption and Wood Balance ('000 m^3/yr):						
Consumption growth: 2% p.a.						
Consumption	600	631	663	697	732	769
Surplus/Deficit (+/-)	+ 47	+ 32	+ 17	+ 4	- 7	-16

Assumptions:
Agricultural area: 0.5 ha/capita.
Population: as in Tables 5.3 - 5.5.
Consumption growth as shown.
All wood from land cleared for agriculture is used as fuel.
Wood availability equals stock from land clearance plus yield of remaining woodlands; i.e. no trees are cut for the direct purpose of providing fuel.

Furthermore, farm trees are fully accessible to the local consumers of their products. The accessibility of forest and woodland resources is rarely 100% and is usually much less than this because of physical reasons (remoteness from consumers, difficult terrain), economic reasons (transport costs to major demand centers), or legal reasons (prohibitions on access to, or cutting within, game and forest reserve). Consequently, available or net yields of fuelwood are normally much less than the gross yields used in the examples above. The present accessibility of these resources and likely changes in population density and location, costs and prices, and infrastructural factors such as road building are often critical factors to consider in making projections of the kind discussed here. However, these factors are difficult to quantify as they are subject to great uncertainty.

FIGURE 5.1: Indices of Forest Stocks, Varying On-farm Fuelwood Production and the Rate of Decline in Per Capita Fuelwood Consumption



Common Assumptions:
Annual Population Growth: 3%
Annual Increase in Agricultural Productivity: 3%
(i.e. Constant Agricultural Land Area)

World Bank—30736:4

The effect of including on-farm fuelwood production in the wood balance of our "model system" is shown for two cases in Figure 5.1. In both cases agricultural productivity grows in line with population so that the area of agricultural land remains constant. In the top figure, on-farm wood production is initially low and per hectare yields do not increase. Consequently, if the decline of the forest stock is to be arrested, per capita fuelwood demand must fall by about 5% annually. In the lower figure, on-farm production is initially quite high, while average per hectare yields grow at 2% annually, reflecting a fairly vigorous programme of rural tree planting. Now the forest stock is stabilized at close to its initial level with only a 3% annual decline in per capita fuelwood consumption.

All the examples in this section illustrate the necessity of elaborating on even the simplest wood balance projections. Without the progressive addition of the concepts outlined above, the projections will be of little value and may actually misdirect the process of selecting and examining policy options.

D. DISAGGREGATED ANALYSES

In practice the models and projection methods used for national planning cannot be as aggregated as in the examples presented above. The diversity of the basic projection parameters and their trends makes it necessary to use some degree of disaggregation both for demand and supply projections.

Aggregated models also are limited in that they can be used only on a limited number of well-defined "target" subsystems or regions within the country. The target may be a major urban demand center, a rural area experiencing rapid population growth or inward migration, an area of rapid agricultural expansion, or a region that is suitable for afforestation or rural tree-planting schemes. The target may be as small as a single village.

Demand Disaggregation

As discussed in Chapter III, household energy demand and the mix of fuels employed vary greatly by settlement size, household income, availability, prices, and other factors. Different household groups also vary in the opportunities, constraints and costs they perceive are involved in changing their energy use and supply patterns. Therefore, national demand/supply projections and balances, wherever possible, should be derived from disaggregated projections for the major types of households. The level of disaggregation of these projections must be a judgement for the analyst, based on available data and the degree of difference existing between the sub-groups.

Another major criterion in determining the optimal level of disaggregation is the computational effort involved. For the examples presented above, results were obtained quite rapidly by using either a programmable calculator or simple computer programs. For disaggregated models, computer "spreadsheets" or software designed specifically for analyses of this kind are almost a necessity. A good example of the special software, which has been installed in a number of developing countries, is the LEAP (LDC Energy Alternative Planning) system, developed by the Beijer Institute, Stockholm, and the Energy Systems Research Group, Boston, Massachusetts, USA. On the demand side, LEAP provides for extensive disaggregation by energy consumption groups, ownership of energy equipment, specific fuel consumption and efficiencies. On the supply side, LEAP has sophisticated modules for the modern energy sector, land use and land types, and the resource and production characteristics of a large range of biofuels.

Resource and Supply Disaggregation

The need to disaggregate biofuel resources and supplies is illustrated in Table 5.7, which shows population, land use and types, and fuelwood production characteristics, averaged for six East African countries (Ethiopia, Kenya, Malawi, Somalia, Tanzania and Zambia). Gross fuelwood yields vary by a factor of 17 from the least to the most productive regions and land types. Furthermore, while the average yield per hectare ranges from about 50 to 600 kg/yr, the average yield per capita is not related to this quantity because of the large variations in population density: compare, for example, Zones 1 and 6.

The main lesson to be learned from the type of regional breakdown presented in Table 5.7 is that woodfuel deficits, as well as demand and resources, usually vary considerably. This variation is often the result of differences in population density and agricultural land area, which are themselves related to the basic biological productivity of ecosystems. Thus in Table 5.7 one sees that on average sustainable woodfuel yields probably exceed demand in all but two areas: the dry savanna (Zone 3, with a yield of 0.73 m^3/ha/yr) and the heavily populated highlands (Zone 6, with a yield of 0.39 m^3/ha/yr). These are clearly the areas most likely to be suffering severe deficits and woodland depletion and hence are priority areas for more detailed assessments or project development. However, other areas may well be in a similar plight, since the table shows only the gross yields and not the net yields, allowing for accessibility. Note also that there are large differences between the zones in the proportion and growth rates of agricultural land, and hence in on-farm wood supplies.

Table 5.7: Population and Fuelwood Data by Land Type: Averages for East Africa, 1980

Land type	1	2	3	4	5	6
% Population	4.2	8.4	37.4	7.7	2.1	40.2
% Total land area	26.5	9.8	36.7	12.0	7.1	7.9
Population density (persons/km^2)	3.0	16.0	19.2	12.2	5.6	96.4
Area of land by type (% total area)						
Closed forest	0.2	3.6	1.5	3.1	12.6	5.1
Woodlands	1.8	4.0	3.7	9.6	12.1	2.8
Bushlands	8.8	30.6	21.9	32.2	27.7	17.7
Scrublands	46.4	54.3	29.6	12.1	6.0	22.2
TOTAL	57.2	92.5	56.7	57.0	58.4	47.8
(Agriculture)	(4.2)	(6.4)	(16.7)	(14.0)	(8.1)	(33.6)
Gross fuelwood yield; i.e. without deductions for accessibility (m^3/ha/yr)						
Closed forest	1.0	2.0	1.0	1.5	1.8	2.5
Woodlands	0.4	0.6	0.8	1.0	1.2	1.2
Bushlands	0.15	0.4	0.3	0.75	0.8	0.85
Scrublands	0.05	0.15	0.1	0.25	0.3	0.3
(Farm lands)	(0.2)	(0.35)	(0.25)	(0.4)	(0.45)	(0.5)
(Plantations)	(2.0)	(10.0)	(5.0)	(14.0)	(15.0)	(16.0)
Note: standing stock = 80 x gross yield.						
Average yield per total area: m^3/ha/yr	0.046	0.300	0.141	0.414	0.613	0.379
Average yield per capita: m^3/yr	1.50	1.88	0.73	3.40	11.0	0.39

Land type	Altitude (m)	Rainfall (mm)
1. Desert/sub-desert.	200-1,000	<400
2. Warm, humid lowlands.	0- 500	500-1,000
3. Dry savanna.	500-1,500	500- 900
4. Rapid agricultural expansion.	1,000-2,000	800-1,200
5. Low population/slow or no agricultural expansion	1,000-2,500	1,000-1,300
6. Heavily populated highlands.	1,500-3,000	<1,200

Source: Kamweti [1984].

