



# SUSTAINABLE ENERGY ACCESS PLANNING A FRAMEWORK

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**Ram M. Shrestha**  
**Jiwan S. Acharya**



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# Foreword

The developing countries of Asia and the Pacific region face a number of stark challenges in their energy sectors: energy security, the interlinked issue of energy generation and climate change, and widespread energy poverty, with hundreds of millions having no access to electricity and billions more having no access to modern fuels for cooking or heating.

The Asian Development Bank (ADB) is guided by an energy policy that was shaped to respond to these challenges, and help developing Asian countries achieve a supply of energy that is secure, reliable, accessible to all, and clean to support the region's continued transition toward low-carbon, sustainable development. Sustainable energy access planning (SEAP) provides a new framework with which to achieve that goal.

SEAP considers new options which traditional planning was unable to properly assess. SEAP allows for a direct and comprehensive response to the energy demands of the poor and the nonpoor alike, and links the issues of access and affordability together, to address those cases where poor families living within the range of the grid are nevertheless "priced out" of access to modern energy services.

SEAP researches and weighs a number of closely linked factors: resources, cost, benefit, sustainability, and affordability, to plan out the ideal solution for an energy access program of high quality, wide reach, and positive effects. It is flexible enough to cover the major concerns of access to electricity and modern fuels as well as energy for productive activities and mechanical energy applications, which include pumping water and milling grain.

ADB's commitment to energy access is expressed through our Energy for All Initiative, which has guided our investments in energy access, and through our role as a lead organization and host of the Sustainable Energy for All Initiative's (SE4ALL) Regional Hub for Asia and the Pacific. ADB, as part of SE4ALL's global partnership, is contributing to the achievement of its 2030 goals, most notably the goal to provide universal energy access. This publication hopes to contribute to that work being done by ADB, and by all organizations seeking to maximize access to energy by providing an improved framework and assessment basis to shape responses and build better solutions.

This publication was made possible with the support of the Government of Japan, and guided by the expertise of ADB's Energy Sector Group. I extend my thanks to them and to the authors, Ram M. Shrestha and Jiwan S. Acharya, for adding to our knowledge of sustainable development planning.



Bindu Lohani  
Vice-President (Knowledge Management and Sustainable Development)  
Asian Development Bank

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# Abbreviations

BAU	business as usual
CFL	compact fluorescent lamp
EAP	energy access program
Eq	equation
ESMAP	Energy Sector Management Assistance Program
GHG	greenhouse gas
GIS	geographic information system
GTF	Global Tracking Framework
HICS	highly efficient biomass cookstoves
IEA	International Energy Agency
IEAC	incremental energy access cost
IEACC	incremental energy access cost curve
kg	kilogram
kgoe	kilogram of oil equivalent
kW	kilowatt
kWh	kilowatt-hour
LPG	liquefied petroleum gas
MEPI	Multidimensional Energy Poverty Index
MICS	moderately efficient biomass cookstoves
NREL	National Renewable Energy Laboratory

O&M	operation and maintenance
SE4ALL	Sustainable Energy for All
SEAP	sustainable energy access planning
SWERA	Solar and Wind Energy Resource Assessment
TEA	Total Energy Access (approach)
UN	United Nations
VDC	village development committee



## Executive Summary

**S**ustainable energy access planning (SEAP) is aimed at developing a socially inclusive energy supply system that gives both the poor and the nonpoor sustainable access to at least the minimum amount of energy for their basic needs. This type of planning is also done to identify environmentally sound and climate-friendly technologies and resource options for providing energy access, and the associated investment opportunities.

Unlike traditional energy and electricity planning, SEAP explicitly considers (i) the acceptable minimum level of cleaner-energy services to energy-poor households, as well as the energy demand of the nonpoor; (ii) the interrelationship between affordability and accessibility of cleaner energy to the poor, and hence the need to make cleaner-energy services affordable to the poor; (iii) the costs of both supply-side and demand-side access options (the latter are typically ignored in traditional energy supply planning) to determine the total cost and affordability of basic energy services to a household; and (iv) the sustainability of technology and resource options and their benefits.

A comprehensive framework has been developed to capture these SEAP features. The proposed SEAP framework, which is discussed in this report, consists of assessments of the following:

- **Energy poverty.** This assessment of the number of households below the energy poverty line and their energy consumption provides the basis for estimating the additional energy demand that must be met by an energy supply system under an energy access program (EAP).
- **Energy demand.** This is an assessment of the present and future demand of energy-poor households for lighting, cooking, water heating, space heating, use of other electrical appliances, and other energy services, which must be met with the acceptable minimum level of basic energy services, e.g., as specified in the Global Tracking Framework (World Bank/ESMAP and IEA 2013). The energy demand of nonpoor households and other sectors (cottage industry, community services, etc.) is also assessed. The acceptable minimum level of basic energy services may, however, differ between countries with different climatic and other conditions.
- **Energy resources.** Energy resource assessment determines whether enough energy resources are available to meet the present and future demand for the desired amount of energy services in a reliable and sustainable way in the short, medium, and long term.
- **Cost.** The cost implications of cleaner-energy access options and programs are assessed to get information about the total investment and other costs involved in developing and implementing a least-cost EAP, and the energy burden on poor households (affordability) in the program. Both the supply-side and the demand-side costs of providing predefined levels of energy services under the EAP are estimated. The assessment can be easily extended to produce information about the incremental costs incurred in providing various levels of energy access to a target population or expanding EAP coverage to a wider area or population.

An important part of the cost assessment is deriving an incremental energy access cost curve (IEACC), which traces the energy supply for different levels of access and the corresponding incremental total costs per unit of energy use (i.e., per unit total cost including both supply- and demand-side costs). The cost assessment also helps to derive the incremental energy supply cost curve, which considers only the EAP supply-side cost components. The IEACC helps in ranking the cleaner-energy resource, and supply- and demand-side technology options according to cost per unit of energy used.

- **Benefits.** A cleaner-energy access program can have several benefits. It can improve environmental quality (particularly indoor air quality), health and energy security, and social benefits (e.g., more education opportunities, more income generation through productive activities at home and local employment opportunities, less human drudgery); reduce energy inequality between countries and between regions in a country; and lower greenhouse gas (GHG) emissions.
- **Sustainability.** The technology and resource options for providing energy access that are considered in an EAP are evaluated for technical, economic, social, environmental, and institutional sustainability over their lifetime—from initial installation to operation and maintenance—against relevant indicators.
- **Affordability.** The affordability assessment determines the amount that energy-poor households can afford to pay for basic energy services (e.g., lighting, cooking, heating) and the size of the population that cannot afford to do so. Affordability can be measured in terms of the energy burden (the share of a household's energy and energy-related expenditure in its total expenditure or income). A household whose energy burden exceeds the acceptable threshold is regarded as energy poor. The affordability assessment considers variations in acceptable minimum levels of basic energy services, the corresponding energy service costs, and income levels across countries and subnational regions, rather than requiring a common set of values for these parameters. It is done not only to determine energy poverty and demand at the start of the SEAP process but also to gauge the ability of the poor to bear the cost of access to cleaner-energy services after the energy supply- and demand-side costs have been estimated in the cost assessment component.

These assessments are linked—the energy poverty assessment, which defines the size of the energy-poor population, with the energy demand assessment; the latter with the cost assessment, which also relies on technological data and the assessment of resource availability, costs, and economic potential; the cost assessment and its identification of least-cost technology options, with the sustainability, affordability (including the necessary support schemes), and benefit assessments; the sustainability assessment of a technology or an EAP, with resource, cost, benefit, affordability, and other assessments.

The concluding chapter brings out several issues related to the implementation of the SEAP framework. At the very start of the process, energy-access planners and policy makers must address some policy-related matters on the basis of independent research, national development goals, priorities, and capability, in the absence of universally applicable standards. For example, the acceptable minimum levels of basic energy services, on which the energy poverty and demand assessments are based, can vary between countries and even between subnational regions within a country because of several factors, e.g., types and quantities of food cooked, devices used, and climatic and geographic variations. The maximum acceptable energy burden can also be country specific, reflecting not only national development goals and priorities but also the financial and other capability of governments to sustain efforts to reduce energy poverty.

Another issue pertains to data requirements. The SEAP framework can be especially difficult to implement in an area with no access to cleaner energy. Secondary sources of information about comparable areas must be used in that case. Having a sound database of typical household economic and energy-use characteristics of different subnational regions, categorized according to physiographic, socioeconomic, and other key criteria, would make expensive and time-consuming household surveys for each target area unnecessary.

Finally, the effective use of the SEAP framework in developing sustainable and cost-effective energy access plans and programs would greatly depend on the capacity of the national and subnational planning and program development institutions to conduct the various assessments. Capacity-building activities relevant to the SEAP framework should therefore be made a regular part of energy access programs and projects.





# 1 Introduction

## Background

Over one-third of the world's population, particularly in the rural areas in many developing countries, has no access to reliable, affordable, and modern energy services (IIASA 2012a). In 2012, around 1.3 billion people in the world lacked electricity supply; more than half of them were in developing Asia. Despite the high economic growth in the region, around 17% of the people in the developing Asia had no access to electricity in 2012 (which included 23% of the people in Southeast Asia, 25% of the people in India, and 39% of the people in the rest of developing Asia). Electrification rates also vary significantly between the rural (74%) and urban areas (95%) in developing Asia (IEA 2014b). In 2012, around 2.7 billion people worldwide, including around 1.9 billion (about 70% of the total) in developing Asia, relied on traditional biomass for cooking (IEA 2014b).

Universal access to reliable, efficient, affordable, and environmentally friendly modern energy services for basic needs is necessary for human development and sustainable economic growth. Recognizing this fact, the United Nations (UN) has made universal access to modern energy services by 2030 a global goal under its Sustainable Energy for All initiative.

But access to modern energy services is not defined the same way everywhere. The Global Tracking Framework (GTF) of the multiagency Sustainable Energy for All (SE4ALL) initiative defines electricity access as “availability of an electricity connection at home or the use of electricity as the primary source for lighting,” and access to modern cooking solutions as “relying primarily on nonsolid fuels for cooking” (World Bank/ESMAP and IEA 2013). The multidimensional GTF classifies access to energy into five tiers (see World Bank/

ESMAP and IEA 2013). A report issued earlier by the UN Secretary-General's Advisory Group on Climate Change (AGECC 2010) referred to energy access “to a basic minimum threshold of modern energy services for both consumption and productive uses ... [that is] reliable and affordable, sustainable and where feasible, from low-[greenhouse gas (GHG)]-emitting energy sources.”

The International Energy Agency (IEA) defines access to modern energy as “a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average” (IEA 2011). The IEA (2014) adds that

for any energy supply to provide a genuine opportunity to use modern energy services there needs to be a technical possibility to use it (availability), a price that is not prohibitive (affordability), sufficient supply (adequacy) and a supply that is easy to use (and pay for), including being located nearby, available at desired hours of the day and safe to use (convenience). Importantly, the supply must be of the right quality (e.g., voltage level) and be usable for most of the time (reliability).

India's Ministry of New and Renewable Energy (MNRE) has broadly defined energy access as “the physical availability of modern energy carriers and improved end-use devices at the household level at affordable prices” (MNRE 2013). The definition further states that energy access includes access to less polluting and efficient household energy for cooking and heating, energy from renewable sources for powering appliances and lights in households, and mechanical power from either electricity or other energy sources that improve the productivity of labor.

The international development charity Practical Action (2012), in its Poor People's Energy Outlook, uses the term "energy access" to mean the "use of modern energy services by unserved and underserved people." It also introduces the concept of "total energy access" of households, with energy service level standards for lighting, cooking and water heating, space heating, cooling, and information and communication technology.

Access to modern cooking fuels has to do with the percentage of people for whom electricity, liquid fuels, or gaseous fuels are the primary cooking fuels. These fuels include liquefied petroleum gas (LPG), natural gas, kerosene, ethanol, and biofuels, and exclude traditional biomass (fuelwood, charcoal, animal dung, and agricultural residues) and coal (Legros et al. 2009). According to the IEA (2012), access to clean cooking refers to the percentage of households having an efficient stove that meets the minimum requirements for indoor air quality. Access to mechanical power pertains to the percentage of people that use mechanical power for productive, nonindustrial applications, such as water pumping, agricultural mechanization, and small-scale agro-processing. Apart from these indicators, other factors, such as the quality and quantity of energy provided, energy end-use appliances and equipment (and their efficiency), the services they provide, the socioeconomic profile of energy users, and energy affordability, are also relevant to energy access.

Energy access has both direct and indirect benefits. Direct benefits include better health; less time spent, generally by women and children for harvesting and searching for biomass fuels for use in traditional cookstoves (with the attendant opportunity cost); and less manual labor expended, as enhanced mechanical power is used instead for pumping water, threshing and grinding grains, and other household activities. Indirect benefits include time savings, increased employment opportunities or income generating activities, improved quality of life etc.

Some people may not have access to electricity or may be unable to use it for several reasons. In the urban areas, households within reach of the grid infrastructure may still face unreliable supply or may be unable to pay for energy services; others may be living in informal settlements and are prevented by their informal status

from having access to electricity. People living in the rural areas, beyond the reach of the grid, may also be unserved by local power supply (Tawney, Miller, and Bazilian 2013). On the other hand, some rural households, despite their close proximity to the grid, may have no physical access to it.

The UN has declared 2014–2024 the Decade of Sustainable Energy for All and has called on member states "to galvanize efforts to make universal access to sustainable modern energy services a priority." The UN has also expressed concern over the inability of millions of poor people to pay for energy services even when these are available, and has stressed the need to address the twin issues of availability and affordability in the pursuit of the objective of universal access to energy (UN 2012).

The Asian Development Bank (ADB) is leading the Energy for All Partnership, which allows governments, civil society, and the private sector to share knowledge, build capacity, and develop energy projects, and is the regional hub for the global SE4ALL initiative. An activity under ADB's technical assistance program Enhancing Knowledge on Climate Technology and Financing Mechanisms is an assessment of the growth in energy demand among the poor in rural and urban areas in Asia and the Pacific, and energy supply options that are both cost effective and climate friendly. An analytical approach to sustainable energy access planning has been developed under the technical assistance program and a number of case studies are being planned with a view to determining sustainable and cost-effective climate-friendly energy supply options for all at the national and subnational (district, village, etc.) levels.

## Objectives of this Study

To provide everyone with sustainable access to affordable energy services based on cleaner energy, planners and policy makers must identify the cost-effective technology and resource options to be employed, as well as their investment and other cost implications. Ideally, such solutions should be least expensive and sustainable from a societal viewpoint, and at the same time most affordable from the users' perspective. A comprehensive

assessment of the energy demand of both energy-poor and nonpoor households and other energy-using activities and sectors is required. In addition, the availability and sustainability of the energy supply options (decentralized and centralized, local and nonlocal) and the demand-side technology options must be established. Clearly, sustainable energy access planning (SEAP) is a multidimensional process, which requires a comprehensive analytical framework. This study is an attempt to develop such a framework for SEAP in order to systematically determine cost-effective and cleaner (environmentally sound and climate-friendly) energy resources and technology options for providing sustainable access to modern energy services and their associated investment requirements. In addition, the study seeks to identify methods for assessing the affordability of basic energy services using cleaner energy to the energy poor.

## Structure of the Report

This report has 10 chapters. Chapter 2 outlines the SEAP framework and the links between its various assessments. Chapter 3 discusses the energy poverty assessment and the different methods of estimating the number of households below the energy poverty line and their energy consumption levels. The next four chapters cover other assessments—of demand for energy or energy services, in Chapter 4; of energy resources, in Chapter 5; of the cost implications of various cleaner-energy access options and programs, in Chapter 6; and of the benefits of energy access, in Chapter 7. Chapter 8 discusses the method of evaluating the sustainability of energy resource or technology options for providing access to cleaner energy, and Chapter 9 analyzes the affordability of electricity and modern cooking fuels to poor households and others. Finally, Chapter 10 presents the implementation issues associated with energy access planning.

## 2 Sustainable Energy Access Planning Framework

### Introduction

The main objectives of sustainable energy access planning (SEAP) are to identify cost-effective and sustainable resource and technology options for providing universal access to basic energy services and to assess the affordability of cleaner-energy service options to energy-poor households. The proposed SEAP framework has several features that are distinct from those of traditional electricity and energy planning frameworks:

- First, unlike traditional energy planning and electrification frameworks, the SEAP framework focuses on social inclusiveness and takes into account the ability of even the poorest households in gaining access to electricity and other cleaner forms of energy to meet their basic energy needs for lighting, cooking and heating.
- Second, the SEAP framework considers the acceptable minimum level of basic energy services to the energy poor and allows the use of econometric and other traditional approaches to assess the energy demand of nonpoor households.
- Third, the SEAP framework assesses the financial implications of even the most cost-effective options of supplying electricity and other cleaner energy to see if these are affordable to the poor.
- Fourth, the SEAP framework analyzes the sustainability, reliability, and acceptability of cleaner energy options to ensure quality and sustainability of energy access programs at the local level.
- Fifth, the SEAP framework generates crucial information on investment requirements, as well as benefits of energy access programs in terms of improvements in social well-being and

environmental quality, greenhouse gas mitigation, and reduction in energy inequality.

- The framework also analyzes the sustainability, reliability, and acceptability of clean-energy service options to ensure the quality and continuity of energy access programs.

By determining the incremental costs of energy access and other assessments, the SEAP framework provides a sound basis for investment planning and helps in prioritizing investment opportunities for energy access options. Use of SEAP in subnational regions of a country can indicate regions where a particular resource or technology (e.g., microhydro, biomass, solar, and grid supply) would be the most cost-effective and sustainable energy access option.

The rest of this chapter discusses the components of the SEAP framework, along with the key steps in assessment and the links between assessments within the framework.

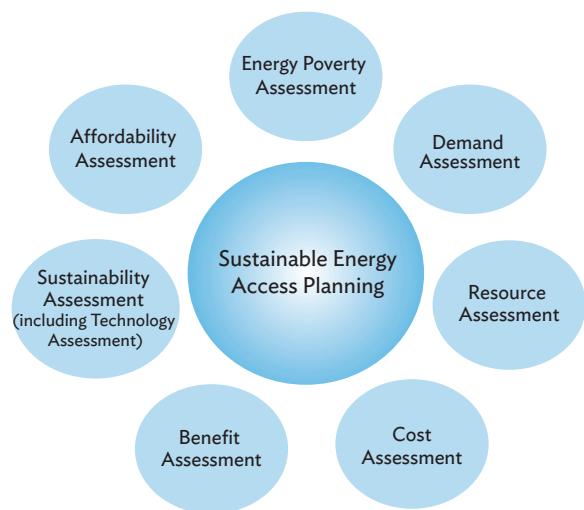
### Elements of Sustainable Energy Access Planning

The SEAP framework consists of seven different assessments, as shown in Figure 2.1. The main features of these assessments are described below.

#### Energy Poverty Assessment

The main objective of this assessment is to estimate the size of the population that does not have access to cleaner sources of energy, as well as the number of households whose present energy consumption is below that required to meet the minimum acceptable level of basic energy services (e.g., lighting, cooking, and heating),

**Figure 2.1 Elements of the Sustainable Energy Access Planning Framework**



Source: Authors.

in areas where electricity and other cleaner energy supply systems already exist. This information forms the basis for the estimation of the amount of additional cleaner energy that needs to be supplied to provide energy access to the above categories of population to meet the acceptable minimum level of basic energy services. This assessment presupposes the existence of information about the acceptable minimum level of energy services, which forms the basis for the minimum level of cleaner energy to be provided, and can vary across countries. Even within a particular country, the acceptable minimum level of basic energy services can vary across different subnational areas because of variations in climate and other factors (e.g., differences in types of food cooked).

## Demand Assessment

As one of the distinctive features of the SEAP framework, the demand assessment estimates the increase in the total demand for electricity or other cleaner-energy resources, in order to provide the energy-poor population with an acceptable minimum level of basic energy services. The demand assessment therefore involves an estimation of total demand for cleaner energy in two cases: (i) the “business as usual (BAU) case,” in which the energy-poor population either has no access to cleaner energy services

or is using such services below the acceptable minimum levels; and (ii) the “energy access case,” in which the total demand for cleaner-energy sources includes the level of such resources required to meet the acceptable level of basic energy services for the energy poor in addition to the total demand in the BAU case. These two kinds of demand assessments are needed to estimate the incremental level of investment and increase in total cost involved in providing the desired level of energy access in an area. The demand assessment also involves estimating the typical pattern of use of energy services and hence the energy use profile for different periods within a year.

## Resource Assessment

The use of sustainable energy resources to provide the acceptable level of basic energy services is the main criterion of a sustainable energy access plan or program. An assessment of cleaner-energy resources (especially renewable resources) that are available both at the local level and in neighboring areas is therefore an essential component of the SEAP process. The resource assessment provides information about the economically exploitable level of cleaner-energy resources (biomass, hydro, solar, wind, and others) around the targeted area of an energy access program (EAP), as well as their temporal availability pattern and costs.

## Cost Assessment

This assessment is done to determine the least-cost options for providing the acceptable minimum level of basic energy services to the energy-poor household population. It involves an estimation of the total costs of energy access (including both supply- and demand-side costs) in a given area, with and without an EAP. The difference between these costs represents the total cost of the EAP. The assessment determines the capacity of different cleaner-energy supply technologies and the corresponding levels of investment required for the EAP. It also indicates the types of devices to be used and the upfront cost on the user side in order to minimize the total societal resource cost of providing the acceptable minimum level of basic energy services. An important outcome of this assessment is the incremental energy access cost curve (IEACC), which helps in prioritizing the implementation of different energy access options on the basis of their cost-effectiveness.

## Benefit Assessment

The different types of benefits associated with energy access are time savings, better productivity, health, educational opportunities; improved environmental quality, energy security, and energy equality; and greenhouse gas (GHG) reduction. At the macro level, the benefit assessment also looks into the reduction in energy inequality between subnational regions of a country due to the EAP.

## Sustainability Assessment

This assessment is done to identify a set of appropriate sustainable energy technology and resource options for providing access to cleaner energy. The multidimensional aspects of sustainability—technical, economic, social, environmental, and institutional—are considered. Each of these dimensions is captured through relevant indicators (see Chapter 8), including the following, to arrive at a composite index of sustainability for each option:

- **Technical dimension.** Energy efficiency, capacity factor, life of the technology, reliability, ease of operation and maintenance (O&M), and availability.
- **Economic dimension.** Capital cost, O&M cost, net energy import dependency, affordability.
- **Social dimension.** Job creation, public preference (acceptability), ease of operation, availability of maintenance services, local maintenance capacity.
- **Environmental dimension.** Reduction in GHG emissions and indoor air pollution, amount of land used over the entire life cycle of the technology, extent of use of forest land, improvement in health.
- **Institutional dimension.** Degree of local ownership, need for skilled staff, ability to protect consumers and investors, ability to monitor and control energy systems.