5.1 It is clearly beyond the scope of this handbook to design micro-computer spreadsheet data bases and models to encompass regional disaggregation and its complications. However, this process would call for no more than simple arithmetic and algebra and an ordered approach. The basic formulae for making projections are presented in this handbook or can be derived by common sense. Alternatively, packaged systems such as LEAP can be used.

E. CASE STUDIES

5.2 To summarize the methods and concepts outlined above, this section provides a case study of a target analysis for household energy demand and supply. The example is based on an analysis of supply options for the household sector of the Antananarivo district ("Faritany") of Madagascar [UNDP/The World Bank 1985a].

5.3 Per capita and total fuel consumption were estimated by surveys of a few main regions of the country. Demographic data also were assembled. The results of this demand analysis for woodfuels are summarized in Table 5.8, although data on modern fuels also were collected. Note the large consumption differences between the regions and the fact that the energy unit is "tonnes woodfuel equivalent" rather than GJ, etc. Although this may upset energy analysts, it is a descriptive term useful for politicians and economic planners in countries where woodfuels dominate the energy market. It is also more easily understood and utilized by foresters and transport planners.

Table 5.8: Household Woodfuel Use in Urban and Rural Centers of Madagascar

(A) Per capita woodfuel consumption (kg wood eqivalent per year)

	Highlands		Lowlands	Overall Average	
Fuel	Urban	Rural	Urban	Rural	Both fuels
Firewood	70	550	100	365	
Charcoal	140	0	70	0	548

(B) Total Woodfuel Consumption (thousand tonnes wood equivalent)

	Highlands	Lowlands	Overall Total
Firewood	2,344	1,482	3,826
Charcoal	1,148	362	1,510
Total	3,491	1,844	5,336

Source: FAO/CP, Fuelwood Project Preparation Mission (1983) and UNDP/World Bank [1985a].

On the supply side, data were collected and estimates made of forest cover, stocks, yields and sustainable and accessible supplies of woodfuels. Some summary data on forest areas are given in Table 5.9. Table 5.10 presents summary data on sustainable and accessible woodfuel supplies, for present conditions, as well as present woodfuel demand. Woodfuel deficits and surpluses are shown for each region.

Table 5.9: Contiguous Forest Cover by Province, Madagascar, 1983-84

Faritany	Natural Forest	Plantations	Forest Cover (% of faritany)
Antananarivo	114.5	60.9	29%
Antsiranana	1,504.3	5.5	34%
Fianaranrsoa	1,285.0	77.6	13%
Mahajanga	2,127.4	6.7	14%
Toamasina	2,813.7	102.1	41%
Toliara	4,462.0	11.9	27%
Total:	12,306.9	264.8 a/	21%

a/ Excludes the fanalamanga pine plantations.
Source: UNDP/World Bank [1985a].

Although Table 5.10 shows that the country as a whole had surplus supplies on a sustainable basis, it clearly identifies a major deficit for the Antananarivo district. Further studies therefore focused on this area and the implications of introducing a range of new biofuel supply options. The latter included rural afforestation and peri-urban plantations for fuelwood and charcoal; the use of logging and sawmill residues for charcoal and the briquetting of charcoal fines or "wastes;" and the briquetting of agricultural residues. Also included were the upgrading of existing supply systems, such as traditional charcoal production methods and tree coppicing for charcoal.

Table 5.10: Woodfuel Demand and Supply Balance by Region, Madagascar, 1985
(thousand tonnes woodfuel equivalent)

Faritany (District)	Accessible Sustainable Supply	Demand			Supply/Demand Deficit or (Surplus)
		Firewood	Charcoal	Total	
Antananarivo	371	1,287	887	27,174	1,803
Fianarantsoa	929	1,123	300	1,423	494
Antsiranana	688	231	92	323	(363)
Mahajanga	1,143	337	93	430	(713)
Toamasina	1,673	492	105	597	(1,076)
Toliary	1,946	464	83	547	(1,399)
TOTAL	6,750	3,934	1,560	5,494	(1,256)

Note: Surpluses cannot be credited or "transferred" to deficit areas due to lack of transport infrastructure and high costs.

Source: UNDP/World Bank [1985a].

A summary of the main findings is presented in Table 5.11. The calculation method is straightforward and can be followed easily by running down the rows of the table.

On the demand side (Section A), rural and urban population and population growth rates are estimated separately, as are per capita rural and urban household demand. These are held constant. A second analysis could have explored possible changes in per capita consumption and their effects on supply options. Total demand is then calculated for each year.

The second block of data (Section B) estimates the present sustainable woodfuel supply and holds this constant. An alternative projection might have considered the effects of agricultural land changes on these supplies. The contribution from modern fuels and from the increase of urban trees and woody residues is then added to these supplies to give a projection of the woodfuel deficit with no intervention.

The third block of data (Section C) sets out the increases in woodfuel supply from a range of proposed interventions (i.e. projects) designed to introduce new sources of biofuels, upgrade existing resources and expand the supply and use of modern fuels. Finally in Section D, the supplies are totalled and an overall projection of woodfuel deficits is obtained.

Supplementary tables, not shown here, could provide indications of the scale of the proposed interventions such as the areas of peri-urban plantations and number of seedlings required in each period.

The penultimate step is to cost the various new supply options (and demand management options, if these are included). This step is not shown here since it involves conventional and familiar methods. Finally, alternatives can be examined to provide one or more least cost set of options, which can be compared for their effects on supply/demand deficits and balances.

It is this final comparison with its presentation of associated costs and indications of the scale of interventions required that will attract the most attention from local officials, aid agencies, and others; indeed, that will form the starting point for negotiations on project selection and detailed project design, possibly leading to eventual project implementation.

However, it cannot be stressed strongly enough that the "paper assessments" described above are only a starting point for a more practical and meaningful energy strategy or set of projects.