## Affordability Assessment

Affordability is an important precondition for the use of cleaner-energy resources by the energy poor. Even if cleaner energy resources are available locally or a cleaner

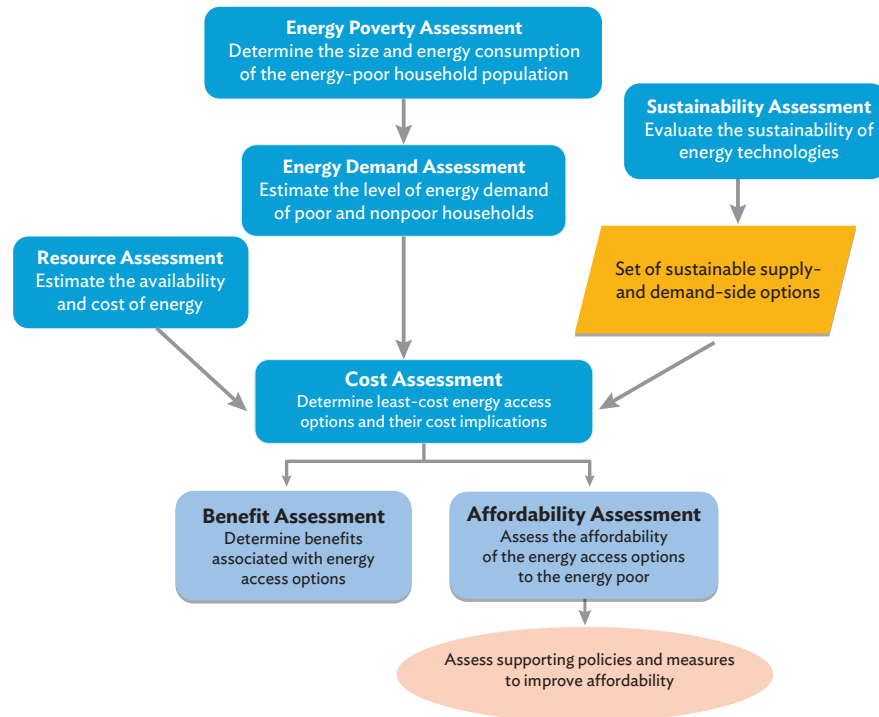
energy supply system exists, an energy-poor household may not benefit because of lack of affordability. The affordability assessment estimates the energy burden, which is defined as the share of energy expenditure in the total household income. A household is considered energy poor if its energy burden exceeds an acceptable level. The affordability assessment would therefore also provide a basis for determining the size of the energy-poor population in an area for which an EAP is being developed. More importantly, the assessment would help planners determine the energy burden of providing cleaner energy services under an EAP and the amount of increase or decrease in the energy burden with the EAP. That information would then guide the design of subsidy or other support schemes to make the cleaner-energy services affordable to the energy poor.

The aforementioned assessments require several kinds of data. These data requirements are listed in Appendix 1.

## Key Steps in Sustainable Energy Access Planning and Linkages between Assessments

Figure 2.2 shows the links between the different SEAP components. As shown in the figure, the first step in SEAP involves energy poverty assessment to determine the size of the energy-poor population, which includes households with no access to cleaner-energy sources as well as households whose current use of basic energy services is inadequate (below the acceptable minimum). The assessment also generates information about the level of energy consumption of the energy-poor population, indicating the total energy requirement under an EAP, and is thus linked with the energy demand assessment component of the framework.

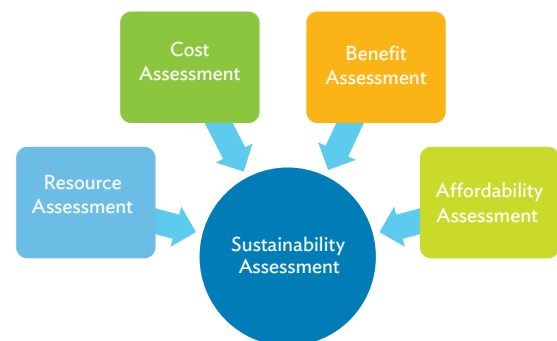
The cost assessment component of SEAP determines the least-cost technology and resource options for providing access to cleaner energy through the EAP, taking into account the demand for energy (information derived from the energy demand assessment), the availability of energy resources and their cost and economic potential (from the resource assessment), and the sustainability of the technology options that are available (identified through the sustainability assessment).

**Figure 2.2 Sustainable Energy Access Planning Framework: Overall Flow Diagram**

Source: Authors.

The cost assessment in turn generates information about the total cost and investment requirements associated with the least costly mix of energy access options and about the per-unit cost of cleaner-energy use. This information is needed to assess the affordability of energy access options to the poor, determine the type and level of subsidy and other support schemes that would make cleaner-energy resources more accessible and affordable, and evaluate the benefits of a cost-efficient EAP.

Besides the above-mentioned links, the sustainability assessment is also linked with resource assessment (and its information about adequacy, ease of access, and cost of cleaner-energy resources), cost assessment (and its information about per-unit cost of energy supply), and benefit assessment (and its information about environmental, health, and climate-change improvements and other benefits—including employment, cost and time savings, and reduced drudgery—associated with the energy technology and resource options assessed). The sustainability assessment is also linked with the affordability assessment (and its information about

**Figure 2.3 Links between Sustainability Assessment and Other Assessments**

Source: Authors.

capital and operating cost burden imposed on the user, including amount of financial support needed for the use of particular energy technology and resource option).

# 3 Energy Poverty Assessment

## Introduction

Identifying energy-poor households—those that have no access to cleaner energy or are unable to use an adequate amount of cleaner energy—is an important sustainable energy access planning (SEAP) activity. For that to be done, energy poverty must first be defined. However, Khandker, Barnes, and Samad (2012) state that “... no consensus has emerged as to how energy poverty can be defined, measured and monitored” despite the fact that the relationship between energy and poverty has attracted the attention of development specialists for decades.

The primary objective of the energy poverty assessment in the present framework is to estimate the number of households at or below the energy poverty line and their energy consumption levels. To the extent possible, these energy-poor households will be further classified according to their income and electricity or energy consumption levels, to aid in determining the supply level of modern energy (or cleaner energy) that would provide those households with the desired amount of energy access.

Various definitions of energy poverty and different approaches to its assessment are discussed in the next two sections. The chapter then outlines the process of selecting the appropriate assessment approach, including the data requirements, following a review of comparisons

that have been made between the different approaches in literature.

## Energy Poverty Defined

Energy poverty is variously defined in literature. The International Energy Agency (IEA) defines energy poverty as “a lack of access to modern energy services.” These services refer to electricity and clean-energy cooking facilities, e.g., fuels and stoves, which do not cause indoor air pollution (IEA 2014a). The definitions are based on different indicators:

- minimum amount of physical energy that meets cooking, lighting, heating, and other basic needs (Barnes 2010);
- type and amount of energy used by households at or below the poverty line (Barnes 2010);
- household energy spending beyond a certain percentage of the household budget (Barnes 2010);
- income level sufficient only to sustain the bare minimum energy needs (below that, energy use or energy expenditure remains the same) (Barnes 2010);<sup>1</sup>
- poverty and lack of access to modern forms of energy (Modi et al. 2006); or
- lack of access to energy services (Pachauri et al. 2004).

<sup>1</sup> D. F. Barnes. 2010. “The Concept of Energy Poverty.” *Energy for Development and Poverty Reduction*. <http://www.energyfordevelopment.com/2010/06/energy-poverty.html>

## Approaches to Energy Poverty Assessment

Several approaches proposed or used to identify (or measure) energy poverty are mentioned in literature (e.g., World Bank/ESMAP and IEA 2013; Khandker, Barnes, and Samad 2012; Pachauri and Spreng 2011; Foster, Tre, and Wodon 2000). Energy use in households is often the basis for measure of energy poverty: households that use energy above a minimum level are considered nonpoor, while the rest are considered energy poor. Such methods require information such as the minimum amount of energy needed to meet direct energy needs (e.g., for cooking, lighting, and heating the home) and the energy embodied in additional goods and services used. One drawback of such an approach, however, is the difficulty in determining the exact acceptable minimum level of basic energy services required, because of the significant differences in cooking practices and space heating or cooling requirements between countries and even between regions within a country. Energy consumption is often location specific because of the large variations in climatic conditions worldwide. On a country level, approaches to measuring energy poverty can be categorized as discussed in the following paragraphs.

### Energy Poverty Defined by Minimum Level of Energy Required to Meet Basic Energy Needs

Energy poverty using this approach is measured on the basis of a household's direct energy needs. These needs are, however, likely to vary with cooking practices, space conditioning (heating and cooling) requirements, and climatic and cultural differences across regions. In most existing studies, the minimum energy needs are chosen somewhat arbitrarily (Barnes, Khandker, and Samad 2011).

This approach can be used to determine the energy requirements for a normative set of basic needs, given

assumptions about the types of energy used and the size, energy efficiency, and frequency of use of end-use devices. This approach can also be used to analyze the basic needs of rural and urban households separately.

The first step in this approach involves identifying the basic energy needs of an average household by defining the threshold levels of those needs (e.g., lumens of demand for lighting; demand for useful energy for cooking, space heating, and cooling). As noted earlier, dissimilarities in climatic, physiographic, sociocultural, and other conditions can cause these needs to vary between countries and between subnational regions within a country; the definition must therefore be context-specific. The second step involves calculating the end-use energy requirement for each specific energy service defined in the previous step, as well as the amount of basic energy or fuel needs per household, considering the type of demand-side technology or device used for an energy service and its energy efficiency.

Minimum energy needs, according to Modi et al. (2006), are the equivalent of 50 kilograms of oil equivalent (kgoe) per person per year—40 kgoe for cooking fuel and 10 kgoe for electricity. Sanchez (2010) proposes a threshold level of 120 kilowatt-hours (kWh) of electricity and the equivalent of 35 kilograms (kg) of LPG per capita per year, but adds a qualitative element related to cookstove efficiency (Practical Action 2010). The *Poor People's Energy Outlook 2010* report considers 300 lumens per household as the minimum standard for lighting; for cooking and water heating, the minimum standard per person per day is set at 1 kg of fuelwood or 0.3 kg of charcoal, 0.04 kg of LPG, or 0.2 liter of kerosene or ethanol, each of which could be obtained by a household in less than 30 minutes (Practical Action 2010).

With regard to electricity, the Global Tracking Framework (GTF) report under the SE4ALL program defines an initial threshold level of electricity consumption of 250 kWh per year for a rural household of five persons and 500 kWh per year for an urban household of the same size (World Bank/ESMAP and IEA 2013).<sup>2</sup>

<sup>2</sup> The threshold level of electricity requirement is discussed in a number of other studies. See, for example, Pachauri et al. (2013a) and Sanchez (2010).

## Energy Poverty Defined by Energy Affordability

In this approach, energy poverty is defined as a household energy consumption level below that of households at the official income or expenditure poverty line (Foster, Tre, and Wodon 2000, cited in Khandker, Barnes, and Samad 2012). Pachauri et al. (2004) equate the energy poverty line with the average energy consumption of all households whose overall per capita consumption expenditure level falls within a  $\pm 10\%$  range of the official expenditure poverty line. The approach is relatively easy to implement with a household survey, since the official income or expenditure line is known. But it assumes that income-poor or expenditure-poor households are energy poor, and that is not always the case. One variant of the affordability-based approach defines energy poverty in terms of energy budget share, that is, the share of household expenditure or income spent on energy and energy-using devices. According to some studies, the poorest group normally spends a greater share of income on energy than middle- and upper-income groups (Pachauri et al. 2004, citing Leach 1987). This is possible, as the share of energy in a household budget depends not only on the type of energy used and its market price, but also on the efficiency and cost of appliances using the energy.

## Energy Poverty Defined by Demand Analysis

Energy poverty defined by demand analysis determines various factors, including household income and the price and availability of different energy sources, to establish minimum energy needs (Barnes, Khandker, and Samad 2011). It assumes that the energy consumption of low-income households up to a certain level of income is insensitive to income change. Energy-poor households can be identified in either of two ways: (i) through a simplified approach, or (ii) a rigorous approach using econometric demand analysis. In the simplified approach, the household sample is divided into different income groups (10 or more groups) and their energy consumption is estimated. This approach assumes that energy consumption will remain flat for certain low-income groups, and increase for other groups. Households within these low-income groups would be considered energy poor.

## Energy Poverty Defined by Energy or Fuel Poverty Line

The economic approach uses the energy or fuel poverty line as the basis for determining energy poverty and identifying energy-poor households. Poor and nonpoor households differ in the amount and type of energy consumed for cooking, heating, and lighting, and this difference defines the energy poverty line or fuel poverty line. The energy or fuel poverty line represents the average level of energy consumption of people whose level of income or expenditure corresponds to the officially specified poverty line, that is, the minimum income needed to meet basic needs (Khandker, Barnes, and Samad 2012; Foster, Tre, and Wodon 2000). Khandker, Barnes, and Samad (2012) define the energy poverty line as the threshold point of energy consumption beyond which energy consumption increases with income. Households below this energy poverty line or fuel poverty line are considered energy poor.

## Energy Poverty Defined by Indexes

### **Multidimensional Energy Poverty Index approach.**

According to Nussbaumer, Bazilian, and Modi (2012), the Multidimensional Energy Poverty Index (MEPI) is designed to capture the multidimensional nature of energy poverty. The index is derived by means of a methodology that is similar in concept to that used in measuring multidimensional poverty. It captures a set of energy deprivations (absence of energy services) that may affect a person's well-being. Basic energy services (e.g., lighting, cooking, space heating and cooling, entertainment, education, mechanical power) are considered as different dimensions in the estimation of the MEPI. The MEPI approach also takes into account the types of energy sources that are accessible, as well as the ownership of appliances that require fuel from such sources. One or more indicators are therefore used in measuring the dimensions for each basic energy service. Relative weights are assigned and deprivation cut-off are defined for each indicator. In addition, a cutoff value for multidimensional energy poverty is required to determine if a person is energy poor. But this is not a simple task. In their study, Nussbaumer, Bazilian, and Modi (2012) assume values appropriate to a specific context, for use in energy poverty assessments.

**Table 3** Dimensions of Energy Poverty: An Illustration from a Study in Africa

Dimension	Indicator (Weight)	Variable	Deprivation Cutoff (Energy Poor If ...) <sup>a</sup>
Cooking	Use of modern cooking fuel (0.2)	Type of cooking fuel used	Uses fuel other than electricity, LPG, kerosene, natural gas, or biogas
	Indoor pollution (0.2)	Type of cooking device and fuel used	Cooks on stove or open fire (no hood/chimney) and uses fuel other than electricity, LPG, or biogas
Lighting	Access to electricity (0.2)	Extent of access to electricity	Has no access to electricity
Services provided by means of household appliances	Ownership of household appliance (0.13)	Ownership of a refrigerator	Does not own a refrigerator
Entertainment, education	Ownership of entertainment or educational appliance (0.13)	Ownership of a radio or television	Does not own a radio or television
Communication	Ownership of means of telecommunication (0.13)	Ownership of a landline or mobile phone	Does not own a landline or mobile phone

LPG = liquefied petroleum gas.

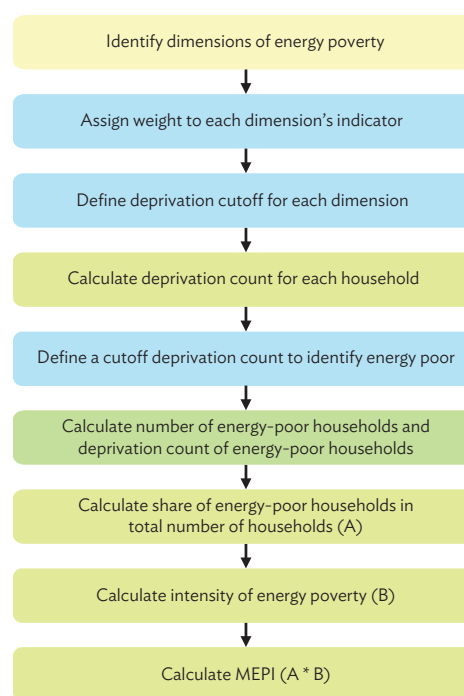
<sup>a</sup> The statement in this column represents an elaboration of the corresponding materials in the original source.

Source: Nussbaumer, P., M. Bazilian, and V. Modi. 2012. Measuring Energy Poverty: Focusing on What Matters. *Renewable and Sustainable Energy Reviews* 16 (1): 231–243.

Table 3 shows the five dimensions and six indicators used by Nussbaumer, Bazilian, and Modi (2012) in a multicountry energy poverty study of Africa. Some energy services, such as space heating, space cooling, and water heating, are not included as dimensions because of limited data availability. The indicators and weights used in that study should be considered indicative only; they must be adapted to suit the specific context.

The MEPI is the product of a head-count ratio (the percentage of people identified as energy poor) and the average intensity of deprivation of the energy poor, defined as the total deprivation count of all energy-poor people, divided by the total number of energy-poor people. The deprivation count here refers to people who have no access to modern energy services. But the determination of weights is a rather controversial issue, as it can be argued that the criteria considered in an index do not necessarily have the same relative or symmetrical importance. The weights may even depend on a particular method used to derive them. The overall MEPI score is highly sensitive to the choice of weights and multidimensional cutoff (the set of conditions to be met) (Nussbaumer, Bazilian, and Modi 2012).

Figure 3.1 shows the steps involved in calculating the MEPI. These steps are described in detail in Appendix 2.

**Figure 3.1** Steps in Calculating the Multidimensional Energy Poverty Index

MEPI = multidimensional energy poverty index.

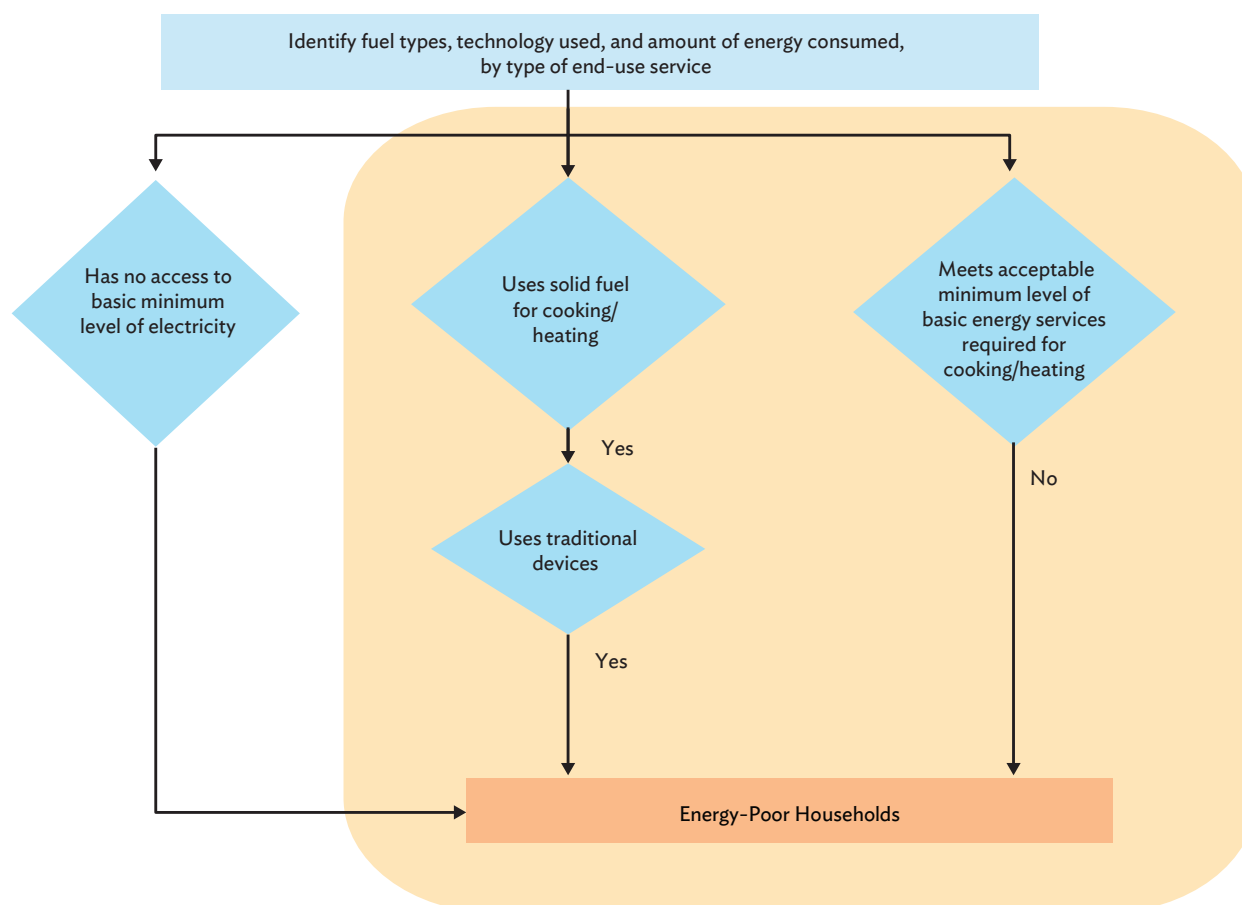
Source: Authors.

Note that MEPI by itself is an overall indicator of energy poverty at a regional, national or subnational level. However, the procedure also includes estimation of the total energy deprivation count at individual household level, which represents a relative measure of household-level energy poverty.

**Total Energy Access approach.** The Total Energy Access (TEA) approach captures five energy services: cooking, lighting, space heating and cooling, and information and communication technology (Practical Action 2012). For each energy service, one or more indicators with their minimum standards have been

defined to aid in TEA assessment. For instance, in the case of lighting services, 300 lumens for at least 4 hours a night is the minimum standard. Nine indicators in all are used for the services. The minimum standards required for providing total energy access developed by Practical Action (2012) are presented in Appendix 3 (see Practical Action 2012 for more details) and the levels of total energy access index are defined in Appendix 4. If some indicators are rendered unnecessary by climatic conditions such as cooling in a cold climate, then such energy services are considered to have been met. A household that meets all of these minimum standards is considered to have total energy access. One that does

**Figure 3.2 Characteristics of Energy-Poor Households**



Source: Authors.

not meet these minimum standards is considered to be in need of an EAP.