Table 5.11: Projected Supply-Demand Balance for Household Energy, Antananarivo, Madagascar
(thousand tons of wood equivalent: twe)

		1983	1985	1987	1989	1991	1993	1995
A	Urban Population ('000)	691.5	762.3	840.5	926.6	1,021.6	1,126.3	1,241.7
	Rural Population ('000)	2,184.5	2,304.1	2,430.2	2,563.2	2,703.4	2,851.4	3,007.4
	Total Population ('000)	2,876.0	3,066.4	3,270.6	3,489.8	3,725.0	3,977.7	4,249.2
	Total Energy Demand ('000 twe)	2,111.4	2,270.4	2,420.6	2,581.1	2,752.6	2,936.0	3,132.0
B	Sustainable Supply							
	Antananarivo Faritany							
	From Plantation ('000 twe)	329.92	317.38	305.33	293.76	282.64	271.97	261.72
	From Forests ('000 twe)	45.82	45.82	45.82	45.82	45.82	45.82	45.82
	Toamasina Faritany							
	From Plantation ('000 twe)	129.60	129.60	129.60	129.60	129.60	129.60	129.60
	From Forests ('000 twe)	281.51	281.51	281.51	281.51	281.51	281.51	281.51
	Total Sustainable Supply ('000 twe)	786.9	774.3	762.3	750.7	739.6	728.9	718.7
	Existing Modern Fuels							
	Electricity ('000 twe)	9.1	10.0	11.1	12.2	13.4	14.8	16.3
	LPG ('000 twe)	62.4	68.8	75.9	83.7	92.2	101.7	112.1
	Kerosene ('000 twe)	9.7	10.7	11.8	13.0	14.4	15.8	17.5
	Sub-total ('000 twe)	81.2	89.6	98.8	108.9	120.0	132.3	145.9
	Urban Trees and Woody Residues ('000 twe)	63.3	68.1	72.6	77.4	82.6	88.1	94.0
	Deficit without Intervention ('000 twe)	1,180.0	1,338.4	1,487.0	1,644.1	1,810.4	1,986.6	2,173.5
	Deficit in ha equivalent ('000 ha plantation)	98.3	111.5	123.9	137.0	150.9	165.6	181.1
C	New Sources							
	Charcoal							
	Haut Mangoro Pine	0.0	0.0	18.7	18.7	18.7	18.7	18.7
	Logging Residues	0.0	0.0	32.3	57.3	102.0	181.3	322.5
	Sawmill Wastes	0.0	0.0	2.1	3.7	6.5	11.5	20.5
	Lac Aloatra Charcoal Briquettes	0.0	0.0	0.0	0.0	3.9	11.2	22.8
	Total Charcoal	0.0	0.0	53.0	79.7	131.1	222.8	384.6
	Agricultural Residues Rice Husk Briquettes	0.0	0.0	3.5	6.3	11.1	19.8	35.2
	Sub-Total A	0.0	0.0	53.0	79.7	131.1	222.8	384.6
D	Upgraded Production							
	Traditional Charcoal	0.0	0.0	21.7	43.3	65.0	86.6	108.5
	Copice Management	0.0	0.0	3.2	5.8	10.2	18.2	32.4
	Sub-Total B	0.0	0.0	24.9	49.1	75.2	104.9	140.7
E	Expanded Modern Fuel Supply							
	Kerosene	0.0	0.0	8.9	15.8	28.1	50.0	89.0
	Electricity	0.0	0.0	-	15.5	30.3	59.4	110.5
	Sub-Total C	0.0	0.0	8.9	31.3	58.5	109.5	199.5
	Total Supply	931.4	932.0	1,024.0	1,103.4	1,218.1	1,406.2	1,718.4
	Deficit	1,180.0	1,338.4	1,396.6	1,477.7	1,534.5	1,529.7	1,413.5

Source: UNDP/World Bank [1985a].

Annex 1

TYPICAL ENERGY CONTENT OF FOSSIL AND BIOMASS FUELS

Solid Fuels	Moisture Content Wet Basis (% mcwb)	Typical Net Heating Values a/ (MJ/kg)
Biomass Fuels		
Wood (wet, freshing cut)	40	10.9
Wood (air-dry, humid zone)	20	15.5
Wood (air-dry, dry zone)	15	6.6
Wood (oven-dry)	0	20.0
Charcoal	5	29.0
Bagasse (wet)	50	8.2
Bagasse (air-dry)	13	16.2
Coffee husks	12	16.0
Ricehulls (air-dry)	9	14.4
Wheat straw	12	15.2
Maize (stalk)	12	14.7
Maize (cobs)	11	15.4
Cotton gin trash	24	11.9
Cotton stalk	12	16.4
Coconut husks	40	9.8
Coconut shells	13	17.9
Dung Cakes (dried)	12	12.0
Fossil-Fuels		
Anthracite	5	31.4
Bituminous coal	5	29.3
Sub-bituminous coal	5	18.8
Lignite	-	11.3
Peat	-	14.6
Lignite briquettes	-	20.1
Coke briquettes	-	23.9
Peat briquettes	-	21.8
Coke	-	28.5
Petroleum coke	-	35.2

TYPICAL ENERGY CONTENT OF FOSSIL AND BIOMASS FUELS (continued)

Liquid Fuels	Specific Gravity	Net Heating Values (MJ/kg)	(MJ/litre)
Fossil Fuels			
Crude oil	0.86	41.9	36.7
LPG	0.54	45.6	24.6
Propane	0.51	45.7	23.3
Butane	0.58	45.3	26.3
Gasoline	0.74	43.9	32.6
Avgas	0.71	44.3	31.5
Motor gasoline	0.74	44.0	32.6
Wide-cut	0.76	43.7	33.3
White spirit	0.78	43.5	34.0
Kerosene	0.81	43.2	35.0
Aviation turbine fuel	0.82	43.1	35.4
Distillate fuel oil			
Heating oil	0.83	43.0	35.7
Autodiesel	0.84	42.8	36.0
Heavy diesel	0.88	42.4	37.3
Residual fuel oil	0.94	41.5	39.0
Light	0.93	41.8	38.9
Heavy	0.96	41.4	39.8
Lubricating oils	0.881	42.4	37.3
Asphalt	1.05	37.0	38.9
Tar	1.20	38.5	46.3
Liquified natural gas	0.42	52.8	22.2
Biomass-Derived liquids			
Ethanol	0.79	27.6	21.9
Methanol	0.80	20.9	16.8

TYPICAL ENERGY CONTENT OF FOSSIL AND BIOMASS FUELS (continued)

Gas	Net Heating Value (MJ/m^3)
Fossil Fuels	
Natural Gas	34.8
Refinery Gas	46.1
Methane	33.5
Ethane	59.5
Propane (LPG)	85.8
Butane (LPG)	111.8
Pentane	134.0
Coke oven gas	17.6
Town gas	16.7
Biomass-Derived	
Producer gas	5.9
Digester or Biogas	22.5
Electricity	3.6 MJ/kWh

a/ Based on given moisture contents.

Note: For biomass fuels, these data should be used only as rough approximations.

Sources: Biomass fuels--various (see text) modern/non-traditional fuels--FEA (1977).

Annex 2

PREFIXES, UNITS AND SYMBOLS

I. Prefixes and Symbols

		SI		American
thousand	10^3	k	kilo	M *
million	10^6	M	mega	MM *
billion	10^9	G	giga	G
trillion	10^{12}	T	tera	T
quadrillion	10^{15}	P	peta	

II. Energy Symbols

	SI
J	joule
Wh	Watt-hour
	American/General
cal, kcal	calorie, kilocalorie (10^3 cal)
Btu, BTU	British Thermal Unit
Q	Quadrillion Btu, or Quad (10^{15} Btu)
toe, TOE	Metric tons of (crude) oil equivalent (defined as 10^7 kcal--41.868 GJ in statistics employing net heating values)
tce, TCE	Metric tons of coal equivalent (defined as 0.7 x 10^7 kcal--29.31 GJ in statistics employing net heating values)
twe	Thousand tons of wood equivalent
boe, BOE	Barrels of (crude) oil equivalent (approx. 5.8 GJ)
bbl, BBL	Barrels of oil (crude or products) (equals 42 US gallons)

Note: American and SI systems use "M" differently.

PREFIXES, UNITS AND SYMBOLS (continued)

III. Power (and Electricity) Symbols

	SI
W	Watt
v, V	Volt
a, A	Ampere
kVA	kilovolt-ampere

	American/General
BTU/hr	British Thermal Units per hour
hp	Horsepower
bd, b/d	Barrels of oil per day
bdoe	Barrels of oil equivalent per day (Barrels of daily oil equivalent)

IV. Weights and Measures

g, kg	Gram or gramme, kilogram
lb, lbs	Pound, pounds
t, te, ton	Metric tonne, or 10^6 g (SI)
lt, ton	Long ton (Imperial; 2,240 pounds)
st, ton	Short ton (US; 2,000 pounds)
tpa, tpy	Tons per year
m, km	Meter, kilometer (SI)
mi	Miles
sq. m, m^2	Square meter
ha	Hectare (10^4 m^2)
ac	Acre
l	Liter, litre (SI)
cu. m, m^3	Cubic meter
gal	gallon (US or Imperial)
SCF, CF	Standard cubic foot (used for gases at normal temperature and pressure)

V. Biomass & Other

od, OD	Oven dry
odt, ODT	Oven dry ton
ad, AD	Air dry
mcwb	Moisture content, wet basis
mcdb	Moisture content, dry basis
MAI	Mean Annual Increment
GHV, NHV	Gross and Net Heating Value

Annex 3

CONVERSION FACTORS

In all cases, multiply by the number in the appropriate cell of the table.
The second number is the power of 10 (e.g. +2 = 100, -3 = 10^{-3} or .001)

LENGTH

To convert --->	m		ft		yd		mile		NM	
Into										
meter	1		3.0480:	-1	9.1440:	-1	1.6093:	+3	1.8520:	+3
foot	3.2808:	0	1		3.0000:	0	5.2800:	+3	6,0761:	+3
yard	1.0936:	0	3.3333:	-1	1		1.7600:	+3	2,0254:	+3
statute mile	6.2137:	-4	1,8939:	-4	5,6818:	-1	1		1.1508:	0
international nautical mile	5.3996:	-4	1,6458:	-4	4.9374:	-4	8.6898:	-1		1

AREA

To convert --->	m^2		in^2		ft^2		yd^2		acre		$mile^2$	
Into												
square meter	1		6.4516	- 4	9.2903:	-2	8.3613:	-1	4.0469:	+3	2.5900:	+6
square inch	1.5500:	+3	1		1.4400:	+2	1.2960	+3	6.2726	+6	4.0145:	+9
square foot	1.0764:	+1	6.9444	- 3	1		9.0000	0	4.3560	+4	2.7878:	+7
square yard	1.1960	0	7.7160	- 4	1.1111	-1	1		4.8400	+3	3.0976:	+6
acre	2.4711:	-4	1.5942	- 7	2.2957	-5	2.0661:	-4	1		6.4000:	+2
square mile	3,8610:	-7	2.4910	-10	3.5870	-8	3.2283	-7	1.5625	-3	1	

CONVERSION FACTORS (continued)

VOLUME

To convert --->	m^3		l		ft^3		yd^3		UK fl oz		UK pt		UK gal		US fl oz		US pt		US gal	
Into																				
cubic metre	1		1.0000:	-3	2.8317:	-2	7.6455:	-1	2.8413:	-5	5.6826:	-4	4.5461:	-3	2.9574:	-5	4.7318:	-4	3.7854:	-3
litre	9.9997	+2	1		2.8316:	+1	7.6453:	+2	2.8412:	-2	5.6825:	-1	4.5460:	0	2.9573:	-2	4.7316:	-1	3.7853:	0
cubic foot	3.5315	+1	3.5316:	-2	1		2.7000:	+1	1.0034:	-3	2.0068:	-2	1.6054:	-1	1.0444:	-3	1.6710:	-2	1.3368:	-1
cubic yard	1.3080	0	1.3080:	-3	3.7037:	-2	1		3.7163:	-5	7.4326:	-4	5.9461:	-3	3.8681:	-5	6.1889:	-4	4.9511:	-3
UK fluid ounce	3.5195	+4	3.5196:	+1	9.9661:	+2	2.6909:	+4	1		2.0000:	+1	1.6000:	+2	1.0408:	0	1.6653:	+1	1.3323:	+2
UK pint	1.7598	+3	1.7598:	0	4.9831:	+1	1.3454:	+3	5.0000:	-2	1		8.0000:	0	5.2042:	-2	8.3267:	-1	6.6614:	0
UK gallon	2.1997	+2	2.1998:	-1	6.2288:	0	1.6818:	+2	6.2500:	-3	1.2500:	-1	1		6.5053:	-3	1.0408:	0	8.3267:	-1
US fluid ounce	3.3814	+4	3.3815:	+1	9.5751:	+2	2.5853:	+4	9.6076:	-1	1.9215:	+1	1.5372:	+2	1		1.6000:	+1	1.2800:	+2
US pint	2.1134	+3	2.1134:	0	5.9844:	+1	1.6158:	+3	6.0047:	-2	1.2009:	0	9.6076:	0	6.2500:	-2	1		8.0000:	0
US gallon	2.6417	+2	2.6418:	-1	7.4805:	0	2.0197:	+2	7.5059:	-3	1.5012:	-1	1.2009:	0	7.8125:	-3	1.2500:	-1	1	

CONVERSION FACTORS (continued)

MASS

To convert--->	kg	t	lb	UK ton	sh ton
Into					
kilogram	1	1.0000: +3	4.5359: -1	1.0160: +3	9.0718: +2
tonne	1.0000: -3	1	4.5359: -4	1.0160: 0	9.0718: -1
pound	2.2046: 0	2.2046: +3	1	2.2400: +3	2.0000: +3
UK ton (=long ton)	9.8421: -4	9.8421: -1	4.4643: -4	1	8.9286: -1
short ton	1.1023: -3	1.1023: 0	5.0000: -4	1.1200: 0	1

WORK ENERGY HEAT

To Convert--->	J	kcal	kWh	hph	Btu
Into					
joule	1	4.1868: +3	3.6000: +6	2.6845: +6	1.0551: +3
kilocalorie	2.3885: -4	1	8.5859: +2	6.4119: +2	2.5200: -1
kilowatt hour	2.7778: -7	1.1630: -3	1	7.4570: -1	2.9307: -4
horsepower hour	3.7251: -7	1.5596: -3	1.3410: 0	1	3.9301: -4
British Thermal unit	9.4782: -4	3.9683: 0	3.4121: +3	2.5444: +3	1