## Energy Poverty Assessment Approaches for Use in Sustainable Energy Access Planning

Different studies have proposed various approaches to measuring energy poverty (reviewed in Pachauri and Spreng 2011, and Khandker, Barnes, and Samad 2012, among others). Only a few approaches reflect the energy poverty concept more accurately. These include the approach that measures energy poverty on the basis of minimum basic energy consumption (Modi et al. 2006; AGECC 2010); the demand-invariant approach (Barnes, Khandker, and Samad 2011); the energy affordability approach (Foster, Tre, and Wodon 2000, cited in Khandker, Barnes, and Samad 2012 and Pachauri et al. 2004); the MEPI approach (Nussbaumer, Bazilian, and Modi 2012); and the TEA standard (Practical Action 2012). Among these approaches, the two based on minimum basic energy consumption and energy affordability, as well as the demand-invariant approach and the TEA standard, could provide a quantitative basis for estimating the acceptable level of energy to be provided to reduce energy poverty under an EAP. However, the levels of energy to be provided under an EAP based on these four approaches can vary significantly. The basic minimum energy consumption approach is the easiest to use in energy access planning, provided information about the acceptable minimum level of basic energy services is available.

Figure 3.2 shows the flow diagram for an approach to identifying energy-poor households (those who need

energy access). As shown in the figure, households whose electricity consumption is below the basic minimum energy requirement are regarded as energy poor and requiring an EAP. The flow diagram within the dotted box in Figure 3.2 shows two different conditions for identifying the energy poor—one in terms of energy and end-use technology used, and the other in terms of ability to meet the basic minimum needs for cooking and heating. As mentioned in the multitier approach to measuring energy access under the GTF, households using traditional cookstoves that burn solid fuels are classified under tier 0 (World Bank/ESMAP and IEA 2013). Tier 0 households whose level of energy consumption falls below the basic minimum energy requirement are considered energy poor (see Appendix 5).

## Data Requirements

The data needed for the assessment of energy poverty includes the following:

- Types of fuel used;
- Fuel consumption data, by end use (amount of fuel usefully consumed per household for cooking, lighting, heating, etc.);
- Number of electrified and nonelectrified households;
- Types of end-use devices used and their energy efficiency;
- Types of household electric appliances used;
- Means of telecommunication;
- Total population and number of households;
- Basic minimum level of energy requirement; and
- Weight based on relative importance of energy services.

# 4 Demand Assessment

## Introduction

While providing energy access to households is the major focus of the present energy access planning framework, planning energy supply facilities only for that purpose is often neither economically efficient nor desirable from the standpoint of overall economic development. Particularly in areas with no electricity supply at present, the demand for energy (and energy-using services) of the industry sector, including small businesses and other sectors, must be assessed and met as well. A wide-ranging demand assessment would also help in the economically efficient development of local energy resources with respect to the timing of construction and the size and projected life of the energy facilities. Such an assessment is especially important for investment decisions regarding supply facilities like hydropower plants, which can be quite expensive to reverse once implemented. Demand assessments that are comprehensive and multisectoral in coverage are therefore desirable.

This chapter discusses methods of assessing the energy demand of the energy poor (for lighting, cooking, water heating, space heating or cooling, and other uses), in order to determine the additional energy requirement that must be provided under the EAP during the energy access planning period to meet the acceptable minimum level of basic energy services. The chapter also discusses the assessment of the energy demand of nonpoor households, the production sectors, and community services (e.g., schools, hospitals). A distinctive feature of

the energy demand assessment in the SEAP framework is its recognition of the dependence of demand for energy on the end-use technologies applied to meet an energy service demand. Energy demand is therefore expressed in terms of either the useful energy involved in an energy service (e.g., kilowatt-hours in the case of cooking and heating) or other appropriate physical units of measurement (e.g., lumen-hours in the case of lighting).

The next section of this chapter presents a brief overview of approaches to assessing energy demand. This is followed by a description of the proposed methods for demand assessment in the SEAP framework and the data required to assess energy demand.

## Approaches to Assessing Energy Demand

Several methods exist in literature for estimating energy demand. They include the trend method, the end-use method (or the engineering-based accounting approach), the econometric approach, time-series methods, and neural network techniques<sup>3</sup> (Bazilian et al. 2012). These methods have their strengths and weaknesses. The choice of the appropriate method is subject to a number of factors, such as the nature and availability of the underlying data, the purpose of the analysis, and the time frame. For many long-term planning exercises, demand projections are based on some econometric relationship to income (gross domestic product), energy price and

<sup>3</sup> The Trend method finds the growth trend by fitting a time trend line. End-use models attempt to establish accounting coherence by using a detailed engineering representation of the energy system. Econometric models are grounded in economic theories and try to validate the economic rules empirically (Bhattacharya and Timilsina 2009). Time-series methods consider the possible internal structure of the data points taken over time, such as autocorrelation, trend, or seasonal variation (NIST 2013). Artificial network techniques, recently developed computational modeling tools, are used for modeling complex real-world problems (Kazemi et al. 2012).

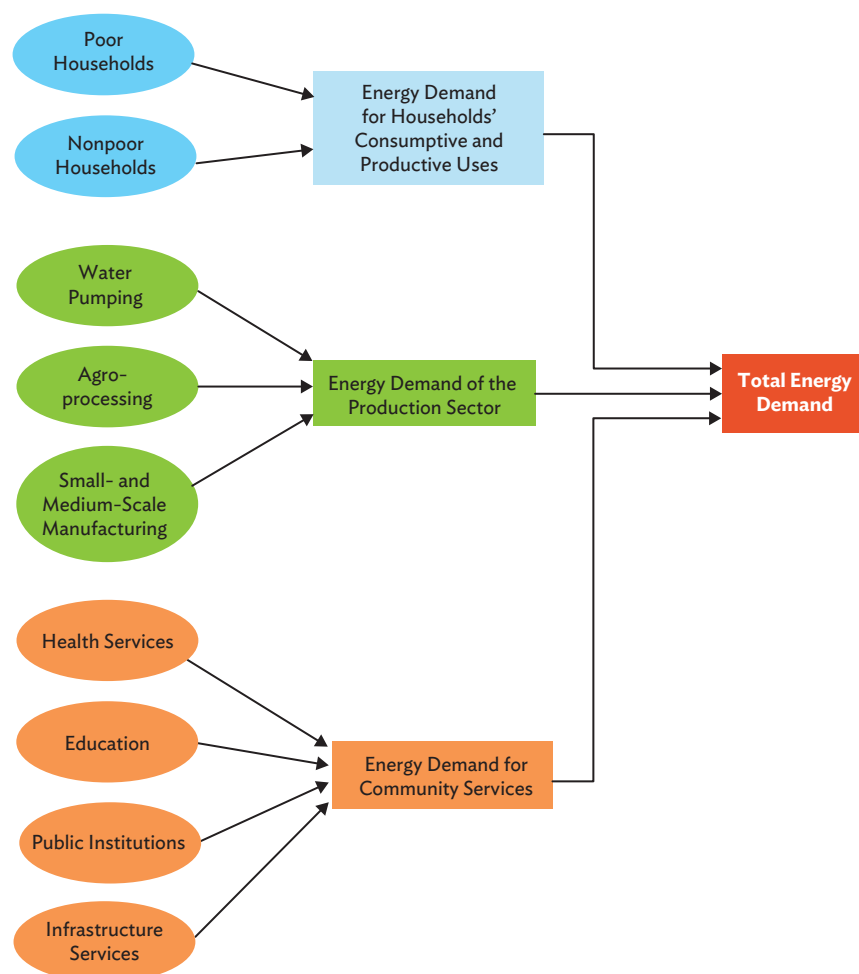
population growth projections, along with an elasticity relationship (Bhattacharyya and Timilsina 2009). In the context of electrification, some studies, e.g., PIDA (2011) have used other parameters such as household connections for demand projections.

Some studies (e.g., Senatla 2011) consider income as the main driver of energy demand at the household level, and include other drivers such as electrification level, population, and household growth. However, in energy access planning, particularly electricity access planning, the level of electrification in the future is an outcome of the planning exercise and cannot be a determinant of future electricity demand.

## Demand Assessment Methodology for Sustainable Energy Access Planning

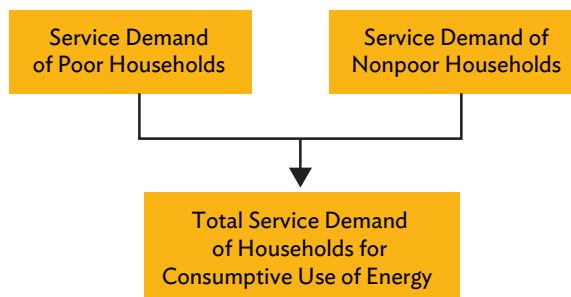
Assessing energy service demand in the target area involves assessing the energy demand of households for consumptive and productive uses of energy, as well as the energy demand of the production sector and community services (see Figure 4.1). Household energy service demand for consumptive use in energy-poor and nonpoor households is estimated. The total energy service demand of the household sector comprises the service demand

**Figure 4.1 Bottom-Up Approach to Demand Assessment**



Source: Authors.

**Figure 4.2 Total Service Demand of Households for Consumptive Use**



Source: Authors.

of both energy-poor and non-energy-poor households (Figure 4.2). The present assessment considers a household energy poor if its energy consumption and the quality of the fuel it uses are below a predefined acceptable level.<sup>4</sup> The energy service demand of the production sector is associated with energy use in activities such as the operation of machinery for agricultural production and agro-processing, water pumps, and tools for small- and medium-scale manufacturing industries. The demand for energy in community services covers energy use for health care services (such as hospitals, clinics, and health posts), education (such as schools, universities, and other education services), public institutions (such as government offices, religious buildings), and infrastructure services (such as water supply and street lighting).

The following discussion deals with the methods proposed for assessing the energy demand of the different sectors.

## Assessment of Energy Demand of Households for Consumptive Use

The approaches to the assessment of energy demand for consumptive use by energy-poor and non-energy-poor households are discussed below.

### Energy service demand of energy-poor households.

Figure 4.3 presents the steps in estimating the energy service demand of energy-poor households. First, an acceptable minimum level of basic energy services is defined. Next, the size of the energy-poor population, which uses less than the minimum acceptable level of basic energy services, is roughly calculated. Finally, the total amount of energy that will provide the energy-poor households with the minimum acceptable level of basic energy services is estimated. Note here that estimation of energy demand to meet the minimum acceptable level of energy services should consider the type of end-use device technology and its energy efficiency.<sup>5</sup> The energy demand estimation in this step can therefore vary depending on the type of fuel and demand-side technologies considered.

**Figure 4.3 Steps in Estimating the Energy Demand of Energy-Poor Households**

Define the minimum acceptable level of basic energy services

Identify the number of households whose energy consumption is below the minimum acceptable level

Estimate the amount of energy required to provide households with the minimum acceptable level of basic energy services

Source: Authors.

If  $ESD_{i,min}$  denotes the minimum level of useful energy requirement per capita (or energy supply standard) for end-use service type  $i$ , and  $POPEP_t$  is the population of the energy poor in year  $t$ , the total energy requirement of the energy-poor population in year  $t$  ( $\overline{tesdp}_{it}$ ) to meet the energy supply standard for energy service type  $i$  under an EAP would be given by

$$\overline{tesdp}_{it} = POPEP_t * ESD_{i,min} \quad (\text{Eq. 4.1})$$

<sup>4</sup> That level could be one of the lower tiers of the GTF (World Bank/ESMAP and IEA 2013). But, in realistic terms, the level must be specific to the context of the country or subnational region concerned.

<sup>5</sup> This is mainly because the level of energy needed to meet household demand for energy services depends on the type of fuel and end-use technologies applied. For example, a compact fluorescent lamp would consume 80% less electricity than an incandescent lamp for providing the same level of lighting.

The total amount of energy needed to meet energy supply standards for different energy services ( $\overline{TESDP}_t$ ) under an EAP would then be given by

$$\overline{TESDP}_t = \sum_i \overline{tesdp}_{it} \quad (\text{Eq. 4.2})$$

The total amount of energy consumption by the energy poor for energy service type  $i$  in year  $t$  ( $tesdp_{it}$ ) in the business as usual (BAU) scenario (without an EAP intervention) can be expressed as

$$tesdp_{it} = POPEP_t * esdp_{it} \quad (\text{Eq. 4.3})$$

where  $esdp_{it}$  denotes the per capita average energy consumption for energy service type  $i$  in year  $t$  by the energy poor in the BAU scenario.

Eq. 4.3 requires information about both the population of the energy poor ( $POPEP_t$ ) and its per capita average energy consumption for energy service type  $i$  in year  $t$  ( $esdp_{it}$ ) in the BAU scenario. The per capita energy consumption of the energy poor for energy service type  $i$  in year  $t$  can be estimated through the use of either an econometric demand model or a techno-economic accounting approach. Normally, separate studies are needed to estimate the future values of  $POPEP_{it}$  and  $esdp_{it}$ . Without such studies, the future values may be based on the historical growth rate of the energy poor and  $esdp_{it}$ . Alternatively, assumptions can be made about the future growth rates of  $POPEP_{it}$  and  $esdp_{it}$ .

The total amount of energy consumption by the energy poor for different energy services ( $\overline{TESDP}_t$ ) in the BAU scenario would then be given by

$$\overline{TESDP}_t = \sum_i \overline{tesdp}_{it} \quad (\text{Eq. 4.4})$$

The total amount of additional energy needed to meet the different energy services for the energy-poor population in year  $t$  under an EAP at the national or subnational level (denoted by  $\Delta TESDP_{it}$ ) is expressed as

$$\Delta TESDP_{it} = \overline{TESDP}_{it} - \overline{TESDP}_t \quad (\text{Eq. 4.5})$$

The foregoing approach can also be used in assessing the total additional energy requirement at the national or subnational level for the different tiers of energy access proposed in the GTF of SE4ALL (World Bank/ESMAP and IEA 2013) since  $ESD_{i,min}$  can be treated as a measure

of the energy supply standard prescribed by the GTF for energy service type  $i$ . The approach can likewise be used in determining the total additional energy required to meet energy supply standards for different energy services proposed under the TEA paradigm of Practical Action (2012).

In the present SEAP framework, the minimum acceptable levels of basic energy services for households (say, energy service standards) are assumed to be predefined or known. But there is no universal value for these levels, as they can vary between countries with different climatic, social, economic, cultural, and other conditions, and even between regions within a country. The minimum acceptable levels must therefore be specific to the national or subnational context of an energy access planning study.

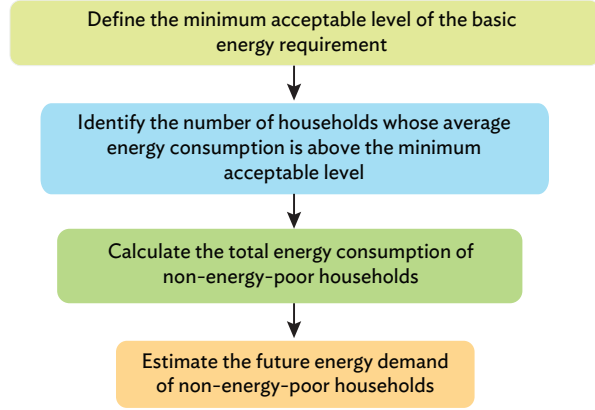
The size of the energy-poor population in the present year can normally be estimated with relevant data from household surveys. Similarly, historical information about the energy-poor population can be based on past household surveys, if they are available. A separate analysis or study is normally needed to obtain information about the size of the future energy-poor population; otherwise, a suitable assumption may have to be made about the growth rate of the energy-poor population in the future.

For the same end-use service (e.g., cooking, space heating), energy consumption varies with the type of fuel and the efficiency of the device used for cooking or heating. The amount of electricity required to meet household demand for lighting (say, in lumen-hours) depends on the type of lamp technology used (e.g., light-emitting diode [LED] lamp, compact fluorescent lamp [CFL], incandescent bulb). The amount of energy to be supplied depends on the demand-side technology used. It is therefore important to define the minimum acceptable level of energy services in terms of the useful energy needed to provide the basic end-use service (cooking, space heating, etc.) or in terms of the appropriate physical units of energy service (e.g., lumen-hours, in the case of lighting).

#### Energy demand of non-energy-poor households.

Figure 4.4 shows the steps involved in estimating the energy demand of non-energy-poor households. As

**Figure 4.4 Estimating the Energy Demand of Non-Energy-Poor Households**



Source: Authors.

mentioned earlier, households whose average energy consumption level is above the minimum acceptable level are regarded as non-energy-poor households.

The energy demand of non-energy-poor households can be estimated through an econometric or a techno-economic (accounting) approach. As demand for energy is a derived demand, this estimate is ideally based on end-use service demand. The type of energy and device technology used determines the level of energy consumption required to meet the end-use service demand.

Econometric energy demand models can be classified into two broad categories: structural demand models and reduced-form demand models (Bohi 1981; Bhattacharya and Timilsina 2009). Structural demand models are, however, relatively difficult to apply in developing countries, as these models require data on appliance ownership and utilization, besides data on household income, fuel prices, prices of appliances, and other variables, and these data are not always available. Conceptually, reduced-form energy demand models require relatively less data for assessing future energy demand. In these models, the demand for energy for end-use service  $i$  can be expressed as a function of household income, price, and other variables (e.g., weather).

Several possible econometric models of energy demand could be considered. However, constant elasticity (Cobb–Douglas) demand models are among the most popular in practice. According to this model, the demand of non-energy-poor households for energy service demand type  $i$  in year  $t$  may be expressed as

$$ESDNP_{it} = ESDNP_{i0} * \left(\frac{I_t}{I_0}\right)^\alpha * \left(\frac{P_{it}}{P_{i0}}\right)^\beta * \left(\frac{Z_t}{Z_0}\right)^\gamma \quad (\text{Eq. 4.6})$$

where

$ESDNP_{it}$  = per capita demand of non-energy-poor households for energy service  $i$  in year  $t$ ;

$ESDNP_{i0}$  = per capita demand of non-energy-poor households for energy service  $i$  in the base year;

$I_t$  = income per capita in year  $t$ ;

$I_0$  = income per capita in the base year;

$P_{it}$  = price of energy service  $i$  in year  $t$ ;

$P_{i0}$  = price of energy service  $i$  in the base year;

$Z_t$  = other explanatory variables in year  $t$ ;

$Z_0$  = other explanatory variables in the base year; and

$\alpha, \beta, \gamma$  = elasticity of energy service demand with respect to income, energy price, and other relevant variables, respectively.<sup>6</sup>

The total energy demand of the non-energy-poor population in year  $t$  ( $TESDNP_t$ ) can be expressed as the sum of energy demand for different services:

$$TESDNP_t = \sum_i ESDNP_{it} * POPNP_t \quad (\text{Eq. 4.7})$$

where  $POPNP_t$  denotes the total population of the non-energy-poor households in year  $t$ .

## Assessment of Energy Service Demand of Households for Productive Use

Besides the consumptive use of energy, some households also use energy for productive activities, including animal feed preparation, alcohol making, motive power, heating applications, and other productive activities at home (Practical Action 2013). Different approaches

<sup>6</sup> The right-hand side of Equation 4.6 can be expanded to include many other relevant variables.

to estimating the future demand of households for electricity for productive use are described below.

One approach is based on the level of productive activity of households and household-specific electricity consumption (electricity consumption per unit of productive activity). That is:

$$PUEL_{it} = q_{it} * N_{it} * e_{it} \quad (\text{Eq. 4.8})$$

where

$PUEL_{it}$  = electricity consumption for productive activity  $i$  in year  $t$ ;

$q_{it}$  = average household level of productive activity  $i$ ;

$e_{it}$  = specific electricity consumption of the activity in year  $t$ ; and

$N_{it}$  = number of households engaged in productive activity  $i$  in year  $t$ .

For energy access planning, this approach would require information about the average level of household productive activity  $i$ , the corresponding specific electricity consumption, and the estimated household population engaged in the productive activity in year  $t$ .

The electricity demand for productive activity  $i$  in year  $t$ , calculated using an econometric approach, could be expressed as

$$PUEL_{it} = PUEL_{i0} \times \left( \frac{PE_t}{PE_0} \right)^\alpha \times \left( \frac{Q_{it}}{Q_{i0}} \right)^\beta \quad (\text{Eq. 4.9})$$

where

$PUEL_{it}$  = amount of electricity used in productive activity  $i$  in a future year  $t$ ;

$PUEL_{i0}$  = amount of electricity used in productive activity  $i$  in the base year;

$PE_t$  = price of electricity in year  $t$ ;

$PE_0$  = price of electricity in the base year;

$Q_{it}$  = level of productive activity  $i$  in year  $t$ ;

$Q_{i0}$  = level of productive activity  $i$  in the base year; and

$\alpha, \beta$  = electricity price and output elasticities of electricity demand.

This approach, however, requires information about the level of productive activity and energy price in the base year and future years, as well as the estimation of elasticity parameters.

If there is information about the projected growth rate of the productive use of electricity, a simplified approach to estimating the level of electricity demand of households for productive use  $i$  in year  $t$  could be

$$PUEL_{it} = PUEL_{i0} * (1 + g)^t \quad (\text{Eq. 4.10})$$

where

$PUEL_{it}$  = electricity consumption for productive use  $i$  in year  $t$ ;

$PUEL_{i0}$  = electricity consumption for productive use  $i$  in the base year; and

$g$  = estimated or projected future growth rate of the productive activity  $i$ .

Equations 4.9 and 4.10 require information about the electricity consumption of households for productive use in the base year ( $PUEL_{i0}$ ). This is normally not measured through a separate meter. It must be estimated indirectly from the power ratings of devices used in productive activity and their utilization rates, as follows:

$$PUEL_{i0} = \sum_j (d_{ij,0} \times W_{ij,0} \times h_{ij,0}) * N_{i0} \quad (\text{Eq. 4.11})$$

where

$j$  = device type (e.g., CFL, fluorescent tubular lamp, light-emitting diode [LED] lamp, etc.); lumen-hours in the case of lighting;

$d_{ij,0}$  = average number of type  $j$  devices used in productive activity  $i$  in the base year;

$W_{ij,0}$  = average power rating of device type  $j$  used in productive activity  $i$  in the base year;

$h_{ij,0}$  = average hours of productive use  $i$  of device  $j$  in the base year; and

$N_{i0}$  = number of households engaged in productive activity  $i$  in the base year.