POWER ENERGY CONSUMPTION RATE

To convert--->	W	kW	CV	hp	kcal min	Btu min^{-1}
Into						
watt	1	1.0000: +3	7.3550: +2	7.4570: +2	6.9780: +1	1.7584: +1
kilowatt	1.0000: -3	1	7.3550: -1	7.4570: -1	6.9780: -2	1.7584: -2
metric horsepower (cheval-vapeur)	1.3596: -3	1.3596: 0	1	1.0139: 0	9.4874: -2	2.3908: -2
horsepower	1.3410: -3	1.3410: 0	9.8632: -1	1	9.3577: -2	2.3581: -2
kilocalorie per minute	1.4331: -2	1.4331: +1	1.0540: +1	1.0686: +1	1	2.5200: -1
British thermal unit per minute	5.6869: -2	5.6869: +1	4.1827: +1	4.2407: +1	3.9683: 0	1

Note: A few examples: 2 yd = 2 x 4.9374 x 10^{-4} international nautical miles

1 acre = 4.0469 x 10^{3} square meters

3 mile^{2} = 3 x 4.0145 x 10^{9} square inch.

Annex 4

GLOSSARY

Air-dried weight	A fuel's moisture content after being exposed over time to local atmospheric conditions.
Anaerobic processes	A name for some biomass digestion systems, these are biological/chemical processes which typically break down organic material into gaseous fuels in the absence of oxygen.
Bagasse	The burnable fibre remaining after sugar has been extracted from sugar cane.
Biogas	A gas of medium energy value ($22MJ/m^3$), generally containing 55-65% methane and produced by anaerobic decomposition of organic materials such as animal wastes and crop residues.
Biomass fuels	Combustible and/or fermentable organic material; for example wood, charcoal, bagasse, cereal stalks, rice husks, and animal wastes.
British Thermal Unit (BTU)	A measure of energy; specifically, the heat required to raise the temperature of one pound of water by one degree Fahrenheit.
Calorie	A metric measure of energy: specifically, the heat required to raise the temperature of one gram of water from 14.5° to 15.5°C at a constant pressure of one atmosphere.
Coal equivalent	The heat content of a fuel in terms of the equivalent heat contained in an average ton of coal. Measures for local coal, or international standards, may be used.

Coal replacement	A measure of the amount of coal that would be needed to substitute for other fuels in an energy conversion process.
Commercial energy/fuel	This term is often used in the context of developing countries to refer to all non-traditional, or non-biomass fuels such as coal, oil, natural gas, and electricity. "Commercialized" (or "monetized") energy includes traditional fuels that are exchanged for cash payments.
Conventional energy/fuel	Another term for "commercial energy," as defined above.
Combustion efficiency	The utilized heat output of a combustion technology divided by the heat content of the fuel input. See Chapter II for other definitions, and equations.
Energy content as received	The energy content of a fuel just before combustion. It reflects moisture content losses due to air-drying or processing (e.g., kiln or crack drying, logging or chopping). For these reasons, the energy content as received is generally higher per unit weight than that of the fuel at harvest.
Energy content of fuel at harvest	Normally used for biomass resources, the energy content of a fuel at the time of harvest. It is often referred to as the "green" energy content.
Gross Heating Value (GHV)	This is the total heat energy content of a fuel. It equals the heat released by complete combustion under conditions of constant volume (i.e., in a "bomb calorimeter"). It equals the thermodynamic "enthalpy" of the fuel and depends only on the fuel's chemical composition and weight, which includes contained water. It is sometimes referred to as the "higher heating value."

Moisture content dry basis (mcdb)	The ratio of the water weight of a fuel to the oven-dry (solid fuel) weight, expressed as a percentage.
Moisture content wet basis (mcwb)	The ratio of the water weight of a fuel to the total (water plus solid fuel) weight, expressed as a percentage.
Net Heating Value (NHV)	This is a practical measure of the heat obtained by complete combustion of a fuel under the usual conditions of constant pressure. It is less than the Gross Heating Value by an amount representing mainly the chemical energy and latent heat involved in vaporization of exhaust gases and water vapour, etc. It is sometimes referred to as the "lower heating value."
Oven-dried weight	The weight of a fuel or biomass material with zero moisture content.
Photovoltaic (PV) cell	Solid state technology which converts solar energy directly into electricity.
System efficiency	System efficiency in the context of this handbook is the total efficiency of converting primary energy resources into utilized energy.
Traditional energy/fuel	In the context of developing countries, firewood, charcoal, crop residues and animal wastes or other biomass fuels. See: Commercial Energy/Fuel; Conventional Energy/Fuel.

Utilized energy	The energy actually utilized for a specific task, such as cooking or lighting. Energy losses in conversion technologies ensure that utilized energy is always less than energy as received.
Green weight	The weight of a biomass fuel at harvest, including moisture content.

Note: Definitions come primarily from the text but some are adopted from Renewable Energy Resources in Developing Countries, World Bank, January 1981.

SUMMARY OF CLASSES OF CONSTRAINTS FOR WOOD STOVE DESIGNS

CLASS Material	ADVANTAGES	DISADVANTAGES	SOLUTION OPTIONS
Clay	(i) available in more abundance	non-uniform in quality; will require beneficiation	
	(ii) fabrications do not need sophisticated machinery	quality control difficult	
	(iii) runs cool, stable on the ground and safe in operation	heavy, not portable, to be built in-situ, not amenable to marketing through conventional channels, uncertain life expectancy	
Ceramic	(i) same as with clay	material requirement more stringent special kilns required	(i) clay with metal reinforcements
	(ii) quality control better than with clay		(ii) clay with ceramic inner liner
	(iii) lighter, portable and can be marketed more easily	runs hotter than clay rather high risks of shattering & uncertain life expectancy	(iii) metal with clay/ceramic inner liner
Metal	(i) available according to designer's desires	not as accessible as clay --most of these improvements cost more, but overcome many disadvantages of the individual sophisticated machinery for fabrication dependent on the material; for example, thick steel sheet requires special welding and bending equipment	
	(ii) excellent quality control possibilities		
	(iii) light, portable and excellent marketability	runs hot, special features for stability required	

CLASS Manufacturing Method	ADVANTAGES	DISADVANTAGES	SOLUTION OPTIONS
Owner-built	(i) little or no cash outlay	Poor quality control; material procurement difficult	
	(ii) small design changes to accommodate individual variations	significant design changes difficult	
	(iii) individual independence	no special community advantage; maintains subsistence existence	(not connected with design, manufacturing, but with organization) (i) a single large unit manufacturing elements like grates, top plates and chimneys servicing a large number of itinerant artisans. (ii) several small scale production units operated by a single management
Itinerant artisan	(i) skilled craftsmanship at work; quality control better	labor of craftsman needs to be paid for entity responsible for R & D, design and marketing.	
	(ii) possible to bring in new ideas of design with time	isolated work situation with no stimulus for radically new ideas	
	(iii) promotes the formation of a guild of artisans; slight movement towards a monetized economy	required to adjust to the artisan's method and time of work	
Industrial	(i) a standard product with a reliable performance possible	requires higher capital outlay and sophisticated infrastructure--both unavailable now in rural areas	
	(ii) could sustain an in-house design capability for continuous product innovation	product may not be available for the really poor	
	(iii) sophisticated marketing techniques feasible		
	(iv) helps in moving subsistence living patterns into productive entreprenurial patterns		

CLASS Design Type	ADVANTAGES	DISADVANTAGES	SOLUTION OPTIONS
Two-hole, single point firing system	(i) higher thermodynamic efficiency	poor flexibility in operation heavy structure not amenable to conventional marketing approach	better to work with both designs; let the users decide.
Single pay	(i) great flexibility for the operator (ii) lighter structure (iii) easily marketable	lesser thermodynamic efficiency	

Annex 6

PROCEDURES FOR TESTING STOVE PERFORMANCE

Efficiency testing procedures must be standardized so that results can be compared. Procedures and results must also be reproducible and well documented. Furthermore, efficiency tests should take into account the cooking practices of a given region or country. Since these factors vary widely, the requirements for measuring stove efficiency often can conflict. To resolve this problem three separate test procedures have been established: the Water Boiling Test (WBT), Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT). The set of "Provisional International Standards" for testing the efficiency of wood-burning cookstoves was developed at a VITA conference in 1982 with the involvement of the major ICS programs.

The three tests basically cover the spectrum from highly controlled, "easily" measured tests (WBT) to more realistic but consequently more variable test procedures (KPT). The WBT measures efficiencies at the high power phase when water is brought to the boil and the low power phase when water is kept simmering just below boiling. In the WBT, measurements of efficiencies at maximum power (p_{max}) and minimum power (p_{min}) phases are taken and an average efficiency calculated. Using an average efficiency is important since stove efficiency may actually drop to near zero during the simmering, low power phase. These power ranges reflect common cooking requirements in developing countries, where water is often brought to a rapid boil for cooking rice or other cereals and then simmered for long periods.

WBT test results should give reliable comparisons so long as the procedures are not varied and are well documented. Consistency in seemingly minor matters such as using or not using a lid, the type of pot, and fire maintenance, are important to the results.

Although WBT results give efficiencies which are easily comparable, they may not reflect efficiencies achieved when cooking a meal. The Controlled Cooking Test was developed to allow for this. In the CCT, a regular meal representative of a region or country is cooked by a trained worker to simulate actual cooking procedures followed by local households. Cooking efficiencies derived from these tests should correspond more closely to "actual" household efficiencies. As with the WBT, these tests are conducted in a laboratory or in the field by trained stove technicians or extension workers. Given the many variables in the CCT that could affect efficiency results, these tests require careful measurement of ingredients and documentation of pot sizes, pot types, fuel, and sequencing of procedures by the cooker.

The KPT is a more realistic and even more specific test than the CCT. Using individual families under "normal" household conditions, household cooks prepare their usual meals with the improved stove. These tests show the impact of a new stove on the overall household energy use. KPT testers may also demonstrate to potential users the fuel saving quality of the new stove and recommend more efficient operating practices. This test thus can be far more than a measure of stove efficiency by combining scientific data gathering with active household participation.

Annex 7

METHODS FOR ESTIMATING PAYBACK TIMES FOR STOVES

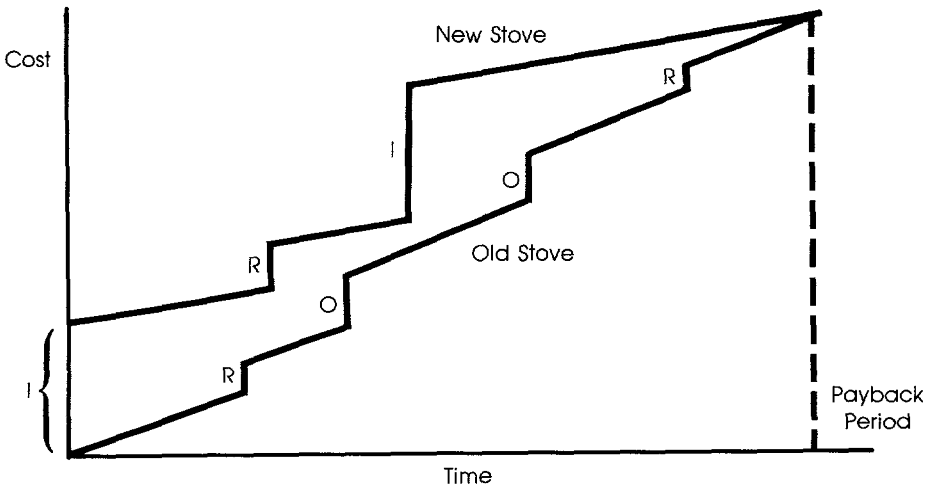
If the costs of operating stoves include repairs and periodic stove replacement, mathematical expressions for estimating payback times are quite complex. It is usually far simpler to use graphical methods.

Figure A1 shows the cumulative costs of an improved stove and the existing unit which it replaces, plotted against time. I is the initial cost of the new stove, which is replaced once during the period shown. O is the replacement cost of the existing ("old") stove, which is replaced twice. R denotes repair costs, which may be different for the new and old stoves. The slopes of the cost curves are given by the fuel cost per unit of time: i.e., by fuel consumption per unit of time multiplied by the fuel price.

The payback time can be read off the plot at the point where the cost curves intersect.

More sophisticated analyses can be made in which the initial and repair costs are discounted using an appropriate rate (e.g. the prevailing interest rate on capital borrowing). This sophistication is rarely justified for small investments such as stoves, especially given the large uncertainties over costs, lifetime between repairs, or fuel savings.

FIGURE A1: Estimating Payback Times



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If the costs and timing of repairs are unknown, a good approximation to the payback time can be made simply by equating the investment plus fuel costs of the new stove to the fuel costs of the old unit for any time period, thus:

$$I + F \times P = f \times p.$$

Where I is the investment cost of the new stove, F, f are the quantities of fuel consumed per unit of time (day, week, etc.) by the new and old stove, and p represents fuel prices. The payback period, in the time units used for F, f, is given by:

$$\text{Payback period} = I \;/\; (f \times p - F \times P).$$

Annex 8

IMPACT OF URBAN WOODFUEL SUPPLIES

The supply of urban woodfuels is almost exclusively on a commercial basis. In small towns, woodfuel supply mechanisms tend to be relatively informal. Rural suppliers may themselves transport fuel to the towns, using donkeys or bullock carts, carrying it on buses, or bringing it in by headload. Some sell to dealers while others trade directly in the market place.

In larger cities, trade is more often organized around a series of wholesale depots, from which smaller retailers obtain their supplies. Wood and charcoal are usually brought in by truck from the surrounding areas.