Some approaches are more demanding than others in terms of data needed. The choice of the approach to be

used in estimating the future demand of households for electricity for productive use would therefore depend largely on data availability. Approaches similar to the previous approaches can also be used in estimating the nonelectric energy demand of households for productive activities.

## Assessment of Energy Service Demand of Production Sectors

The demand of the production sectors for energy can be estimated with the help of an econometric energy demand model. For example, the demand for electricity by the production sector  $i$  in year  $t$  can be expressed as

$$PSED_{it} = PSED_{i0} \times \left( \frac{EP_{it}}{EP_0} \right)^\alpha \times \left( \frac{PROD_{it}}{PROD_{i0}} \right)^\beta \quad (\text{Eq. 4.12})$$

where

$PSED_{it}$  = demand of production sector  $i$  for electricity in year  $t$ ;

$PSED_{i0}$  = demand of production sector  $i$  for electricity in the base year;

$EP_{it}$  = price paid for electricity by production sector  $i$  in year  $t$ ;

$EP_0$  = price paid for electricity by production sector  $i$  in the base year;

$PROD_{it}$  = output level from production sector  $i$  in year  $t$ ;

$PROD_{i0}$  = output level from production sector  $i$  in the base year; and

$\alpha, \beta$  = electricity price and output elasticities of electricity demand.

The electricity consumption of the production sector  $i$  in the base year ( $PSED_{i0}$ ) can be estimated as follows:

$$PSED_{i0} = SEC_{i0} * PROD_{i0} \quad (\text{Eq. 4.13})$$

where

$SEC_{i0}$  = specific electricity consumption per unit output of production sector  $i$  in the base year; and

$PROD_{i0}$  = total output of production sector  $i$  in the base year.

A similar approach can be used in estimating the demand for nonelectric energy in the production sector.

## Assessment of Energy Demand for Community Services

Community services include health care services, education, public (or government) institutions, and utilities and infrastructure services. The electricity consumption of a community service sector can be estimated by means of an econometric demand model. The approach uses information about the activity level or output of the sector and the specific energy consumption of the service activity or output (energy consumption per unit of service). The econometric model for estimating electricity demand in any year  $t$  for community service type  $c$  can be expressed as

$$TECCS_{ct} = TECCS_{c0} \times \left( \frac{Q_{ct}}{Q_{c0}} \right)^\alpha \quad (\text{Eq. 4.14})$$

where

$TECCS_{ct}$  = total energy demand of community service sector type  $c$  in year  $t$ ;

$TECCS_{c0}$  = total energy demand of community service sector type  $c$  in the base year;

$Q_{ct}$  = total output or activity level of community service sector type  $c$  in year  $t$ ;

$Q_{c0}$  = total output or activity level of community service sector type  $c$  in the base year; and

$\alpha$  = output or activity-level elasticity of electricity consumption of a community service sector.

The total energy consumed by community service sector type  $c$  in the base year (year 0) can be estimated by means of the following equation:

$$TECCS_{c0} = q_{c0} \times SEC_{c0} \times N_{c0} \quad (\text{Eq. 4.15})$$

where

$q_{c0}$  = average activity or output level of organizations providing community service type  $c$  in the base year;

$SEC_{c0}$  = average specific electricity consumption of organizations providing community service type  $c$  in the base year;

$N_{c0}$  = number of organizations providing community service type  $c$  in the base year;

Note that

$$Q_{c0} = q_{c0} \times N_{c0} \quad (\text{Eq. 4.16})$$

where

$Q_{c0}$  = total output or activity level of community service;

$q_{c0}$  = average activity or output level of organizations providing community service type  $c$  in the base year; and,

$N_{c0}$  = number of organizations providing community service type  $c$  in the base year.

The total energy demand for community services in year  $t$  ( $TECCS_t$ ) is then given by

$$TECCS_t = \sum_c TECCS_{ct} \quad (\text{Eq. 4.17})$$

where

$TECCS_{ct}$  = total energy consumed by community service sector type  $c$  in year  $t$ .

## Estimation of Temporal Demand Profile

In electricity access planning, besides the total electricity demand, the typical daily demand profile (load profile) for different months or seasons of a year also contains valuable information, since electricity consumption varies during the day and during the year. In areas already supplied with electricity, the demand profile at the system level could be combined with information about household use patterns to arrive at the demand profile with an electricity access program. In an area without electricity supply, the demand profile of electrified areas that are similar enough to the area for which an EAP is being planned would indicate the likely demand profile of the area.

## Data Requirements

The main data required for projections of service demand for cooking, heating, and lighting energy needs are the number and types of appliances used in the household, and the amount of energy consumed by each appliance. Changes in income level and distribution, urbanization, and population growth also affect energy service demand. In summary, the data required for demand assessment include the following:

- Demographic data (urban and rural population, energy-poor and non-energy-poor population, number of households);
- Types of energy used, level of energy consumed, per capita average energy consumption;
- Minimum level of useful energy requirement;
- Types and number of devices, by end use and device efficiency;
- Average power rating of device;
- Average hours of use of device;
- Income (per capita household income);
- Gross domestic product;
- Income, price, population, and output elasticities;
- Price of energy;
- Level of household productive activity, volume of production by productive sectors, activity level of community services;
- Specific electricity consumption per household productive activity;
- Number of production sectors and community services by type of productive or community service (small and medium enterprises, health care centers, public institutions, other infrastructure services, etc); and
- Number of households engaged in productive activity;
- Average activity or output level by type of community service organization; and
- Average specific energy consumption by type of community service organization.

# 5 Resource Assessment

## Introduction

As one of the key SEAP objectives is a cost-effective and sustainable energy supply, it is necessary to have full knowledge of available energy resource options and their associated development and use costs. The resource assessment in this framework focuses on primary energy resources. In the case of electricity access programs, these comprise local renewable energy resources in the geographic area where an EAP is to be developed (for off-grid power supply) and centralized or grid-based options relevant to SEAP. The resource assessment generates information about the economically exploitable potential (or “economic potential”) of available energy resources, their spatial distribution, and temporal availability patterns over different periods in a year. The assessment also indicates the cost involved in harnessing the resources.<sup>7</sup> In addition, the resource assessment provides information about other important aspects of resources, e.g., their proximity to users, ease of access to the resources, and adequacy of the resources given the current and future demand for energy. Some key information from the resource assessment is used in the cost assessment component or in the sustainability assessment of resource and technology options under the SEAP framework.

This chapter outlines the various dimensions of resource assessment and the approaches to resource assessment that studies have taken. The data requirements are listed at the end of the chapter.

## Dimensions of Resource Assessment

Under the present SEAP framework, the resource assessment activity focuses on five key dimensions (Figure 5.1): (i) availability and economic potential, (ii) adequacy, (iii) sustainability, (iv) ease of access, and (v) cost of use. Each of these dimensions of resource assessment is described briefly below.

### Availability of Resources

The availability of a resource in the context of resource assessment refers to the economically exploitable potential of resources, including decentralized or local energy resource options, and the spatial and temporal distribution of the resources.

### Adequacy of Resources

The resource assessment determines whether enough resources are available to meet the energy demand in the energy access planning area over the short, medium and long term. For SEAP, a resource that is consistently available in sufficient quantities to meet local demand over a longer term is often preferable to a resource that is insufficient to meet either the present or the projected demand or is only intermittently available.

<sup>7</sup> The potential of a resource can be expressed in three different ways—theoretical, technical, or economic. Theoretical potential is derived from natural and climatic (physical) parameters (e.g., total solar irradiation on a continent’s surface). The theoretical potential can be quantified with reasonable accuracy, but the information is of limited practical relevance. It represents the upper limit of what can be produced from an energy resource based on the basis of physical principles and current scientific knowledge. It does not take into account energy losses during the conversion process necessary to make use of the resource, nor any kind of barriers. Technical potential is the amount of renewable energy output that can be obtained through full implementation of demonstrated technologies or practices. No explicit reference to costs, barriers, or policies is made. Economic potential is the amount of renewable energy output projected when all social costs and benefits related to that output are included, there is full transparency of information, and it is assumed that exchanges in the economy install a general equilibrium characterized by spatial and temporal efficiency (Edenhofer et al. 2011). Resource assessment mainly considers the economic potential of a resource.

## Sustainability of Resources

In general, success in supplying a community with its energy needs depends on the sustainability of the resources (GEA, 2012). The resource assessment therefore also considers whether one resource is more sustainable than others from an environmental, health, energy security, and economic standpoint.

## Ease of Access to Resources

Another aspect covered by the resource assessment is the ease of access to a resource for its economic exploitation; for example, how far one has to go and how many hours one has to spend to collect the fuel. A resource that is relatively small in size, far from the users, and difficult to harness may be less preferable than a resource that is nearer and more easily accessible to the users.

## Cost of Resource Use

The resource assessment must determine the cost of using a resource to provide access to basic energy services. The costs associated with a particular resource

can vary with the amount used. Information about the cost of resources would help in determining the most cost-effective resource.

## Approaches to Resource Assessment

The spatial distribution of energy resources mapped over different periods is the main basis for the SEAP resource assessment. Maps of renewable resources (biomass, hydropower, solar, wind) are often available in relevant national databases or in international sources. Many countries already have such information and may have used it as part of national energy (including electricity) planning. Countries without a similar database will have to collect data to assess energy resource availability, in particular economic potential, in the EAP target area. But primary data collection can be both costly and time consuming. As far as possible, therefore, information about local energy resource potential should be compiled from the available GIS database and other secondary sources.

The assessment should include determining the local availability of biomass resources such as fuelwood, agricultural residues, biomass briquettes, etc., at the district, village, or community level. Regarding solar energy resources, information about solar insolation can be obtained from the National Aeronautics and Space Administration (NASA),<sup>8</sup> which provides monthly solar resource information for all locations worldwide. The solar resource information includes average sunlight received per day, number of consecutive sunless days, and minimum amount of sunlight available per month. As local wind resources are less consistently available than solar energy, any wind power installation should be preceded by proper site monitoring for several months (USAID, n.d.).

The methodology and data requirements for the assessment of renewable resources vary with the type of resource. Many countries conduct spatially distributed assessments (resource mapping) of individual resources in different subregions within those countries.<sup>9</sup> International sources, such as the Solar and

**Figure 5.1 Dimensions of Resource Assessment**



Source: Authors.

<sup>8</sup> NASA website: <http://eosweb.larc.nasa.gov/sse/>

<sup>9</sup> For example, the US National Renewable Energy Laboratory (NREL) assesses renewable resources in the United States by county (<http://www.nrel.gov/gis/>).

Wind Energy Resource Assessment (SWERA), a United Nations Environment Programme (UNEP)–facilitated effort administered by the National Renewable Energy Laboratory (NREL), provide information about solar and wind energy resources for each country and region (<http://en.openei.org/apps/SWERA/>). A SEAP activity could rely on such secondary sources. But a spatially disaggregated assessment of all renewable resources may not exist for some countries. The key parameters of an assessment of individual resources are briefly discussed next, together with references for the detailed methodology.

## Assessment of Biomass Energy Resources

Biomass energy resources comprise fuelwood, agricultural residues, and animal waste. The resource assessment in this regard generates information about the local availability (or production potential) of different biomass resources on a monthly or annual basis. The resource assessment should also generate information about the proximity of the biomass resource sites and their accessibility to local users. The information could be obtained through a survey of users or stakeholders in the area. The following section discusses the information required to estimate the production potential of fuelwood, agricultural residues, and animal waste using a general approach.

- **Fuelwood.** A map showing the spatial extent of the various types of ground cover and biomass is needed to estimate the production potential of fuelwood. The general techniques of map preparation include low spatial resolution imagery. The estimation of fuelwood availability also requires some ground inventory data for various trees, such as annual sustainable yield, growing stock, area of forest, productivity, density of biomass, and rotation age (Maithel 2009). For details, see Maithel (2009) and Milbrandt and Overend (2008). A number of GIS-based assessments of bioenergy cover fuelwood availability and yields (Gormally et al. 2012, citing Viana et al. 2010; Lovett et al. 2009).
- **Agriculture residues.** The resource assessment must generate information about the monthly or annual production of agricultural residues at

the local level in the EAP area and their effective availability for energy use. For this purpose, the resource assessment needs information such as grain production and residue-to-product ratio. The residue-to-product ratio can be estimated through direct measurement in the field during harvesting. However, crop yield and agriculture residue production depend on seed variety, soil irrigation, and weather (Maithel 2009). For details, see Maithel (2009) and Milbrandt and Overend (2008).

- **Animal waste.** Estimates of the production potential of animal waste for a country or a subnational area can be based on the population of a particular type of animal and the corresponding animal waste productivity factor per head. However, the production of animal waste differs between countries and between regions within a country because of differences in animal size, weight, and feed intake (Maithel 2009). See Maithel (2009) and Milbrandt and Overend (2008) for details of the approach to estimating the production level and availability of animal waste. For some technology options like biogas production, information about the size of cattle ownership of households is also needed to estimate the potential for use of family-size biogas plants. Such information should therefore also be a part of the resource assessment.

## Assessment of Hydropower Resources

An assessment of hydropower resources is necessary to gauge the possibility of using hydropower as an electricity production option. Since the economic potential of hydro resources is site specific, the resource assessment requires information about potential hydropower production sites, such as the economically efficient size of a hydropower plant (in kilowatt or megawatt) and the level of hydroelectric energy generation (in megawatt-hours or gigawatt-hours) at each site, as well as the investment costs associated with the hydropower plants and transmission lines. Therefore, the resource assessment requires information such as site location and proximity from the demand center, site hydrologic data (magnitude and temporal variations in hydro-energy flow pattern over different periods in a year, and net hydraulic head). For a detailed description of the methodology

used in assessing hydropower production potential, see INL (2014), US DOI/BR (2011), CEC (2006), and UK DOECC (2010).

## Assessment of Solar Energy Resources

This resource assessment generates information about solar radiation (kilowatt-hours per square meter per day) over different months of a year in the EAP area. For this purpose, the resource assessment requires site-specific time series solar resource information, along with associated weather data. In particular, it needs annual and seasonal climatological solar radiation maps, meteorological data, mean monthly values of total and opaque cloud cover, aerosol optical depth, precipitable water vapor, atmospheric pressure, total ozone, and surface albedo.

For a detailed description of the methodology used in assessing solar power potential, see the NREL website (<http://www.nrel.gov/rredc/publications.html>), Renné et al. (2008), and Renné et al. (2003). In some countries, a proper solar resource information center already exists to provide data and tools for the solar research team (for details, visit the NREL website [http://www.nrel.gov/rredc/solar\\_resource.html](http://www.nrel.gov/rredc/solar_resource.html)). As mentioned earlier, some international sources, such as SWERA (<http://en.openei.org/apps/SWERA/>), also provide information about renewable energy potential in different countries.

## Assessment of Wind Energy Resources

The resource assessment must provide information about potential wind power generation sites and the level of wind power that could be produced at the sites over different periods in a year. The key parameters needed to assess wind potential at a particular site are wind power class, wind power density, wind speed, wind direction, temperature, and optional parameters (such as solar radiation, vertical wind speed, barometric pressure, and change in temperature with height). However, wind data are site specific and vary according to the location of the wind station, local topography, anemometer height and exposure, type of observation (either instantaneous or average), and recording duration. For a detailed description of

the methods used in assessing wind power potential, see NREL (1997); AWS Truepower (2010); Coppin, Ayotte, and Steggel (2003); and US EERE (<http://energy.gov/eere/wind/wind-resource-assessment-and-characterization>).

## Assessment of Fossil Fuel Resources

The resource assessment compiles information about the availability of fossil fuels and their costs in the country concerned. In most countries, fossil fuels may have to be imported, in which case the resource assessment would be limited to an estimation of the delivery cost (or market price) of fossil fuels in the EAP area.

## Data Requirements

Data required for the assessment of local energy resources include the following categories:

- Production or availability of fuelwood in the area;
- Source of fuelwood supply;
- Distance to be traveled to collect fuelwood, location of the forest or village woodlots and other sources of fuelwood;
- Amount of fuelwood collected per month (or week);
- Amount of agricultural residues (e.g., paddy straw, rice husk, corn) produced by a household;
- Distance to be traveled to collect agricultural residues (for each type of residue);
- Number of cattle owned by each household;
- Amount of animal waste produced by each household;
- Location of potential hydropower generation site or distance from users;
- Local hydropower generation potential;
- Solar energy potential;
- Wind power generation potential and location; and
- GIS platform for determining the location and availability of resources.

# 6 Cost Assessment

## Introduction

In the sustainable energy access planning (SEAP) context, the overall objective of the cost assessment is to determine the cost-effective options for providing access to cleaner-energy sources, the total energy access cost (which includes both energy supply- and demand-side costs). The assessment would provide information about the total investment needed as well as other costs, which are important for energy access program (EAP) development and implementation. It also provides information about the per-unit cost of cleaner energy and the total cost of energy service to a poor household, which can be used to assess the energy burden implication (affordability) of an EAP. In addition, the assessment has the following specific objectives:

- Estimate the incremental cost of providing different levels of access to electricity,
- Estimate the incremental cost of providing access to different levels of cleaner nonelectric energy mainly for end uses like cooking and space heating, and
- Assess the incremental cost of expanding an energy or electricity access program in a country or within a subnational region.

As a cost assessment tool, a cost minimization model is typically needed to determine the most cost-effective energy access option. This chapter first reviews briefly the different cost assessment models in the literature, then describes the proposed cost assessment methodology, gives an illustration of incremental energy access cost, and summarizes the data requirements.

## Review of Cost Assessment Models

There are a number of models in the literature for determining the least-cost options for electricity supply. Models vary in supply planning horizon—a particular year (snapshot year) or a number of years in the future. Some models consider seasonal or daily variations in resource availability patterns (hydro energy, solar, wind, biomass, etc.), and seasonal variations in demand, reliability of supply, etc.; others do not. Models also vary in their spatial considerations and the way they characterize technologies.

The models can be categorized as simulation, equilibrium, top-down, bottom-up, operation optimization, or investment optimization models (Connolly et al. 2010). A simulation model simulates the operation of a given energy system to supply a given set of energy demands, and is operated in some time steps over a year. An equilibrium model takes into account the behavior of supply, demand, and prices in a whole economy or part of an economy with several markets. A top-down model is a macroeconomic tool that takes general macroeconomic data into account in determining growth in energy prices and demand. A bottom-up model identifies the demand and specific technologies, and then the investment requirements. An operation optimization model is a simulation tool that optimizes the operation of a given system. An investment optimization model is a scenario tool that optimizes the investments in new energy resources and technologies (Connolly et al. 2010). Some models combine some of these features. Table 6.1 gives an overview of the tools available in literature for energy system planning and analysis.

In the context of SEAP, the cost assessment model should ideally assess both the supply- and demand-side options at the same time, to minimize the total societal resource

cost of providing access to cleaner-energy services. The model should also be able to consider both decentralized and centralized supply options.

**Table 6.1 Cost Assessment Models for Energy System Planning and Analysis**

Model and Reference	Geographic Area	Scenario Time Frame	Model Type				Investment Optimization	Description
			Simulation	Top-Down	Bottom-Up	Operation Optimization		
AIM/Enduse (NIES 2014)	National, state, regional	No limit			Yes	Yes	Yes	Cost minimization modeling tool for energy planning
EFFECT (CAI 2013)	National	25+ years						Quantifies fuel consumption and GHG emissions
ENACT (IIASA, 2014)	National, regional	2030	Yes	–	–	–	–	Web-based scenario analysis tool which allows assessment of multiple energy access policies
GEOSIM ( <a href="http://www.geosim.fr/uploads/GEOSIM-EN.pdf">http://www.geosim.fr/uploads/GEOSIM-EN.pdf</a> )	Community						Yes	Determines the most cost-effective electricity generation options
HOMER ( <a href="http://homerenergy.com/software.html">http://homerenergy.com/software.html</a> )	Local community	1 year <sup>a</sup>	Yes		Yes	Yes	Yes	Handles grid and off-grid system
LEAP ( <a href="http://www.energycommunity.org/default.asp?action=47">http://www.energycommunity.org/default.asp?action=47</a> )	National, state, regional	No limit	Yes	Yes	Yes		Yes	Modeling tool used to track energy consumption, production, and resource extraction
MARKAL/TIMES (Seebregts, Goldstein, and Smekens, n.d.)	National, state, regional	Up to 50 years		Partly	Yes		Yes	Economic-environmental optimization model for least-cost planning of energy systems
MESSAGE (IIASA 2012b)	Global	50+ years			Yes	Yes	Yes	Used for medium- to long-term energy system planning, energy policy analysis, and scenario development

*continued on next page*

Table 6.1 *continued*

Model and Reference	Geographic Area	Scenario Time Frame	Model Type				Investment Optimization	Description
			Simulation	Top-Down	Bottom-Up	Operation Optimization		
MESSAGE –Access (IIASA, 2012c)	Global	50+ years	–	–	Yes	Yes	Yes	Global scale, multiregion, energy system model used for assessing future transitions in household energy use and the costs of alternative policies; an extension of MESSAGE model
Network Planner ( <a href="http://networkplanner.modilabs.org/docs/index.html">http://networkplanner.modilabs.org/docs/index.html</a> )	Community, national						Yes	Used for least-cost planning for grid, minigrid, and off-grid systems
RETScreen ( <a href="http://www.retscreen.net/ang/version4.php">http://www.retscreen.net/ang/version4.php</a> )	User-defined	Up to 50 years			Yes			Used to determine whether or not a proposed renewable energy, energy efficiency, or cogeneration project is financially viable
REDEO (Yalamas 2005)	Local, community							Handles off-grid systems; used to compare various distributed power generation options
WASP (IAEA 2001)	National, state, regional	Up to 30 years	Yes		Yes		Yes	Expansion plan optimization model for electricity generation

GHG = greenhouse gas.

<sup>a</sup> Tools can simulate only 1 year at a time, but these can be combined to create a scenario of several years.

Source: Authors.

## Proposed SEAP Methodology

The following section discusses the approach proposed in the SEAP framework to provide universal energy access.

### Cost of Providing Electricity Access

Ideally, an integrated energy system model is used to determine the total cost of providing energy services. The

model tries to minimize the total supply- and demand-side cost of providing energy access. The total supply-side cost includes investments in electricity generation technologies, transmission and distribution lines,<sup>10</sup> and fuel, along with the O&M cost of supply-side technologies and resources. The investment cost associated with the local distribution system would depend on a number of factors, such as distance from the substation, size of the conductor, power demand, substation characteristics (including capacity, protection devices, transformer connection, etc.),

<sup>10</sup> Depending on the type of electricity supply system, the estimation of the distribution line cost may also include estimating the cost of minigrid and microgrid distribution. In the case of grid-based power supply, the transmission line cost will involve the cost of extending the grid.

population density, and distance between households (USAID/NRECA, n.d.). For details of the methodology used in estimating distribution line cost, see USAID/NRECA (n.d.) and World Bank (2000).