The Kenyan charcoal market is to a large extent controlled by truck owners. They purchase the charcoal from rural producers and sell it through their own outlets in the cities. In some cases, charcoal is picked up on the way back from delivering other goods to outlying districts. This alters the economics completely, and opens up a much wider area of potential sources. As a result, charcoal may sometimes be brought from surprisingly long distances away. Some of the trucks carrying charcoal to Nairobi come from as far away as the Sudanese border, 600 kilometers to the north.

As trucks and other vehicles are usually the predominant method of transporting woodfuel supplies to urban areas, the road network has a major bearing on the sources of supply. The opening up of forest areas to logging, for example, often results in the development of a concomitant trade in woodfuel. Simply improving a road into a village so that it can be used by a bus may have the same effect.

As long as rural areas remain relatively isolated the effects of increasing woodfuel pressure usually will be gradual. When areas become subject to concentrated urban demands, however, this can bring about a dramatic increase in the depletion rate. The cash incentive created by these demands means that people have a much stronger motive to cut trees. They will go further afield to gather wood and will take greater risks in entering and illegally cutting trees from forests and unprotected private lands.

The impact of an urban woodfuel market has been described as follows:

<u>Note</u>: Extracted, with permission, from Barnard [1985].

> (it) creates not only a distinctive spatial character for fuelwood production...but also changes the character of fuelwood exploitation. It is more selective of tree species, whether for charcoal production or urban fuelwood for consumers, and it is also more wasteful of the wood resource. It employs paid labor, sometimes specialized cutting or processing skills, and it has to deal with problems of storage and seasonality in production and supply. It also diverts wood fuel from subsistence use as poor people in areas of short supply sell their wood or charcoal to higher income groups in the towns [Morgan 1983].

In some countries, wood cutting is carried out by large well-organized gangs, sometimes operating in collusion with local forestry officials so as to avoid cutting regulations and licence fees. More often, however, it is the poor who are involved, as families are forced to turn to wood selling because of the lack of other income earning opportunities. The reasons behind this have been described with specific reference to Karnataka State in India:

> Denudation of forests has often been viewed merely as the result of rural energy consumption. However, for a villager who has no food, the attack on forests is for collection of firewood for sale in urban and semi-urban centres, rather than his own consumption, because selling firewood is often the only means of subsistence for many poor families. This firewood, with the help of bus and truck drivers goes to the urban markets like Bangalore...Theft of wood as a means of survival is becoming the only option left for more and more villagers. Recently 200 villagers were caught stealing firewood in the Sakrabaile forest of Shimoga district and one person was killed in a police encounter: [Shiva et al. 1981].

Trees on private land may also be sold in response to external commercial demands. The amount of these sales will depend on the prices being offered, and on the financial needs of the farmers who own them. In poor areas, or when harvests fail, farmers are sometimes forced to cut their trees to earn cash. In Tamil Nadu, it has been observed in some villages that:

> distress sale of trees, because of drought conditions, is reported. This indicates that the villagers resort to short term exploitation of fuel resources in drought periods when their incomes fall drastically, unmindful of the long term consequences of their act [Neelakantan et al. 1983].

The deforestation that has occurred around the city of Kano in Northern Nigeria over the last 25 years also illustrates this. Formerly there was a tradition whereby farmers used to lop branches from the trees on their land during the dry season and transport them into the town on donkeys to sell in the market. While in town, they picked up dung and sweepings from the streets, which they carried home and used as fertilizer on their fields. With growing wood demands in the city, the incentive to cut trees has increased. As a result, what was once a relatively stable system has broken down to the extent that farming land within a 40 kilometer radius of the city has been largely stripped of trees.

Charcoal making for the urban market is also a major cause of tree depletion in some areas. In the Sahel, this has a long history. The widespread destruction of acacia tortilis, for example, can be traced back to charcoal production carried out for the trans-Saharan camel trade [Corillon and Gritzer 1983].

The opening up of river communications has also led to severe deforestation along the flood plain of the Senegal River, where once extensive stands of Acacia nilotica have been cut for charcoal production. Elsewhere in the Sahel region, improvements in road communications have resulted in similar destruction, as urban charcoal markets become accessible to more remote rural areas [Corillon and Gritzer 1983]. In Kenya, the provision of access roads to Mbere district has reportedly led to a substantial increase in the number of trees being felled for charcoal for urban markets, with a total disappearance of large hardwoods such as Albizia tangankiensis [Brokensha, Riley, and Castro 1983].

The severe impact of cutting for charcoal has also been noted in a detailed study of the woodfuel position in Haiti. Charcoal production was found to be particularly destructive because live trees are harvested, as opposed to the dead branches and twigs which provide the bulk of rural firewood supplies. As is frequently the case, charcoal production in Haiti is carried out only by the very poor. The attitude of local people to the resulting deforestation was summarized as follows:

> Local residents in all of the research sites recognized deforestation as a great problem. Deforestation is seen as contributing to floods and drought. Even young adults can remember when the hillsides, now denuded, were covered with trees. Furthermore, charcoal production is perceived as the cause of this deforestation. More to the point, poverty is seen as the cause of deforestation because only poverty leads a person to make charcoal. Rather than resentment against charcoal makers as destroying a natural resource, there is great sympathy for such people [Conway 1979].

Urban woodfuel demand thus can be a major factor in causing deforestation in the area over which it extends. It reinforces local demand and can greatly accelerate the depletion process. It is therefore important that urban demands are distinguished from local demands when methods of countering the effects of woodfuel scarcities are being considered.

Annex 9

STAGES OF SOIL DEGREDATION DUE TO TREE LOSS AND REMOVAL OF CROP RESIDUES IN ETHIOPIA

At the rate at which peasant agriculturalists are currently clearing the fringes of natural high forest, this resource will be lost in about 30 years. As in the past, during this first stage of forest clearing for the purpose of developing land for food production, local fuelwood is abundant. At present, perhaps 20 million cubic meters of wood, the same quantity that is consumed in all the households of Ethiopia, are burnt off during agricultural clearing each year. It is only sometime later that trees begin to be harvested primarily for fuel. Beyond this point it appears that a critical transition of decline begins within subsistence agriculture whereby the growing scarcity of woodfuels is linked inextricably to falling crop and animal production. This transition leads to, and is clearly exacerbated by, growing urbanization in Ethiopia as the nature and level of fuel use for household cooking for most urban dwellers closely resembles that for their rural counterparts. The demand for woodfuels, and ultimately for any combustible residue, by urban dwellers or members of any concentrated settlement without a sufficient independent resource base (i.e., state farms) becomes an intolerable burden on rural productivity. A conceptualization of the perceived stages of this transition follows below and in Figure A2.

Stage I: The rate of timber harvested locally for all purposes (fuel, construction, tools, fences) exceeds, for the first time, the average rate of production. The existing timber resource is then progressively "mined"; firewood remains the main fuel source. Nutrient cycle No. 1 begins to decline though with imperceptible impact on food production. The general reason for the imbalance is population growth. The specific reasons include urbanization and major land clearing (e.g. state-farms) whereby firewood and charcoal become cash crops leading to overcutting relative to purely local subsistence requirements.

Stage II: The great majority of timber produced on farms and on surrounding land is sold out to other rural and urban markets. Peasants begin to use cereal straw and dung for fuel: the relative proportions depend on the season. Both nutrient cycles No. 2 and No. 3 are breached for the first time and nutrient cycling diminishes. Combustion of crop residues and dung leads to lower inputs of soil organic matter, poor soil structure, low retention of available nutrients in the crop root zone and reduced protection

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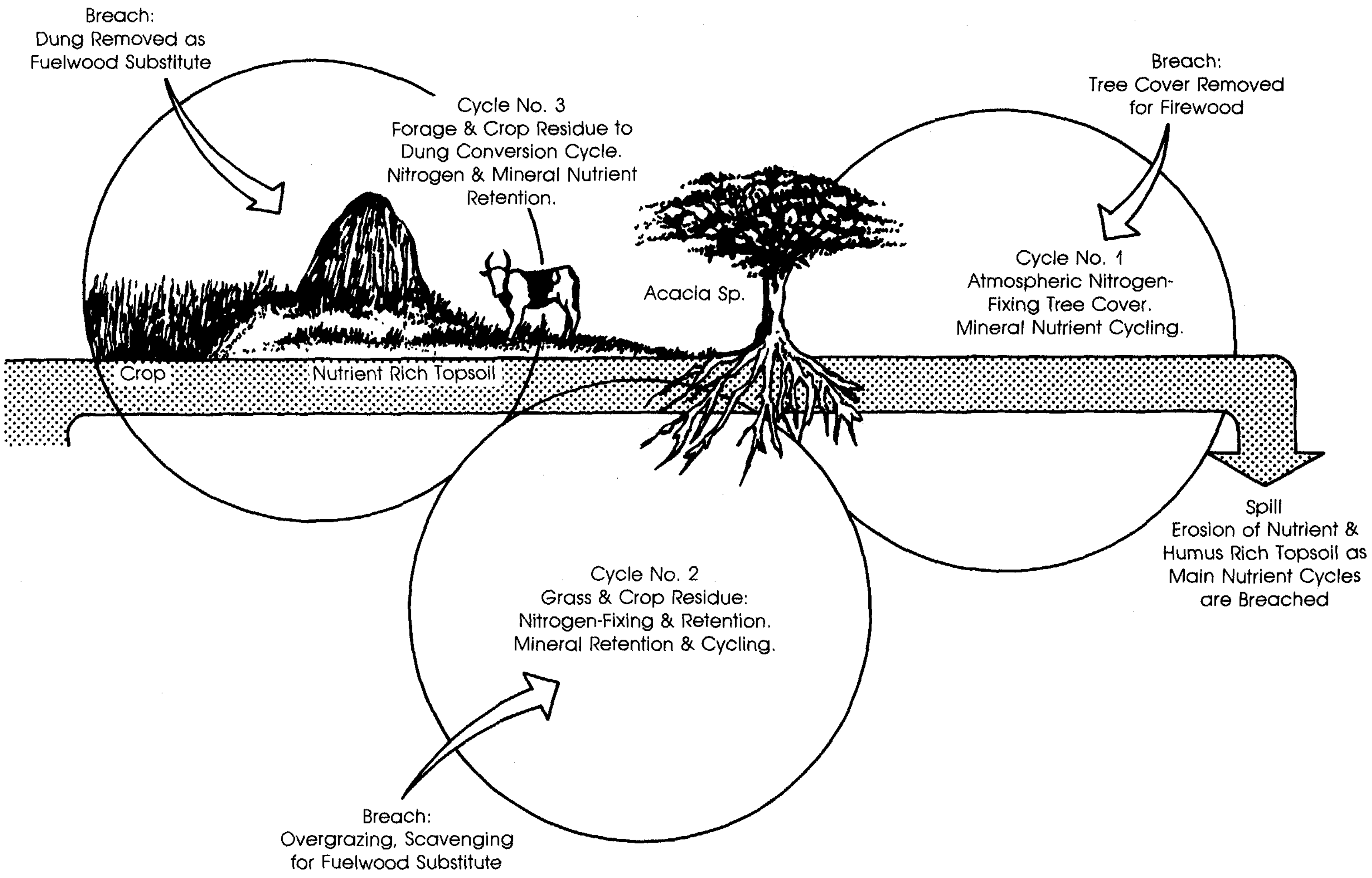
Note: Quoted, with permission, from Newcombe [1985].

FIGURE A2: Pattern of Deterioration in Ethiopian Agroecosystems



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from the erosive effect of heavy rainfall. Hence, topsoil nutrient reserves begin to decline (See "spill" in the Figure).

Stage III: Almost all tree cover is removed. Now a high proportion of cow dung produced is collected; the woodier cereal stalks are systematically collected and stored; and both are sold for cash to urban markets. The yields of cereal crops and, in consequence, animal carrying capacity begins to decline. Draft animal numbers and power output are reduced, hence the area under crop also falls. Soil erosion becomes serious. Nutrient cycle No. 1 ceases altogether.

Stage IV: Dung is the only source of fuel and has become a major cash crop. All dung that can be collected is collected. All crop residues are used for animal feed, though they are not sufficient for the purpose. Nutrient cycle No. 2 is negligible and No. 3 is greatly reduced. Arable land and grazing land is bare most of the year. Soil erosion is dramatic and nutrient-rich topsoil is much depleted. Dung and dry matter production have fallen to a small proportion of previous levels. In such a situation, extended dry periods can be devastating because the ecosystem loses its capacity to recover quickly.

Stage V: There is a total collapse in organic matter production, usually catalyzed by dry periods which were previously tolerable. Peasants abandon their land in search of food and other subsistence needs. Starvation is prevalent. Animal populations are devastated. Rural to urban migration swells city populations, increasing demand on the rural areas for food and fuel, and the impact of urban demand is felt deeper into the hinterland (the "urban shadow" effect).

This transition from the first to the final stage is in process right across Ethiopia and has reached the terminal phase in parts of Tigrai and Eritrea. The only way to prevent the current situation in the remaining populous and fertile areas from sliding toward the terminal state of Stage V is to develop a strategy which will:

(a) remove the dependency of urban settlements on their rural hinterlands for woody fuels, and

(b) reestablish a dynamic equilibrium between supply and demand for firewood in rural areas.

While the development of peri-urban fuelwood plantations is an obvious component of a strategy to serve the first objective, the time required to do this is such that, even if design work began immediately, the production of woodfuels would hardly begin to be augmented before the end of the decade. Without urban self-sufficiency it will be extremely difficult to achieve the second objective, as biomass fuels will continue to drain from the rural areas to the towns and cities. In addition, the situation of Northern Ethiopia where, in many places, agricultural ecosystems have deteriorated to stages IV and V, demands special, and possibly separate, consideration because of the huge scale of the problem and the implied investment, and the added complexity of local hostilities.

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