The total demand-side cost includes upfront cost (cost of devices and initial connection cost) as well as the O&M cost of demand-side devices. The model would minimize the total cost, provided that a number of conditions (or constraints) are met. A major constraint is the satisfaction of peak and off-peak power demand in meeting energy service demand (normally expressed as useful energy). Other constraints are related to limiting energy resource use for electricity generation (in view of seasonal or daily variations in resource availability) and not using any power generation unit beyond its installed capacity. The model may also consider the reliability of electricity supply.

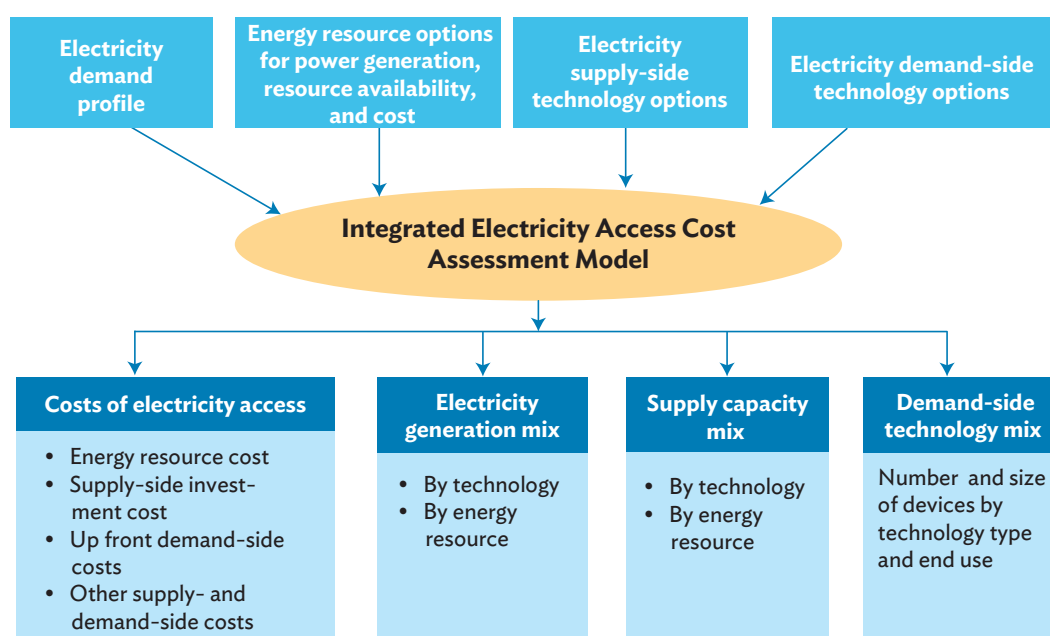
Figure 6.1 presents an integrated methodological framework for assessing the cost of providing electricity access. The integrated cost assessment framework requires an electricity demand profile for different periods of the year, daily and seasonal variations in resource availability, as well as supply- and demand-side technology options. The framework also requires data on the investment, fuel, and O&M costs of

technology options on the supply side, as well as the upfront and O&M costs of devices on the demand-side.

Note that the SEAP framework stipulates the use of an integrated electricity cost assessment model to determine the most cost-effective combination of supply- and demand-side options to provide energy services. In the absence of an integrated electricity cost assessment model, the cost-effective supply- and demand-side options for an access to cleaner-energy services would have to be determined through an iterative process. Energy requirements for different service demands would be determined depending on the types of demand-side technologies considered. For each set of predefined demand-side technologies, there would be different combinations of supply-side technologies with differing capacities to minimize the corresponding supply-side costs. The repetitive and time-consuming determination of cost-optimal supply- and demand-side options for the various demand-side technologies, particularly when many such technologies are considered, is a limitation of this approach.

The integrated cost assessment model has the following output: total electricity access costs (including energy resource cost, supply-side investment costs and up-front

**Figure 6.1 Overall Methodological Framework for Assessing the Cost of Electricity Access**



Source: Authors.

demand-side costs), electricity generation, and capacity mix, by type of technology and energy resource. Use of the cost assessment framework with and without an electricity access program generates corresponding total costs. The difference between the two costs represents the additional cost of an electricity access program.

## Cost of Providing Cleaner Cooking and Heating

A similar approach can be used to estimate the cost of providing cleaner energy for cooking and heating. Such a method of estimation in the case of cooking is described below. The total cost of providing access to cleaner energy for cooking can be expressed as follows (Mainali, Pachauri, and Nagai 2012; Pachauri et al. 2013b):

$$\text{Total Cooking Cost} = \text{Fuel Cost} + \text{Annualized Cooking Technology/Stove Cost} + \text{Inconvenience Cost} \quad (\text{Eq. 6.1})$$

In Equation 6.1, the inconvenience cost captures some of the nonmonetary aspects of the preferences of households in developing countries. It is the cost related to inconveniences associated with obtaining and using certain types of fuels (Pachauri et al. 2013b). Gathering and using fuelwood, for example, involves an inconvenience cost: the time spent and hardship involved in collecting it and the difficulties presented by indoor air pollution from fuelwood burning. Households should take this additional cost into account when deciding which fuels they should use. For the methodological details of calculating inconvenience cost, see Ekholm et al. (2010).

## Incremental Cost of Energy Access

An important component of cost assessment is calculating the incremental cost of providing energy access. The total energy access cost in SEAP includes both supply- and demand-side costs. In addition, this assessment estimates the total incremental cost (covering costs associated with both the supply and demand sides) of providing predefined levels of energy services under an EAP. The assessment can therefore be easily extended to generate information about the incremental costs of providing different levels of energy access to a target population. Furthermore, if an EAP is to

be expanded to cover a wider area or population, the cost assessment allows an estimation of the effect of such an energy access expansion program on the incremental cost of supply of cleaner energy or electricity.

The derivation of an incremental energy access cost curve (IEACC), which provides information about the amounts of energy to be supplied for different levels of energy access and the corresponding incremental costs per unit of energy use, is a major part of the cost assessment. The IEACC helps in ranking the cleaner technologies and resource options in terms of their unit cost of energy supply in providing energy access. Besides the total incremental cost of energy access, the cost assessment activity can also provide information about the incremental cost of energy supply, which forms the basis for deriving a supply-side IEACC for different levels of energy access.

The incremental energy access cost (IEAC) is used for different purposes in SEAP. In one application, the IEAC measures the cost per unit of energy supply when a higher level of energy services per household is considered under an EAP. The resulting information can be valuable. It can show the change in the per-unit energy access cost to households at different levels of energy services, such as those considered in the Global Tracking Framework (GTF) of the Sustainable Energy for All (SE4ALL) program (World Bank/ESMAP and IEA 2013). The IEAC is also used in calculating the cost per unit of energy supply when a larger targeted population is to be provided with energy access at a given level of basic energy services per household. Such a measure of IEAC can give useful information to planners and policy makers about the cost implications of providing energy access to a larger population. Thus, in the first case, the level of basic energy services is different, while the size of the energy access population stays the same; in the second case, the size of the energy access population is different, while the level of basic energy services remains the same.

The following section presents the steps involved in calculating the IEAC of providing electricity and clean cooking or heating services.

## Calculation of Incremental Energy Access Cost

The IEAC, in the case of an electricity access program, measures the cost per unit of electricity used that will meet a

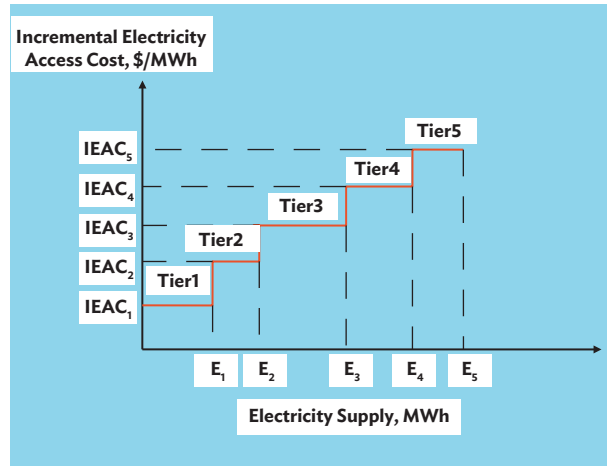
targeted level of electricity service demand (e.g., for lighting, charging of batteries for mobile phones, rice cooking, space cooling) of energy-poor households (households that consume electricity below the targeted levels). The IEAC can be calculated with the following steps:

- Identify the number of households whose present levels of electricity service demand is below the target levels (energy-poor households) and estimate the electricity required to meet the service demand with the set of electrical device technologies considered.
- Estimate the total electricity demand of all users (including both energy-poor and non-energy-poor households, as well as the productive and other sectors) in the target area without an EAP. In this case, let the electricity demand in different years during the planning horizon of  $T$  years be  $E_{0,p}, E_{0,2}, \dots, E_{0,T}$ .
- Determine the least-cost options for meeting the electricity demand  $E_{0,t}$  in the targeted area in the business as usual (BAU) case (without the EAP). Let the present value of total cost of meeting the electricity demand (including both supply- and demand-side costs) in the BAU case be  $TC_0$ .
- Define the target levels of electricity service demand per household and the associated device technologies under the EAP  $i$ . Estimate the total electricity demand of all users, including both poor and nonpoor households as well as the productive and other sectors, under EAP  $i$ . In this case, let the electricity demand in different years during the planning horizon of  $T$  years be  $E_{i,1}, E_{i,2}, \dots, E_{i,T}$ .
- Determine the least-cost options of meeting the electricity demand during the planning horizon in the targeted area under the EAP. Let the present value of the total cost of energy access (i.e., the sum of supply- and demand-side costs) in this case be  $TC_i$ .
- The incremental cost of electricity access under the EAP  $i$  is expressed as<sup>11</sup>

$$IEAC_i = \frac{(TC_i - TC_0)}{\sum_t (E_{i,t} - E_{0,t}) / (1+r)^t} \quad (\text{Eq. 6.2})$$

An IEACC can then be obtained by plotting IEAC values at different levels (or tiers) of electricity access. Figure 6.2 shows the IEACC when the level of energy services is

**Figure 6.2 Incremental Electricity Access Cost with Increasing Tiers of Electricity Supply**



MWh = megawatt-hour.

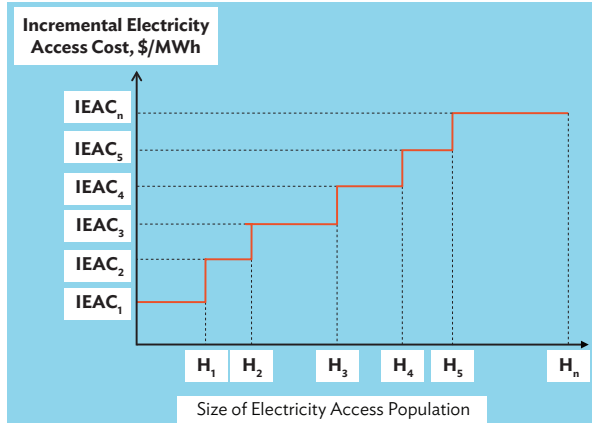
Source: Authors.

increased for a given size of the energy access population. In the figure, note that the values on the horizontal axis show the total amount of electricity to be supplied in an area under different levels (or ‘tiers’) of energy service considered per household under the EAP (e.g.,  $E_1$  represents the total amount of energy to be supplied to the population in an area under energy access level 1 (or “Tier 1”);  $E_2$  is the total amount of energy to be supplied under energy access level 2 (or “Tier 2”) and so on. The values on the vertical axis of the figure represent the corresponding IEAC.

In Figure 6.2,  $E_1, E_2, E_3, E_4$ , and  $E_5$  represent the total electricity demand at different target levels of basic energy services to households under an EAP, with  $E_1 < E_2 < E_3 < E_4 < E_5$  in a target year. Note that  $E_1$  here represents the total electricity demand corresponding to the lowest target level of electricity access, while  $E_5$  corresponds to the highest electricity access target level. Suppose that the total cost of supplying increasing levels of basic energy services ( $E_1, E_2, E_3, E_4$ , and  $E_5$ ) to a given household population is  $TC_1, TC_2, TC_3, TC_4$ , and  $TC_5$ , respectively. Then,  $IEAC_1$ , corresponding to the incremental cost

<sup>11</sup> In Eq. 6.2,  $r$  denotes the discount rate. If the EAP  $i$  in a particular year is considered, then the incremental cost can be expressed as  $IEAC_i = (TC_i - TC_0) / (E_i - E_0)$ .

**Figure 6.3 Incremental Cost of Electricity Access with Increasing Size of Electricity Access Population**



MWh = megawatt-hour.  
Source: Authors.

associated with the lowest electricity access target, would be calculated as

$$IEAC_1 = \frac{(TC_1 - TC_0)}{(E_1 - E_0)} \quad (\text{Eq. 6.3})$$

where

$E_0$  (which is less than  $E_1$ ) = total electricity demand, and  
 $TC_0$  = total cost of meeting demand in the business as usual (BAU) case (i.e., without an EAP).

$IEAC_2$  for the next-higher level of electricity access target is calculated as

$$IEAC_2 = \frac{(TC_2 - TC_1)}{(E_2 - E_1)} \quad (\text{Eq. 6.4})$$

$IEAC_3, IEAC_4, IEAC_5$ , etc., are similarly calculated.

Figure 6.3 illustrates another application of IEACC. The figure shows the IEAC values, when an energy access program with a given level of cleaner energy services per household is extended to serve higher levels of population (or larger geographic areas). In the figure,  $H_1, H_2, H_3$ , etc. represent the different levels of household population when additional geographic areas are considered for cleaner energy supply under energy access programs. Such type of IEAC analysis would be of particular interest when the assessment of the effect of expanding the geographic coverage of an energy access program is desired.

It should be noted that one can also calculate the incremental supply-side costs of electricity access and derive an incremental supply-side electricity access cost curve in a similar way as described above (only difference being that the supply-side cost of electricity would be used in the IEAC calculation instead of the total supply and demand side cost in using electricity).

## Calculation of Incremental Cost of Access to Clean Energy for Cooking

The incremental cost of access to cleaner energy for cooking measures the incremental cost per unit of cleaner energy used (including the cost of the device). It can be estimated as follows:

- Estimate the amount of traditional biomass fuel used by households for cooking on inefficient stoves and calculate the corresponding life-cycle cost (including fuel and device costs).
- Estimate the amount of cleaner fuel  $j$  to be used by households for cooking under an EAP and calculate the corresponding life-cycle cost (including fuel and device costs).
- Calculate the incremental cost of access to cleaner energy (ICACE) option  $j$  for cooking by using the equation

$$ICACE_j = \frac{(LCOE_j - LCOE_b)}{(E_j - E_b)} \quad (\text{Eq. 6.5})$$

where

$LCOE_j$  = life cycle cost of using cleaner-energy option  $j$  in cooking (including all costs of fuel and devices using fuel  $j$ );

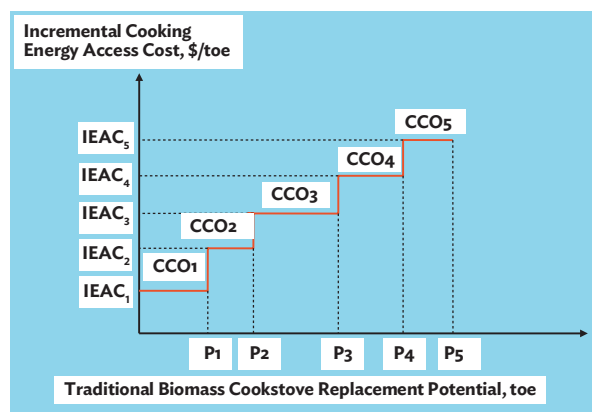
$LCOE_b$  = life-cycle cost of traditional biomass-based cooking using inefficient stoves (including all costs of biomass fuel and traditional stoves);

$E_j$  = energy consumption using energy option  $j$ ; and

$E_b$  = energy consumption using traditional biomass-based fuel for cooking on inefficient stoves.

Figure 6.4 shows the incremental cost of providing access to clean energy for cooking. In the figure,  $IEAC_1, \dots, IEAC_5$  represent the incremental cost of providing access to clean-energy cooking options 1 to 5;  $CCO_1, \dots, CCO_5$  represent clean energy cooking options 1 to 5; and  $P_1, \dots,$

**Figure 6.4 Incremental Cost of Access to Clean Energy for Cooking**



CCO = cleaner cooking option, toe = ton of oil equivalent.

Source: Authors.

$P_5$  represent the potential biomass saving through the replacement of traditional biomass cookstoves. Note that in the figure  $P_1$  represents the total amount of biomass consumption avoided by cleaner cooking option 1 (CCO<sub>1</sub>),  $P_2$  is the total amount of biomass consumption avoided by the combination of cleaner cooking options 1 and 2 (i.e., CCO<sub>1</sub> and CCO<sub>2</sub> combined) and so on. In some cases,  $P_1, \dots, P_5$  can even represent the cumulative percentage replacement of traditional or inefficient cookstoves instead of the amount of total amount of biomass replaced.

## Applications of the Incremental Energy Access Cost, with Case Studies

To illustrate possible applications of the IEAC case studies of two rural administrative areas in Pyuthan

district of Nepal—one for the IEAC of electricity access and another for the IEAC of access to cleaner energy for cooking—are presented in this section.<sup>12</sup>

### Incremental Energy Access Cost: The Case of Damri Village Development Committee in Nepal

Damri, a village development committee (VDC)<sup>13</sup> in the Pyuthan district of Nepal, had around 882 households and a total population of about 4,808 in 2014. Around 46% of these households have no access to any electricity, while the rest have access to electricity supplied by solar home systems. Compact fluorescent lamps (CFLs) are mainly used for lighting in all the electrified households. Around 10% of the households that use CFLs also use incandescent lamps. Radio and mobile phones are the only other devices that used electricity in Damri. The VDC, 10.2 kilometers away from the central power grid, has a site for microhydro power generation of up to 17 kilowatts (kW), besides biomass-based and solar photovoltaic-based power generation options, among other available local resources.

For this study, three different electrification scenarios (cases 1, 2, and 3) were considered in addition to the base case. In the base case, the electricity demand of all the households in 2017 was assumed to follow the present pattern of electricity consumption. Under cases 1, 2, and 3, electricity demand in all the households was upgraded at least to the level specified for tiers 1, 2, and 3, respectively, of the GTF (World Bank/ESMAP and IEA 2013).<sup>14</sup> Table 6.2 gives the end-use technology details considered for each tier. The demand of households whose energy consumption already exceeds the threshold for the specified tier was assumed to grow as the economy grew. The survey results showed that, of the total electrified households in Damri, only about 54% use tier 1 level electricity and that no electrified households consume electricity beyond that level.

<sup>12</sup> The analysis in this section are based on both primary and secondary data. The primary data were obtained from households' surveyed in each of the 49 village development committees (VDCs) of the Pyuthan district in February–March 2014; secondary data and statistics were obtained from reports published by government and nongovernment organizations in Nepal.

<sup>13</sup> A village development committee in Nepal is a smaller local government area, one of several, under an administrative district.

<sup>14</sup> That is, each energy-poor household is to be provided with 3 kWh of electricity in tier 1, 66 kWh in tier 2, and 285 kWh in tier 3.

**Table 6.2 Appliance Mix and Total Electricity Requirement under the Multitier Framework for Electricity Access**

Item	Tier 1	Tier 2	Tier 3
<b>Appliances</b>	Radio	Radio	Radio
	Task lighting	Task lighting	Task lighting
	Phone charger	Phone charger	Phone charger
		General lighting	General lighting
		Air circulator (fan)	Air circulator (fan)
		Television	Television
			Food processor
			Rice cooker
Total Electricity Requirement per Year per Household (kWh)	3	66	285

kWh = kilowatt-hour.

Source: World Bank/ESMAP and IEA (2013).

**Table 6.3 Electricity Demand under Various Cases for 2017 (kWh)**

Household Category	Base Case	Case 1 (Tier 1)	Case 2 (Tier 2)	Case 3 (Tier 3)
Energy-Poor	0	1,248	28,274	122,521
Non-Energy-Poor	11,531	11,531	32,739	141,867

kWh = kilowatt-hour.

Source: Authors.

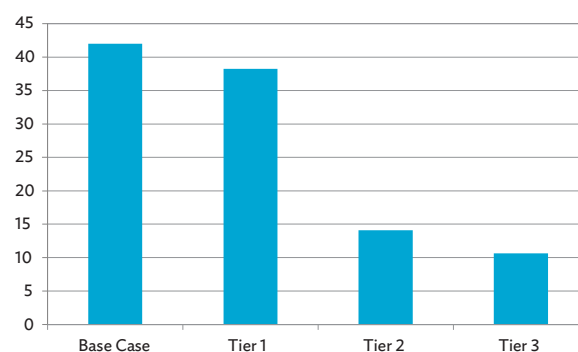
Table 6.3 shows the projected electricity demand in 2017 of energy-poor and non-energy-poor households in Damri in the different cases.<sup>15</sup>

Different options for supplying electricity in the VDC were analyzed using the electricity supply cost analysis model HOMER.<sup>16</sup> The cost of supplying electricity to

Damri under the base and energy access cases in 2017 is shown in Table 6.4. According to the table, hydropower is the most cost-effective option in all three cases. In case 2, batteries, which can store excess power from the microhydro power plant during off-peak hours, are used along with inverters and the microhydro plant to provide power during peak demand hours. However, in case 3, where all the households were assumed to have tier 3 electricity access, available hydropower capacity would be insufficient to meet the total electricity demand; as a result, biomass gasifier power plants would also be used.

The average cost of electricity under the various cases is shown in Figure 6.5. From the figure, it can be seen that there is a sharp drop in the average cost of electricity in the higher tiers. The cost of electricity is NRs42/kWh in the base case and decreases to NRs38/kWh in tier 1. The relatively higher cost under these cases is due to the low utilization of transmission and distribution capacity. At a higher level of household demand in case 2, microhydro, plus battery and inverter, is found to be cost effective despite the higher average cost of electricity supply partly because of the higher utilization of the transmission and distribution capacity. Finally, the average cost of electricity decreases further in tier 3 because of the full

**Figure 6.5 Average Cost of Electricity Supply for Damri, 2017 (NRs/kWh)**



kWh = kilowatt-hour.

Source: Authors.

<sup>15</sup> In this study, households consuming energy below the tier 1 level were regarded as energy-poor households.

<sup>16</sup> Originally, short for "Hybrid Optimization Model for Electric Renewables." However, according to the National Renewable Energy Laboratory of the US Department of Energy, which developed the model, HOMER can now model nonhybrid systems such as simple photovoltaic and diesel systems. See [www.homerenergy.com](http://www.homerenergy.com)

**Table 6.4 Power Plant Capacity Mix, Electricity Generation, and Costs in Different Cases, 2017**

	Case	Technology Type				
		Microhydro	Solar PV	Biomass	Battery (20Ah)	Inverter
Installed Capacity (kW)	Base case	2.25				
	Case 1	2.38				
	Case 2	12.00			1 <sup>a</sup>	1
	Case 3	17.00	70.00	10.00	100 <sup>a</sup>	50
Energy Generation Capacity (kWh) <sup>b</sup>	Base Case	29,582				
	Case 1	31,326				
	Case 2	145,171				
	Case 3	204,946	106,636	6,290		
Investment Cost (NRs) <sup>c</sup>	Base Case	4,687,480				
	Case 1	4,734,280				
	Case 2	8,197,840			7,500	80,000
	Case 3	9,997,482	9,450,000	2,954,546	750,000	4,000,000
Total Cost (NRs)	Base Case	6,185,524				
	Case 1	6,247,281				
	Case 2	10,907,065				
	Case 3	27,152,028				

Ah = ampere-hour (battery rating based on discharge), kW = kilowatt, kWh = kilowatt-hour.

<sup>a</sup> Number of batteries.

<sup>b</sup> Represents the energy generation capacity of a power plant, and may exceed the actual demand.

<sup>c</sup> \$1 = NRs100.

Source: Authors.

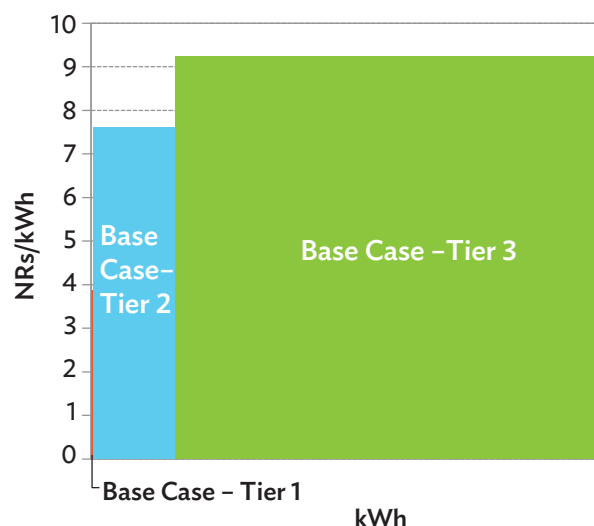
use of the microhydro plant capacity and the higher use of transmission and distribution line capacity due to the high power demand in this case.

Figure 6.6 shows the incremental supply-side cost of energy access (IEACS) of moving from the base case to different levels of electricity access in cases 1, 2 and 3 (i.e., Tier 1, Tier 2 and Tier 3). The horizontal axis in the figure shows the incremental level of electricity supply under an electricity access case, while the values in the vertical axis represent the corresponding IEACS per kWh. As can be seen, in the case of Damri, the incremental supply-side cost of electricity access would be increasing with the

level of access. Note that the total increase in electricity supply due to energy access program under tier 1 relative to the energy consumption level in the base case is too small to be noticed in the figure.

The supply-side-related incremental electricity access costs of moving to each successively higher level of electricity access in Damri is shown in Figure 6.7. The per-unit supply-side cost of electricity access increases with the level of access. Note as in Figure 6.6 that the total increase in electricity supply due to energy access program under tier 1 relative to the energy consumption level in the base case is too small to be noticed in Figure 6.7.

**Figure 6.6 Supply-Side-Related Incremental Energy Access Cost for Damri (Considering Increments in Demand Relative to the Base Case) (NRs/kWh)**



kWh = kilowatt-hour.

Source: Authors.

**Figure 6.7 Supply-Side-Related Incremental Electricity Access Cost for Damri (Considering Successive Increments in Demand at the Different Levels of Access) (NRs/kWh)**



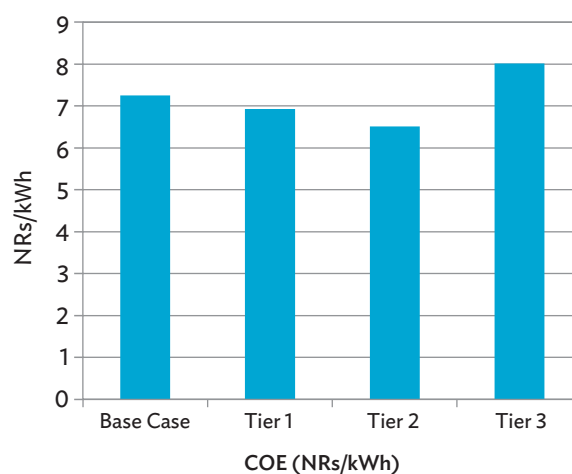
kWh = kilowatt-hour.

Source: Authors.

## Incremental Electricity Generation Cost

In the preceding section, the average cost of electricity supply (NRs/kWh) in Figure 6.5 included the costs of transmission, distribution and generation. The average cost of electricity generation for different tiers of electricity access is presented in Figure 6.8. It should be noted that the average cost of electricity supply is consistently decreasing in Figure 6.5; however, similar pattern is not exhibited by the average cost of generation; as can be seen in Figure 6.8, it decreases up to tier 2 and increases in tier 3 case. The decreasing average electricity supply cost with the increase in the level of electricity access in Figure 6.5 is because of the fixed transmission and distribution cost. In the case of average cost of electricity generation, the increase in the cost in tier 3 case in Figure 6.8, occurs because the hydropower plant capacity would be inadequate and, as a result, additional capacity based on more expensive option would have to be used to meet the increased level of demand. The incremental cost of electricity generation to meet the increment in demand from base case to different tiers of electricity access is shown in Figure 6.9. Similarly, the incremental costs of electricity generation for providing the successively higher tiers of electricity access are shown in Figure 6.10. As can be seen, the incremental generation cost is found to increase with the level of electricity access in both cases. It should be noted

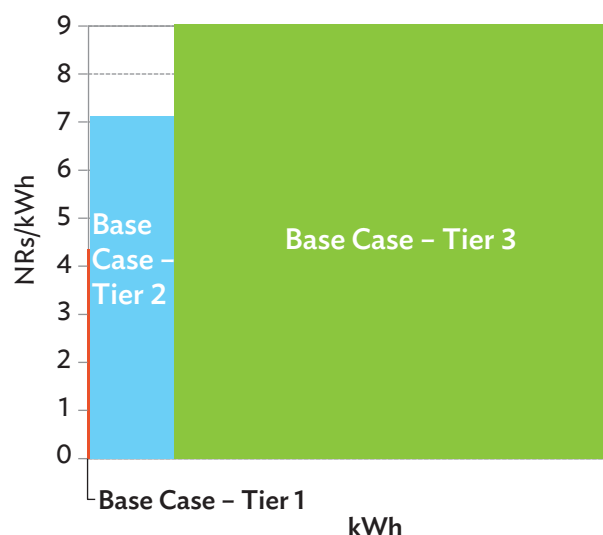
**Figure 6.8 Average Cost of Electricity Generation, 2017 (NRs/kWh)**



kWh = kilowatt-hour.

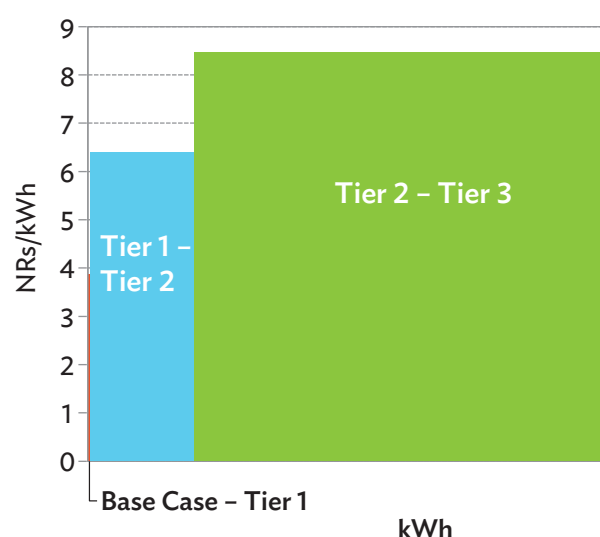
Source: Authors.

**Figure 6.9 Incremental Cost of Electricity Generation (Considering Increments in Demand Relative to the Base Case) (NRs/kWh)**



kWh = kilowatt-hour.  
Source: Authors.

**Figure 6.10 Incremental Cost of Electricity Generation (Considering Successive Increments in Demand at the Different Levels of Access) (NRs/kWh)**



kWh = kilowatt-hour.  
Source: Authors.

here that the total increases in electricity supply from the base case level to tier 1 level are too small to be noticeable in Figures 6.9 and 6.10.

### Incremental Energy Access Cost for Cooking: The Case of Liwang Village Development Committee in Nepal

Liwang is a VDC in Pyuthan district of Nepal. According to a household survey conducted in Liwang in 2014, traditional biomass supplies the fuel needed to meet around 95% of the energy demand for cooking; improved biomass provides the rest. At the same time, around 64% of the households in the VDC had more than two heads of cattle, with a total biogas potential of 197,665 kgoe in 2014. Biogas could meet around 69% of the cooking energy demand among households that own at least three heads of cattle. Considering the cattle ownership required to run a family-size biogas plant, the maximum potential biomass saving through the replacement of

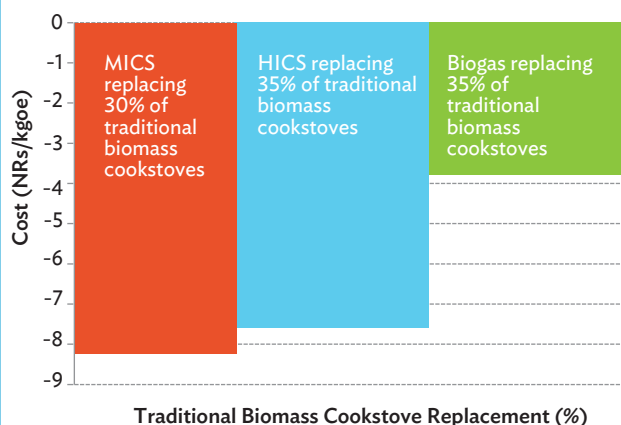
traditional biomass cookstoves in Liwang with cleaner-energy cookstoves was considered to be 35% in this study. Figure 6.11 shows the IEACC for cooking in Liwang VDC in 2017 if only biomass-based cleaner options are used to replace traditional biomass-based cooking—moderately efficient biomass cookstoves (MICS)<sup>17</sup> replacing 30%, and, highly efficient biomass cookstoves (HICS),<sup>18</sup> and the biogas cookstoves replacing 35% each. The values on the horizontal axis in the figure represent the percentage replacement of biomass use in traditional cookstoves with various efficient biomass- or biogas-based cookstoves for cooking. The values on the vertical axis represent the corresponding incremental costs. It is interesting to note that, as shown in Figure 6.11, the replacement of traditional biomass cookstoves with MICS, HICS, or biogas cookstoves involves negative IEAC. In other words, all three cleaner-energy options are in fact cost saving.

If all cooking only with biomass is considered impractical, more diversified cleaner-energy options, including nonbiomass-based options, should be considered as

<sup>17</sup> The study considers the efficiency of moderately efficient biomass cookstoves to be 20% (considering improved mud cookstoves) (AEPC 2008).

<sup>18</sup> The study considers the efficiency of highly efficient biomass cookstoves to be 30% (considering rocket stoves) (AEPC 2008).

**Figure 6.11 Incremental Cooking Energy Access Cost Curve for Liwang with Only Cleaner Biomass Options, 2017**



HICS = highly efficient biomass cookstoves, kgoe = kilogram of oil equivalent, MICS = moderately efficient biomass cookstoves.

Source: Authors.

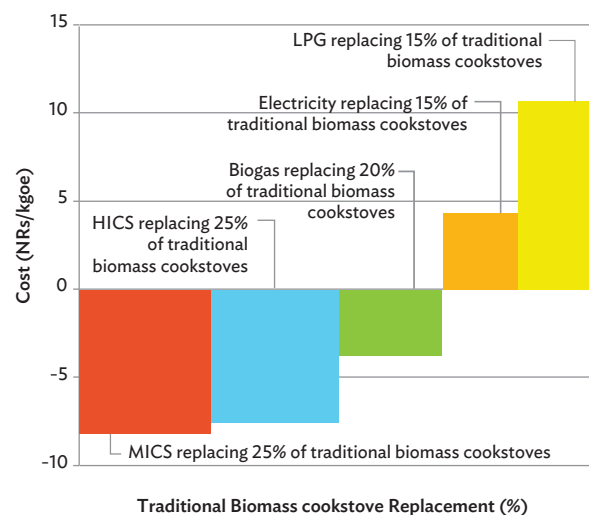
replacements for traditional biomass cookstoves. For example, a scenario is considered in which MICS replace 25% of traditional biomass cookstoves, HICS replace another 25%, biogas based cooking replaces 20%, and electric- and LPG-based cooking replaces 15% each. Figure 6.12 shows the IEACC for cooking in 2017 in Liwang VDC in this case. The figure shows that replacing traditional biomass cookstoves with MICS, HICS, or biogas would in fact be a cost-saving option (note the negative IEAC values), while using electricity or LPG for cooking would increase the costs significantly.

## Data Requirements

The main data required for cost assessment include:

- Investment cost of technology;
- O&M costs;
- Upfront cost of devices;
- Economic potential of energy resource options for power generation;

**Figure 6.12 Incremental Cooking Energy Access Cost Curve for Liwang with Biomass and Nonbiomass Cleaner Options, 2017**



HICS = highly efficient biomass cookstoves, kgoe = kilogram of oil equivalent, MICS = moderately efficient biomass cookstoves.

Source: Authors.

- Characteristics of electricity demand, e.g., daily load profile;
- Available head (meters), discharge rate (liters/second), and flow rate (liters/second) for hydropower plant;
- Available plant size (kW);
- Annual generation (kWh);
- Monthly solar radiation (kWh/square meter/day);
- Monthly wind speed for wind power plant (meters/second);
- Discount rate;
- Economic life;
- Efficiencies of devices;
- Prices of fuels;
- Fuel consumption;
- Total number of households;
- Number of households, by fuel type; and
- Average energy consumption per household, by fuel type.

# 7 Benefit Assessment

## Introduction

Providing cleaner-energy access to all can have several benefits—better education, a cleaner environment (less local and regional pollution), better health, better energy security services, enhanced energy equality, less greenhouse gas (GHG) emissions, less time spent collecting fuelwood, higher productivity, more employment opportunities, and better access to lighting, entertainment, and modern media and communication.

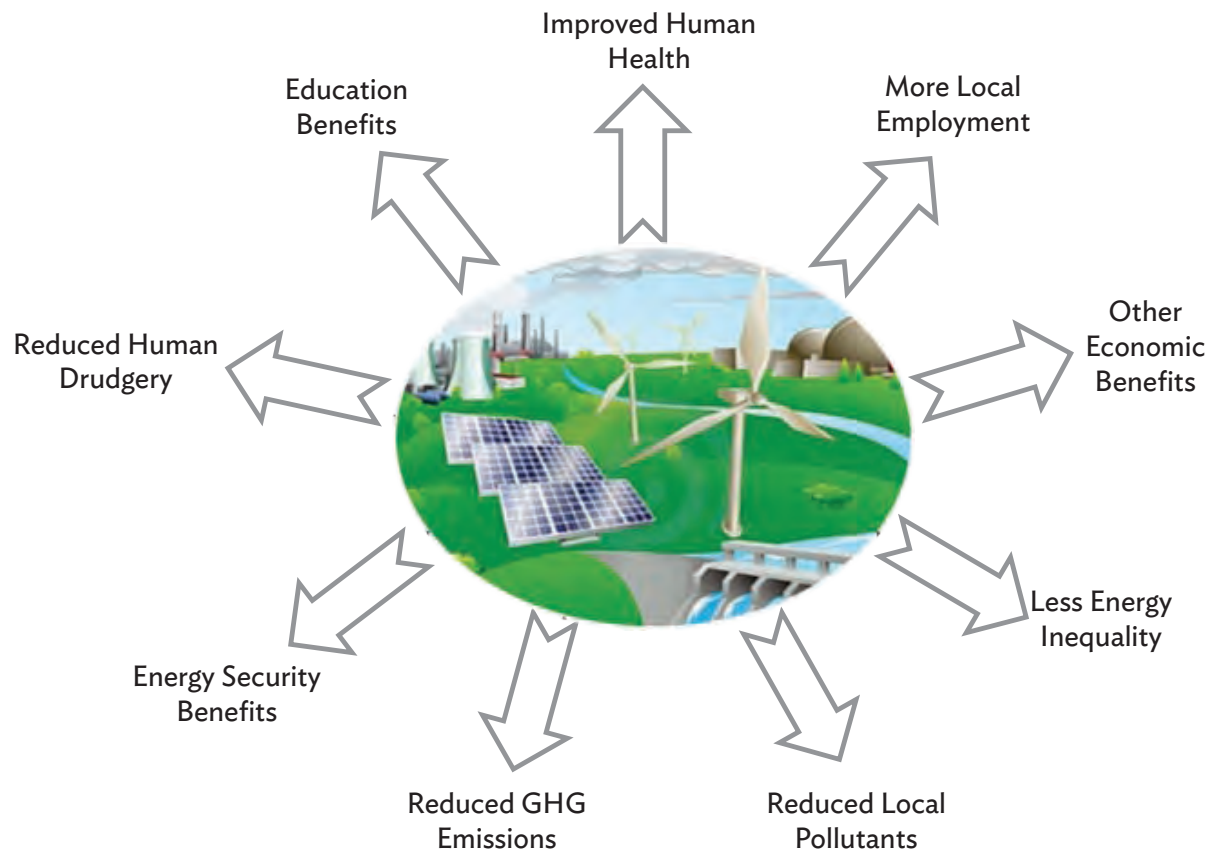
This chapter discusses the various benefits of EAPs and the different approaches studies have taken in assessing the potential benefits and the data requirements.

## Potential Benefits of an Energy Access Program

The potential benefits of a cleaner-energy access program are illustrated in Figure 7 and summarized below.

- Improved lighting with better access to electricity, which replaces kerosene, candles, and other traditional lighting sources in rural areas and provides brighter and more reliable lighting.
- Educational benefits mainly associated with improved lighting due to electricity access, which makes extended hours of study possible and enables the achievement of better educational outcomes over time. Television can also be an educational tool, especially for women and children with increased electricity access at home.
- Health benefits related to improved hygiene as households are better able to store food properly, indoor air pollution is reduced, and electrified medical facilities and clinics provide better health care.
- Entertainment and communication benefits associated with the use of electricity to operate devices such as radios, television sets, video players, and mobile phones.
- Higher productivity for household members, who can spend more time each day in productive activities because domestic activities take up less time with the help of labor-saving electrical appliances, due to better-quality lighting at night.
- Improved safety for households, as a result of the reduced risk from fires by kerosene lamps or fuelwood stoves.
- Increased savings following a switch from kerosene or dry-cell batteries to cheaper and cleaner energy sources such as electricity, and the pursuit of income-generating activities including small businesses (restaurants, barber shops, sewing services, etc.), which can stay open and serve customers longer because of improved energy access.
- Environmental benefits, including reduced local (indoor and outdoor) and regional air pollution due to access to cleaner-energy services.
- More effective climate-change mitigation through a decrease in GHG emissions.
- Increased energy security through reduced dependence on imported energy or fuels and a more diversified energy resource mix.
- Less energy inequality through more equitable distribution of energy.

Figure 7 Potential Benefits of Providing Energy Access



GHG = greenhouse gas.

Source: Authors.

## Approaches to Benefit Assessment

### General Approaches

Not all of the foregoing benefits of EAPs can be valued in monetary terms. Economists generally use three different approaches to benefit assessment (Hutton and Rehfuss 2006): (i) human capital approach, (ii) revealed preference approach, and (iii) contingent valuation approach.

**Human capital approach.** This approach measures a person's economic value, which can increase through

education, better health, or improved productivity. It values change on the basis of labor-market prices; for example, better health reduces absenteeism and raises productivity. However, this approach has been criticized by welfare economists as it does not reflect changes in individual welfare resulting from activities that improve the quality of life. Another shortcoming of this approach is its low regard for the benefits of people outside the labor force such as children and the retired population.

**Revealed preference approach.** This approach is based on economic values derived from human behavior, as revealed through observation, and uses techniques such

as the hedonic pricing method,<sup>19</sup> the travel cost method,<sup>20</sup> time allocation models, or the estimation of consumer surplus (the difference between the maximum amount that an individual is willing to pay for a good and the price actually paid for it). Prices that can be observed in the marketplace are used to measure the value of goods or services. These methods value actual consumer choices and also include welfare effects, which are the strength of these methods. For example, the consumer surplus resulting from a switch to electrical lighting is the amount by which the cost of a given amount of lighting using traditional energy (e.g., candles or kerosene) exceeds the cost of electric lighting of the same quantity. The surplus or economic benefit is calculated when the initial amount of energy for which the consumer is willing to pay is, in fact, acquired at a lower price (Hutton and Rehfuess 2006; Legros, Rijal, and Seyedi 2011).

**Contingent valuation method.** This method is based on the concept of hypothetical survey methods that elicit people's willingness to pay for goods in a hypothetical market. This method is also referred to as a "stated preference" method, as people are asked directly to state the value of the goods or what they would do or pay to obtain them, while the revealed preference method observes actual behavior (Hutton and Rehfuess 2006).

## Specific Approaches

The assessment of specific benefits associated with EAPs may adopt the survey-based approaches discussed below. It should be noted in this regard that, since survey data are specific to a given point in time, the same set of data cannot be used to quantify both present and future benefits. But comparisons made at a particular time between areas with cleaner-energy access and areas without such access can indicate the likely extent of future benefits.

**Time savings.** The opportunity cost of labor can be used to attach a monetary value to time saved through a reduction in household drudgery, an increase in

productive hours during the day, the avoidance of battery-charging trips, etc. ESMAP (2002) uses this approach to value time saved in terms of the average wage estimated from survey data. The study assumes that people would use the time saved to earn income. But this may not always be the case in actual practice: time saved may also be used for nonproductive purposes. The value of time spent on unpaid productive activities would require the application of a shadow wage equal to the wage that a person could earn in paid productive activities or to the cost of replacing the unpaid labor with paid labor at the current market wage. Habermehl (2007) suggests that 50% of the time saved could be considered as time used for productive activities and a monetary value derived from the mean monthly income of a household in the locality could then be assigned to the productive time period. The World Bank (2008), on the other hand, emphasizes the valuation of time at its opportunity cost, depending on the person whose time is being valued, and the use of the average income per capita, rather than the average wage, as the opportunity cost to allow for the distribution of tasks in a household among its members.

**Increased productivity.** According to ESMAP (2002), the increase in productivity might be measured by the market value of the increased output. The study estimates the benefits of electricity for a home business by placing a value on the number of additional hours spent running the business. The additional time is valued at the average wage in the area. Benefits then have to be adjusted to reflect the proportion of households owning a home business. To assess new businesses, the difference between electrified and nonelectrified households in the relative number of households running a home business must be estimated. When feasible, comparing income from similar productive activities with and without electricity is the easiest and most cost-effective way of assessing impact. These activities should be in the same village, or at least in areas with similar access to roads, markets, and microcredit and with similar living standards.

<sup>19</sup> The hedonic pricing method seeks to find a relationship between the characteristics of a good and the prices of marketed goods. It is most commonly applied in real estate economics or consumer price index calculations (Hutton and Rehfuess 2006).

<sup>20</sup> The travel cost method estimates economic use values associated with ecosystems or sites by using time and travel cost expenses, such as prices, to gain access to a specific site (Hutton and Rehfuess 2006).

**Consumer surplus.** The World Bank (2008) uses consumer surplus as a measure of benefits from electrification programs. This approach is not focused on capturing a specific type of benefit; rather, it may reflect several benefits from an EAP. The consumer surplus represents the benefits received by a household from acquiring energy at a lower price than it was actually willing to pay. Consumer surplus can also be described as the amount by which the cost of a given amount of energy from a traditional energy source exceeds the cost of the same quantity of energy supplied with electricity. The economic benefit of lighting is the amount by which the cost of a given amount of traditional lighting, e.g., candles or kerosene, exceeds the cost of electric lighting of the same quantity (compared in terms of price and lumen-hours available). The calculation of the consumer surplus depends on the shape of the demand curve. A linear demand curve overestimates the benefits; using a nonlinear demand curve or taking only a percentage of the surplus estimated with a linear demand curve is therefore preferable. One option is to integrate income elasticity within the demand curve. For example, EmCON (2008) defines demand in kilowatt-hours ( $Q_{kWh}$ ) as a function of the price per kilowatt-hour based on the relationship given by

$$Q_{kWh} = \theta_i \times P^{\mu_i} \times I^{\alpha_i} \quad (\text{Eq. 7.1})$$

where

$P$  = price of electricity per kilowatt-hour;  
 $I$  = household income;  
 $\mu_i$  = (negative) price elasticity of demand;  
 $\alpha_i$  = income elasticity of demand, and  
 $\theta_i$  = a constant.

For more details about the consumer surplus technique of assessing the benefits from electrification, see World Bank (2008).

**Lower health care costs.** The reduction in the annual health care costs of each household using electricity, according to Legros, Rijal, and Seyedi (2011), is the basis for determining the health-cost savings (the health benefit). Habermehl (2007) estimates the number of working hours recovered due to a reduction in the inability to work, visits to health centers and nursing time, then assigns a monetary value (shadow wage) to 50% of the time saved due to better health. Saved costs for health are based on

the reduced annual costs of health care per household using electricity. The health improvements can be traced to better hygiene, reduced indoor air pollution, and improved health care provision at electrified medical facilities and clinics. A similar approach could be used in the case of other cleaner energy sources.

The health cost savings can be quantified through the following relation:

$$\Delta CS_i = CH_{NEA} - CH_{EA} \quad (\text{Eq. 7.2})$$

where

$\Delta CS_i$  = cost savings from fewer hospital and health care visits as a result of energy access program  $i$ ;

$CH_{NEA}$  = costs incurred for hospital and health care visits due to the use of traditional or less energy-efficient fuels; and

$CH_{EA}$  = costs incurred for hospital and health care visits after the energy access program.

**Better education.** Education benefits are estimated through general questionnaires designed to collect data on (i) the increase in the number of study hours, and (ii) the improvement in income prospects, expressed in monetary terms, due to higher educational attainment achieved with better access to electricity. Incremental earnings, assumed to occur from ages 16 to 60, are discounted back to their present value. This present value is then converted to a monthly annuity (World Bank 2008).

The benefits of electricity access in the education sector can be quantified as follows:

- **Longer study hours.** The increase in the number of study hours due to improved lighting with electricity access can be estimated as

$$\Delta SH = SH_{EH} - SH_{NEH} \quad (\text{Eq. 7.3})$$

where

$\Delta SH$  = increase in study hours;

$SH_{EH}$  = study hours in households with electricity access; and

$SH_{NEH}$  = study hours in households without electricity access.

- **Higher future earnings.** As mentioned above, survey-based approaches are time constrained and will not provide information about future years of employment. But comparing a nonelectrified district or area with electrified areas where conditions are similar will provide an indication of future earnings. The following relation could be used for calculating the increase in future earnings due to the EAP:

$$\Delta FE = FE_{EA} - FE_{NEA} \quad (\text{Eq. 7.4})$$

where

$\Delta FE$  = increase in future earnings due to a clean-energy access program;

$FE_{EA}$  = future earnings due to an energy access program, based on a comparison between electrified and nonelectrified districts or areas with similar conditions; and

$FE_{NEA}$  = future earnings without clean-energy access, based on the present earnings of households without electricity access.

**Cleaner environment.** The environmental benefits include a reduction in indoor and outdoor air pollution, which could also be associated with health improvements. The reduction in air pollution could be quantified on the basis of the following relation:

$$\Delta AP_{ji} = AP_{ji} - AP_{j,0} \quad \text{Eq. 7.5}$$

where

$\Delta AP_{ji}$  = reduction in indoor and outdoor air pollution type  $j$  with energy access program  $i$ ;

$AP_{ji}$  = total indoor and outdoor air pollution type  $j$  with energy access program  $i$ ; and

$AP_{j,0}$  = total indoor and outdoor air pollution type  $j$  without an EAP.

The total air pollution type  $j$  from energy-using devices under an energy access program  $i$  can be estimated as

$$AP_{ji} = \sum_{k,l} Fuel_{k,l,i} * EF_{j,k,l,i} \quad \text{Eq. 7.6}$$

where

$AP_{ji}$  = total air pollution type  $j$  under energy access program  $i$ ;

$Fuel_{k,l,i}$  = quantity of fossil fuel type  $k$  used in end-use device type  $l$  under energy access program  $i$ ;

$EF_{j,k,l,i}$  = emission factor for air pollution type  $j$  when fuel type  $k$  is used in device type  $l$  under energy access program  $i$ .

**Less GHG emissions.** Power generation based on renewable energy in an EAP and the use of energy-efficient devices for cooking and other end uses would avoid the GHG emissions that would result without an EAP. GHG emissions with and without an EAP can be compared to estimate the reduction in GHG emissions with an EAP. The emission reduction can be expressed algebraically as

$$\Delta GHG = GHG_i - GHG_0 \quad (\text{Eq. 7.7})$$

where

$\Delta GHG$  = reduction in GHG emissions with an EAP;

$GHG_i$  = total GHG emissions with energy access program  $i$ ; and

$GHG_0$  = total GHG emissions without an EAP.

Total emissions  $GHG_{ji}$  of GHG type  $j$  from energy-using devices under an energy access program  $i$  can be estimated as

$$GHG_{ji} = \sum_{k,l} Fuel_{k,l,i} * EF_{j,k,l,i} \quad (\text{Eq. 7.8})$$

where

$Fuel_{k,l,i}$  = quantity of fossil fuel type  $k$  used in end-use device type  $l$  under energy access program  $i$ ; and

$EF_{j,k,l,i}$  = emission factor for GHG type  $j$  when fuel type  $k$  is used in device type  $l$  under energy access program  $i$ .<sup>21</sup>

Total GHG emission under energy access program  $i$  is calculated as

$$GHG_i = \sum_j GHG_{ji} * GWP_j \quad (\text{Eq. 7.9})$$

<sup>21</sup> See IPCC (2006) for values of emission factors.

where

$GHG_{ji}$  = total emissions of GHG type  $j$  from energy-using devices under an energy access program  $i$ ; and

$GWP_j$  = global warming potential of GHG type  $j$ .<sup>22</sup>

**Greater energy security.** The energy security benefit can be assessed through the use of more than one indicator. A key indicator of energy security is the share of imported energy in total energy consumption in a specific area under study. The size of the reduction the share of imported energy or fuels indicates the degree of improvement in energy security with an EAP. Another indicator of energy security is the extent of diversification in the mix of energy resources: the more diversified the energy supply mix, the higher the level of energy security (if everything else is kept constant). The level of diversification of the energy resource mix can be measured through the Shannon–Wiener index (Grubb, Butler and Twomey 2006).<sup>23</sup>

**Reduced energy inequality.** To measure energy inequality, there may be a comparison of the energy consumption at the household level across countries or across regions, districts, or communities within a country. For purposes of energy access planning, such information could help in identifying areas that should receive priority in EAP development and implementation. An ex ante comparison of the energy inequality index with and without the planned implementation of an EAP would indicate the reduction in energy inequality in an area due to the planned EAP. The index used in literature to measure inequality in energy distribution is an energy Gini coefficient. It is derived from an energy Lorenz curve based on the distribution of energy consumption across the population (Jacobson, Milman and Kammen 2005; Pereira et al. 2011; Ramji et al. 2012). This approach has been adopted in the present study. Details of methods of measuring energy inequality are given in Appendix 6.

## Data Requirements

The data required for the benefit assessment include:

- Average wage or salary (or income per capita);
- Total population;
- Total number of households;
- Total number of households running a business;
- Number of electrified and nonelectrified households;
- Price of electricity per kilowatt-hour;
- Cost of fuels;
- Technology costs;
- Household size for each settlement category (energy-poor or non-energy-poor households);
- Investment expenditure;
- O&M expenditure;
- Expenditure per household;
- Amount of fuel required;
- Types and amounts of fuel currently imported;
- Number of energy-using appliances owned by households ;
- Number of education, health, and community institutions in each settlement category;
- Life of power generation technologies and cooking options;
- Average energy consumption of households and total energy consumption in the area;
- Electricity consumption of households;
- Number of connections per income group;
- Global warming potential of GHGs;
- Emission factors of pollutants;
- Average number of study hours in electrified and unelectrified areas; and
- Number of hospital visits made in electrified and unelectrified areas.

<sup>22</sup> See IPCC (2006) for values of GWP of different GHGs.

<sup>23</sup> The Shannon–Wiener index (SWI) can be expressed as

$$SWI = - \sum_i X_i \ln X_i$$

SWI denotes the Shannon–Wiener index and  $X_i$  represents the share of energy resource (or fuel)  $i$  in total energy supply. Note that the higher the value of SWI, the more diversified the energy supply mix would be.

# 8 Sustainability Assessment

## Introduction

Different options can be used to provide energy access, but some options are more sustainable than others. An energy resource, though cheaper, may not necessarily be environment friendly and may not be easily available in the long run. An energy access technology option may have a low initial cost but its operation and maintenance (O&M) cost could be high. Some options may be more difficult to manage locally than others. To identify a relatively more reliable, cost-effective, affordable, environmentally friendly, locally manageable, and socially acceptable technology option, the sustainability of energy access options must be assessed.

To a large extent, the assessment has to do with the underlying technology and supply options. For example, in electricity access planning, different decentralized off-grid power supply (e.g., biomass, solar, wind, hydro, thermal) and grid-based power supply options are assessed. The sustainability assessment in the SEAP framework screens technology alternatives for energy access to identify a set of relatively more sustainable options.

The concept of sustainability encompasses the economic, technical, social or ethical, environmental, and organizational or institutional dimensions of sustainable development. The sustainability assessment of energy access options is therefore a multidimensional analysis, with each dimension represented by a number of related indicators and their corresponding measures. The result is a composite measure (or index) of sustainability for each option, whose values provide relative measures of sustainability.

The following sections in this chapter discuss the different approaches to sustainability assessment in

the literature and describe alternative sustainability assessment methodologies.

## Approaches to Sustainability Assessment

There are various approaches to sustainability assessment in literature. Some are used purely for technology assessment (Maxim 2014; Afgan, Carvalho, and Hovanov 2000; Musango and Brent 2011); others, to assess the EAPs and relevant energy technologies (Iliskog 2008; Iliskog and Kjellström 2008; Bhattacharyya 2012). All the approaches involve defining the dimensions of sustainability and their related indicators. Studies, however, differ in the number and types of dimensions of sustainability. Iliskog (2008), Iliskog and Kjellström (2008), and Bhattacharyya (2012), for example, consider five dimensions—technical, economic, social or ethical, environmental, and organizational or institutional (Figure 8.1)—whereas Maxim (2014) and Mainali et al. (2014) leave out the institutional dimension and studies done by the UN (2001) and the International Atomic Energy Agency (IAEA 2005) exclude the technical dimension. Afgan, Carvalho, and Hovanov (2000) consider only the resource, environment, social, and economic dimensions, but include some technical characteristics in the resource dimension.

The five sustainability assessment dimensions defined in literature are as follows:

- **Technical.** According to Iliskog (2008), the technical dimension of sustainability is concerned with maintaining the energy services during the economic life of a technology considered for an EAP. In the sustainability assessment, the

technical dimension deals with the technical or resource characteristics of an option and includes information such as the efficiency of a device, transmission and distribution losses, capacity factor, life, reliability, quality of supply, ease of O&M, resource availability, and the ability of electricity generation technologies to respond to changes in demand.

- **Economic.** The economic dimension pertains to the characteristics of technology and energy access options—their cost-effectiveness and cost recovery potential, net energy import dependence, and capital intensity, as well as the operating cost burden imposed on the user (affordability). This dimension also deals with the financial support needed for the deployment of the technology, and the contribution of the technology to income-generating activities (Bhattacharyya 2012). The economic dimension is related to the reduction in the consumption of expensive fuels and covers life-cycle costs. Cost is an important consideration in selecting a particular energy technology or EAP. Some technologies may be a prohibitive choice for low-income groups because of their high initial and life-cycle costs. Solar technology, for instance, besides its high initial cost, requires regular maintenance, replacement of batteries, and a backup system to provide continuous power supply (Clough and Rai 2012). As mentioned in Ilskog (2008), the economic dimension deals with the development of an EAP, “in carrying its own costs on a the short, medium, and long term basis,” taking subsidies, operation and management costs, reinvestment costs, etc., into account.
- **Social.** This dimension is related to the social acceptability of technology or energy access options and their impact on social well-being. Apart from resource availability, accessibility, and household affordability, social acceptability, or the technology preferences of the public (Maxim 2014), is a key factor in the choice of fuels and devices by a household. The social dimension also includes the potential of an option for job creation and the reduction of human drudgery, and its effects on women and children. According to Ilskog (2008), the social or ethical dimension is the most complex among the five dimensions and is a principal value underlying sustainable development.

- **Environmental.** The environmental dimension is concerned with reducing the negative environmental impact of a technology or energy access option on users and the society, given its contribution to local and global pollution, health damage, and other environmental degradation. In the case of electricity access options, the environmental dimension also deals with the effect of electrification and the reduced use of kerosene for lighting and cooking on the indoor environment. The annual rate of change in forest area due to the deployment of the technology and the use of land over the life of the power generation unit are other environmental considerations.
- **Organizational or institutional.** The organizational or institutional dimension pertains to the survival of the implementing organization, and its ability to facilitate the effective performance of the EAP (Ilskog 2008). The energy access program, technology, or facility must be locally manageable and controllable, as indicated by the degree of local ownership, the availability of skilled staff, and the ability of the organization to protect consumers and investors and to monitor and control the energy systems (Bhattacharyya 2012).

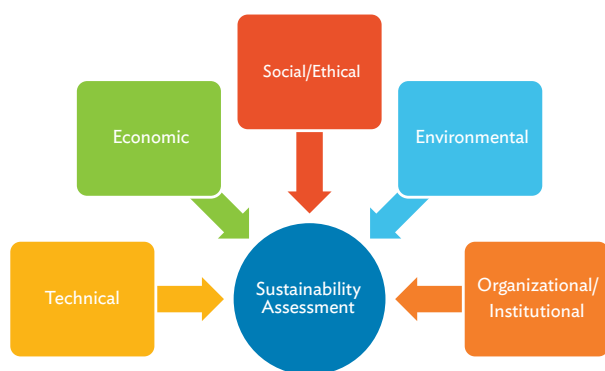
The choice of indicators has an important role in defining the dimensions of sustainable development. Clear indicators would support rational decisions about the design and organization of future energy access projects. A predetermined and carefully structured questionnaire is generally used to collect the relevant data. But it is important to note here that some indicators can find their place in more than one of the five dimensions of sustainable development.

The sustainability assessment helps in the comprehensive ranking of energy access technology options based on their compatibility with the sustainable development of the economy. Economic cost does not always dictate the choice of technology; other considerations, such as effects on local pollution and GHG emissions, resource availability, ease of use and maintenance, local technology production capacity, and availability, may also be taken into account. The selection may depend as well on the projected reduction in deforestation, creation of

local employment, time savings, monetary savings, improvements in living conditions, and other factors (Clough and Rai 2012).

All the approaches to sustainability assessment involve estimation of a composite index, which measures the sustainability of an energy technology or energy access option. The index goes by different names: energy sustainability index (Mainali et al. 2014), general sustainability index (Afgan, Carvalho, and Hovanov 2000), total score (Bhattacharyya 2012), total utility score (Maxim 2014). Studies also, differ in their method of calculating the sustainability index. Mainali et al. (2014) and Doukas et al. (2012) use principal component analysis; Afgan and Carvalho (2008), the general indexes method; Bhattacharyya (2012), the simple averaging approach; Maxim (2014) and Wang et al. (2009), the multiattribute utility method. Demirtas (2013), on the other hand, uses the analytic hierarchy process. Among the approaches, the simple averaging approach used by Bhattacharyya (2012) is the simplest way of computing the sustainability index for individual technology options. It should, however, be noted that there may be some variations in the ranking of energy technologies or energy access options based on these different approaches.

**Figure 8.1 Dimensions of Sustainability Assessment**

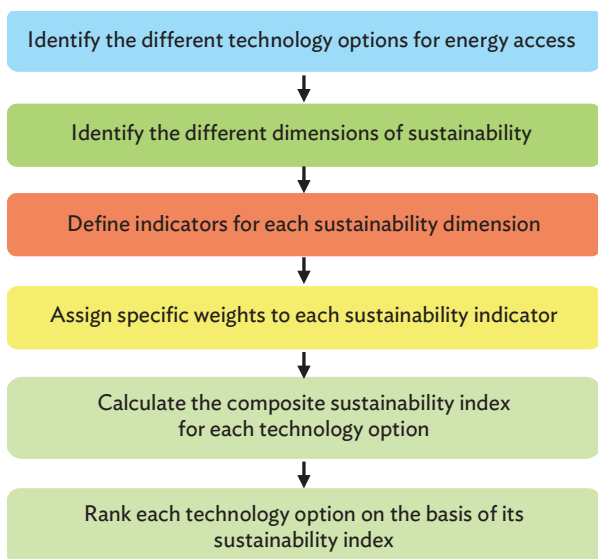


Source: Authors.

## Methodologies for Sustainability Assessment

Figure 8.2 presents the major steps involved in the sustainability assessment of energy access technology options. As stated earlier, the assessment mainly covers five dimensions: technical, economic, social, environmental, and organizational or institutional. The major indicators for each of these sustainability dimensions, compiled from different studies in the literature (Afgan and Carvalho 2008; Bhattacharyya 2012; Iliskog 2008; Iliskog and Kjellström 2008; Mainali et al. 2014; Maxim 2014), are presented in Table 8. Maxim (2014) assigns a “utility value” to each indicator for a dimension, on the basis of a review of the related literature. The scores (or ratings) of each indicator are obtained through a questionnaire survey of different respondents. To compensate for any lack of knowledge of issues related to the options, respondents are also asked

**Figure 8.2 Overall Methodological Flowchart for Sustainability Analysis**



Source: Authors.

for a subjective rating of their own level of familiarity with electricity (or energy) sector on a scale of 1 (for “not at all familiar”) to 10 (for “very familiar”); this rating represents the familiarity score of the respondent. A weighted arithmetic average of the ratings for each indicator (the “indicator weight”) is then calculated using the respondents’ familiarity scores as weights. The method also involves the calculation of a utility score for each indicator. The individual utility score of indicators are multiplied by their corresponding indicator weights which are then summed up to obtain the total utility score for a technology option (see Maxim 2014 for details).

The approach used by Bhattacharyya (2012) involves the following steps. First, the range of scores to be used as “measures” (or specific weights) for the various indicators is defined, and actual scores for the indicators are obtained from a stakeholder survey.<sup>24</sup> Second, an average value is calculated for each indicator on the basis of survey data. Third, the average scores of all indicators related to each dimension (which represent their scores for that dimension) are calculated. Finally, the overall aggregate score of an energy access option is the sum of the scores of all its dimensions. Bhattacharyya (2012) thus implicitly assumes that all dimensions have equal weight.

**Table 8 Sustainability Indicators and Measures**

Dimension	Indicator	Measure (Units)	Value of Measure	Applicability
<b>Technical</b>	Efficiency with which input energy is transformed into useful output energy	Ratio of consumption of final energy to the demand of users for useful energy, or ratio of output to input (%)	- High - Medium - Low	Electricity generation and end-use technologies
	Transmission and distribution (T&D) losses	T&D line losses as a percentage of electricity generation	- High - Medium - Low	Electricity generation technologies
	Ability to respond to demand	Ability to respond to peak demand and ensure overall grid stability in the long term	- Yes, rapid - Yes, slow - No	Electricity generation technologies
	Capacity factor	Ratio of actual electricity produced over a period of time to the maximum theoretical electricity that could have been produced if the plant had been running at full capacity	- High - Medium - Low	Electricity generation technologies
	Life	Life of the technology (years)	- High - Medium - Low	Electricity generation and end-use technologies
	Ability to provide multiple end-use services	Could the technology be used for multiple applications (e.g., cooking along with water heating and space heating, as for traditional biomass cookstoves)?	- Yes - No	End-use technologies

*continued on next page*

<sup>24</sup> In the absence of a stakeholder survey, Bhattacharyya (2012) obtained the scores for the indicators for each option from a brainstorming meeting of experts and stakeholders.

Table 8 continued

Dimension	Indicator	Measure (Units)	Value of Measure	Applicability
	Reliability of energy supply or technology	Is the technology or resource able to meet the demand?	- Yes - No	Electricity generation and end-use technologies
		How often is the new technology maintained in a year?	- Once - Twice - 3 times - More than 3 times	Electricity generation and end-use technologies
		On average, how many hours of electricity supply do users receive from their primary electricity supply source each day?	- Less than 4 hours - 4 hours - More than 4 hours	Electricity generation technologies
		On average, how many times do users face unscheduled supply interruptions from the electricity supply technology in a week?	- Once - Twice - 3 times - More than 3 times	Electricity generation technologies
		On average, how long is each unscheduled electricity supply interruption?	- Less than an hour - 1 hour - 2 hours - More than 2 hours	Electricity generation technologies
	Ease of operation and maintenance	If the new technology can be used or operated easily, then the technology is acceptable	- Very easy - Easy - Not easy	Electricity generation and end-use technologies
	Frequency of maintenance	If the new technology requires more maintenance service, then the technology is less acceptable	- High - Medium - Low	Electricity generation and end-use technologies
	Availability	Ease of availability of cleaner technology	- Not easy - Very easy - Easy	Electricity generation and end-use technologies
<b>Economic</b>	Levelized cost	Annuitized cost of producing energy over the life of the unit	- High - Low	Electricity generation and end-use technologies
	Capital cost	Initial cost of cleaner-technology options	- High - Low	Electricity generation and end-use technologies
	Operation and maintenance (O&M) cost	O&M cost of cleaner-technology options	- High - Low	Electricity generation and end-use technologies
	Electricity use per capita	Ratio of total final electricity consumption to total population (kWh per capita)	- High - Medium - Low	Demand side

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Table 8 continued

Dimension	Indicator	Measure (Units)	Value of Measure	Applicability
	Share of renewable energy in electricity generation	Share of renewable energy generation in total electricity supply (%)	- High - Medium - Low	Electricity generation technologies
	Net energy import dependence	Ratio of energy imports to total primary energy supply (%)	- High - Medium - Low	
	Share of household income spent on fuels and electricity (affordability)	Ratio of household income spent on fuels and electricity to total household income (%)	- Less than 10% - 10% - More than 10%	
	Financial support needs	If the adoption of new technology requires high financial support, then the technology may not be acceptable	- High - Medium - Low	
Social/Ethical	Job creation	Job-years of full-time employment created over the entire life of the unit (no. of paid hours per kWh produced over the life of electricity generation technologies)	- High - Medium - Low	Electricity generation and end-use technologies
	Share of population without electricity	Ratio of population without electricity to total population (%)	- High - Medium - Low	
	Share of population without clean energy	Ratio of households (or population) using traditional solid fuels for their cooking and other household energy uses to total households	- High - Medium - Low	
	Disparity in electricity distribution	Ratio of electricity use of lower quintile to electricity use of upper quintile	- High - Medium - Low	Electricity generation technologies
	Disparity in clean-energy distribution	Ratio of clean-fuel use of lower quintile to clean-fuel use of upper quintile	- High - Medium - Low	
	Public preference (acceptability)	Preference of public for the deployment or use of a technology	- High - Medium - Low	Electricity generation and end-use technologies
	Usability among the poor	If usability among the poor is high, then technology is acceptable	- High - Medium - Low	End-use technologies

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Table 8 continued

Dimension	Indicator	Measure (Units)	Value of Measure	Applicability
	Reduction in human drudgery	If the adoption of the energy access program or technology option has high potential to reduce human drudgery, then acceptable	- High - Medium - Low	Electricity generation and end-use technologies
	Reduction in adverse effects on women and children	If the adoption of the energy access program or technology option has high potential to reduce human drudgery, then acceptable	- High - Medium - Low	Electricity generation and end-use technologies
<b>Environment</b>	Contribution to reduction in indoor air pollution	Percentage reduction in indoor emissions due to use of efficient cooking and heating technologies	- High - Medium - Low	End end-use technologies
	Annual rate of change in forest area	Extent of forestland (%)	- Increase - Decrease	Electricity generation and end-use technologies
	Land use	Land used over the entire life of the power generation unit (for fuel extraction, processing and delivery, construction, operation and decommissioning, and other uses)	- More - Less	Electricity generation technologies
	Impact of household air pollution from energy use	Disability-adjusted life years (DALYs) per 1000 persons	- High - Low	End-use technologies
	Improvement in health	Reduction in frequency of hospital visits  Productivity loss due to illness	- High - Medium - Low	End-use technologies
<b>Organizational/ Institutional</b>	Need for skilled staff	Percentage share of skilled staff	- High - Medium - Low	Electricity generation and end-use technologies
	Availability of maintenance service at the local level	If maintenance service is not available locally, then the new technology is not acceptable	- Available - Not available	Electricity generation and end-use technologies
	Capacity of local maintenance service	If maintenance service personnel are not available locally or if the capacity of the maintenance personnel to fix the problem is poor, then the new technology is not acceptable	- Very poor - Poor - Satisfactory - Good	Electricity generation and end-use technologies
	Ability to protect consumers	Involvement of local users' representatives in management and their techno-economic expertise	- High - Medium - Low	Electricity generation and end-use technologies

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Table 8 continued

Dimension	Indicator	Measure (Units)	Value of Measure	Applicability
<b>Organizational/ Institutional</b>	Ability to protect investors	Involvement of investors' representatives in management and their financial and managerial expertise	- High - Medium - Low	Electricity generation and end-use technologies
	Ability to monitor and control energy systems	Complexity of energy system monitoring and control, and availability of competent experts	- High - Medium - Low	Electricity generation and end-use technologies

kWh = kilowatt-hour.

Sources: Afgan, N. H., and M.G. Carvalho, 2008. Sustainability Assessment of a Hybrid Energy System. *Energy Policy* 36 (8): 2903–2910; Bhattacharyya, S. C. 2012. Energy Access Programmes and Sustainable Development: A Critical Review and Analysis. *Energy for Sustainable Development* 16: 260–271; Iliskog, E. 2008. Indicators for Assessment of Rural Electrification: An Approach for Comparison Apples and Pears. *Energy Policy* 36: 2665–2673; Iliskog, E., and B. Kjellström. 2008. And Then They Lived Sustainably Even After? Assessment of Rural Electrification Cases by Means of Indicators. *Energy Policy* 36: 2674–2684; Mainali, B., S. Pachauri, N. D. Rao, and S. Silveira. 2014. Assessing Rural Energy Sustainability in Developing Countries. *Energy for Sustainable Development* 19: 15–28; Maxim, A. 2014. Sustainability Assessment of Electricity Generation Technologies Using Weighted Multi-criteria Decision Analysis. *Energy Policy* 65: 284–297.

## Data Requirements

The input data needed for the sustainability analysis include:

- Total population in the district or area under study;
- Number of households or population connected to electricity;
- Average number of inhabitants per household (including adults and children);
- Number of households or population using solid fuels for cooking and heating;
- Electricity use by different income group;
- Clean fuels use by different income group;
- Total electricity consumption in the district or area under study;
- Share of renewable energy in total electricity supply (off-grid);
- Total household income;
- Amount of household income spent on fuels and electricity;
- Types and amount of energy imported;
- Types and amount of fuel consumed for cooking and heating;
- Total primary energy supply;
- Transmission and distribution losses of electricity;
- Changes in forest area;
- Devices/technologies available in the geographic area such as
  - Improved biomass cookstoves,
  - Biogas plants,
  - Kerosene stoves,
  - LPG stoves,
  - Kerosene lamps and types of such lamps,
  - Solar home systems,
  - Electric lamps and their wattage, and
  - Water heating devices (electric or nonelectric, such as solar or traditional)
- Availability of repair and maintenance service providers for the different devices/technologies;
- Price of electricity being paid;
- Cost of stove per different types;
- Price of fuel (fuelwood, animal waste, agricultural residue, kerosene, LPG);
- Stability of fuel price;
- Durability of present and new technology;
- Reliability of present and new technology;
- Proportion of the time spent to collect a particular fuel (e.g., fuelwood);

- Different types of fuel used (diversity of energy mix per household to know whether the fuel use per household is concentrated to a single source of energy);
- Share of different energy sources in household energy consumption;
- Ready availability of fuel;
- Monthly expenditure on fuel;
- Number of hours electricity supply received each day and during evening hours; and
- Duration and frequency of supply interruptions.

# 9 Affordability Assessment

## Introduction

The ability of the poor to use modern energy services is a major consideration of sustainable energy access plans and programs. Availability and affordability are not the same thing when it comes to modern (cleaner) energy. Affordable access to electricity, for example, is limited not only to connecting households to an electricity distribution system but also to knowing whether the households can afford to use the acceptable minimum level of electricity services (e.g., lighting). Even the least-cost electricity supply option from the perspective of the society may not be affordable to poor households.

The main objective of the affordability assessment is to determine the amount that poor and nonpoor households can afford to pay for electricity and modern cooking fuels. The assessment determines the increase in household energy burden due to a cleaner-energy access program. It also provides crucial information about the size of energy-poor households and the level of support measures (e.g., subsidies, financing support) required to make the acceptable minimum level of basic cleaner-energy services affordable to all.

This chapter first describes the different situations in which energy could be unaffordable. Then it discusses the key methods for assessing the affordability of basic energy services. Finally, it goes into the level of financial support (subsidies) that would make basic energy services affordable to the energy poor.

## Different Forms of the Affordability Problem

According to Kessides et al. (2009), there are three different types of consumers:

- The absolutely poor, who cannot afford the minimum quantities of services and must therefore be provided with income support;
- Households that, perhaps because of outdated technologies (which may be less energy efficient), are “overconsuming” electricity and other energy services, and require an investigation into the specific reasons for the overconsumption as well as corrective policies; and
- Households that are “underconsuming” electricity and other energy services because of nonmonetary constraints, such as improper connections, or are unserved. These households must be differentiated from those that are underconsuming because of tight budget constraints, and policies that will help to relax the constraints in both cases must be worked out.

As Kessides et al. (2009) emphasize, it is necessary to differentiate between (i) those who are not connected to the energy supply network because they cannot afford it, (ii) those who can afford it but choose not to be connected, and (iii) those who cannot get a connection as they live in a neighborhood unreached by the service. Among the households that are not connected to the energy supply service, it is important to identify those that are in areas covered by the service

but choose not to be connected either because they find the service too expensive or they would have problems paying bills in the future. Even among households that are connected, it is necessary to distinguish those that underconsume because of absolute poverty from those that underconsume because of nonmonetary constraints. Affordability may also be an issue for some households that are overconsuming because of specific needs (e.g., illness) or because of obsolete technologies (e.g., inefficient lighting, cooking, or heating systems). Identifying the source of the problem would help in designing appropriate policies to make energy services more affordable (Kessides et al. 2009).

## Approaches to Affordability Assessment

Affordability of energy means the extent to which households can purchase enough energy for their subsistence needs. According to Foster and Tre (2000), the minimum acceptable threshold must be defined externally, on the basis of what is required to perform basic lighting, cooking, and heating functions. These authors define subsistence energy consumption by looking at the actual energy consumption of a reference group that is believed to be living in a subsistence conditions, e.g., with a total income or consumption close to the extreme poverty line. The affordability index could then be expressed as the proportion of households whose energy consumption exceeds the subsistence threshold (Foster and Tre 2000).

The purchasing power of households, based on income or consumption expenditure, is the best overall indicator of welfare. A traditional monetary indicator of welfare, widely used in the electricity development literature, is the proportion of household income or expenditure devoted to energy. A high share of energy in the total household expenditure is considered an indication of an “unacceptable economic burden” of meeting energy requirements (Foster and Tre 2000). High consumption because of large household size or low efficiency of device used could explain the high share of energy expenditure. Other reasons could be the high unit price of energy or exceptionally low income.

Based on the review of literature, two methods—the “energy burden approach” and the “residual income approach”—are proposed for assessing energy affordability in the SEAP framework. Either one can be used to measure affordability, depending on data availability. As can be seen below, the energy burden approach is relatively simple and requires less information than the residual income approach.

## The Energy Burden Approach

In this approach, the energy burden—the percentage of income that is used to pay energy bills and the costs of energy-related devices and their operation—is calculated to measure affordability.<sup>25</sup> The energy burden of a household type  $j$  ( $EB_j$ ) (when households are categorized according to level of income or energy use) in a period is calculated as

$$EB_j = \frac{P_i E_i + DC_i + OC_i}{I_j} \quad (\text{Eq. 9.1})$$

where

$EB_j$  = energy burden of household (HH) type  $j$ ;

$E_{ij}$  = quantity of energy type  $i$  used by HH type  $j$ ;

$P_i$  = price of energy type  $i$ ;

$DC_i$  = cost of device using energy type  $i$ ;

$OC_i$  = other charges associated with the use of energy type  $i$  (including O&M and initial connection costs) by HH type  $j$ ; and

$I_j$  = income of HH type  $j$ .

For example,  $EB_0$  is the maximum acceptable share of energy expenditure in household income for a household to have the minimum acceptable level of basic energy services. If the energy burden of household type  $j$  ( $EB_j$ ) is higher than  $EB_0$ , then households of type  $j$  are considered to be facing a problem of affordability. The difference between  $EB_j$  and  $EB_0$  would show the increase in the energy burden beyond the maximum acceptable energy expenditure, and therefore the level of support needed to make access to cleaner-energy options affordable. The method assumes that there is already a predefined value of the maximum acceptable level of energy burden ( $EB_0$ ), above which energy

<sup>25</sup> Based on <http://www.opportunitystudies.org/energy-affordability/>

access is considered “unaffordable.”<sup>26</sup> There is, however, no universally agreed value for the maximum acceptable level of energy burden. It has to be determined as an energy policy variable following a detailed, country-specific analysis. Another issue of concern related to the energy burden approach is the generally underestimated share of monetary expenditure on energy and the seemingly lower energy burden in areas where there is use of “free” fuels such as collected biomass. Although biomass collection involves opportunity costs (mostly for women collecting wood), such costs are not reflected in the calculation of the energy burden (Winkler et al. 2011).

In many cases, besides the increase in the total energy burden associated with an EAP, the high upfront costs of cleaner-energy appliance and electricity connection could pose a more serious barrier to the affordability of the program. Assessing the severity of such a barrier entails estimating the burden imposed on a household by

calculating the total upfront costs of the EAP (hereafter known as “energy device cost burden” [EDB]). The energy device cost burden can be expressed as

$$EDB_{ij} = \frac{TDC_i}{I_j} \quad (\text{Eq. 9.2})$$

where

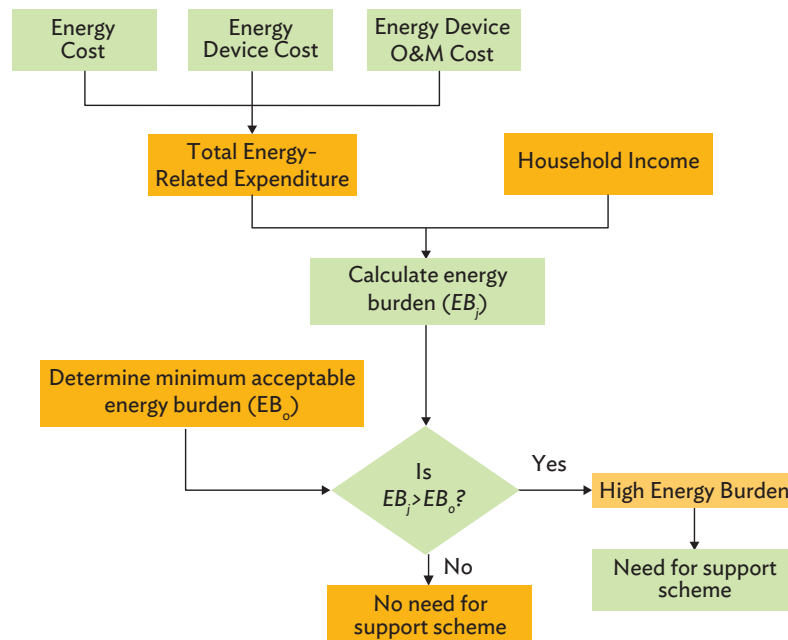
$EDB_{ij}$  = energy device cost burden of energy access program  $i$  on household group  $j$ ;

$TDC_i$  = total upfront cost incurred by an average household in group  $j$  to switch to energy access program  $i$ ; and

$I_j$  = average income of household group  $j$ .

Figure 9.1 shows the steps involved in measuring affordability using the energy burden approach.

**Figure 9.1 Measuring Affordability Using the Energy Burden Approach**



O&M = operation and maintenance.

Source: Authors.

<sup>26</sup> As defined by the UK Department of Trade and Industry (DTI), “a fuel poor household is one that cannot afford to keep adequately warm at reasonable cost.” A fuel-poor household is most widely defined as a household that needs to spend more than 10% of its income on all fuel use and to heat its home to an adequate standard of warmth. This standard of warmth is generally defined as 21°C in the living room and 18°C in the other occupied rooms—the temperature recommended by the World Health Organization (Winkler et al. 2011). The German international cooperation agency GIZ has set its minimum standard of energy affordability: expenditures for energy should not exceed 10% of household income or require more than 10% of the working hours of a household member (Practical Action 2012).

## The Residual Income Approach

This approach, basically an assessment of the affordability of basic energy services to a household, compares the household's residual income (the amount remaining after all expenditures on nonenergy goods and services are deducted from the total household income) with the level of expenditure on basic energy services.<sup>27</sup> A household is deemed to have energy affordability problems if its residual income is not enough to pay for the basic minimum level of energy services. Kessides et al. (2009) take a similar approach in assessing “public utility induced poverty” and the affordability of the minimum level of goods other than public utilities. In that case, a household's residual income (total income minus payments for public utilities) is compared with the total resources required to finance the minimum level of consumption of nonenergy goods (Kessides et al. 2009).

To apply these ideas, the level of consumption of all nonenergy goods and services, as well as the consumption level of the minimum amount of basic energy services, should be considered. The residual income is expressed as

$$RI_k = TI_k - \sum_i P_i Q_i \quad (\text{Eq. 9.3})$$

where

$RI_k$  = residual income of household  $k$ ;

$TI_k$  = total income of household  $k$ ;

$P_i$  = price of nonenergy good or service  $i$ ; and

$Q_i$  = quantity of nonenergy good or service  $i$ .

The cost of the basic minimum level of energy services (lighting, cooking, space heating or cooling, etc.) using cleaner energy is given as

$$XE_{min} = \sum_e (p_e q_{e0} + DC_e + OC_e) \quad (\text{Eq. 9.4})$$

where

$XE_{min}$  = expenditure on the acceptable minimum level of basic energy services;

$p_e$  = price of energy type  $e$ ;

$q_{e0}$  = acceptable minimum amount of energy type  $e$ ;

$DC_e$  = annuitized cost of devices using energy type  $e$  (including initial cost of electricity connection); and

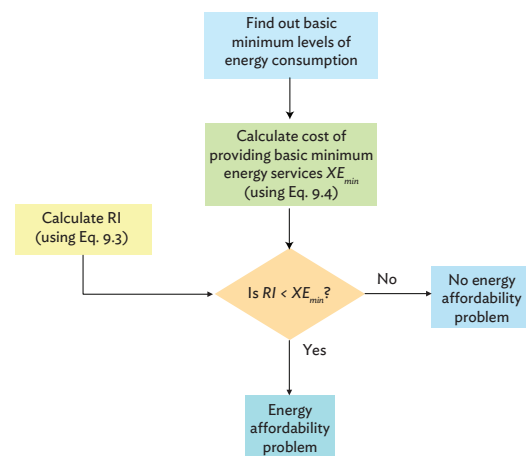
$OC_e$  = O&M cost of devices using energy type  $e$ .

This approach assumes that the minimum acceptable level of basic energy services (lighting, cooking, heating, etc.) for the calculation of  $XE_{min}$  is known. The amount of energy consumption needed to provide the minimum acceptable level of basic energy services, and hence  $XE_{min}$ , would, however, vary with the type of fuel and the efficiency of the energy-using device considered in an EAP.

According to the residual income approach, a household faces an energy affordability problem if its residual income (RI) is lower than the monetary cost of the minimum acceptable level of basic energy services ( $XE_{min}$ ). That is, a household is considered unable to pay for its basic minimum energy needs if  $RI < XE_{min}$ . The steps in this approach are shown in Figure 9.2.

In the assessment of the economic (or true resource) cost of an EAP, the prices of energy commodities and devices should reflect their real (unsubsidized) prices. In the assessment of the cost of energy services and energy affordability from a household perspective, on the other hand, the actual cost borne by the household should be used.

**Figure 9.2 Measurement of Affordability through the Residual Income Approach**



Source: Authors.

<sup>27</sup> Based on Kessides et al. (2009).

## Assessment of Support Programs to Make Energy Services Affordable

In designing a support program to make the EAP affordable to energy-poor households, it is important to estimate the amount by which  $XE_{min}$  exceeds the residual income (RI) of the households. That is, the annuitized level of support needed by an energy-poor household is thus represented by the energy expenditure-related income deficit or “energy expenditure deficit (EED)” as

$$EED = XE_{min} - RI \quad (\text{Eq. 9.5})$$

where

$XE_{min}$  = total cost of meeting the minimum acceptable level of basic energy services with the EAP.

For the basic energy services considered in an EAP, the household energy expenditure deficit would vary with  $XE_{min}$  associated with the program.

In an electricity access program, the upfront cost of devices and initial connection can pose a significant affordability problem to poor households that are unable to shoulder such costs. The following ratios would indicate the burden imposed by the upfront costs on a household's total income and residual income (RI):

$$UEB(TI)_k = \frac{UFC}{TI_k} \quad (\text{Eq. 9.6})$$

$$UEB(RI)_k = \frac{UFC}{RI_k} \quad (\text{Eq. 9.7})$$

where

$UEB(TI)_k$  = upfront energy cost burden on total income of household group  $k$ ;

$UEB(RI)_k$  = upfront energy cost burden on residual income of household group  $k$ ;

$UFC$  = total energy-related upfront cost under the EAP;

$TI_k$  = total income per month of household group  $k$ ; and

$RI_k$  = residual income per month of household group  $k$ .

The upfront cost energy burden ratio related to total annual income ( $UEB(TI)_k$ ) show the length of time needed to earn enough income to meet the energy-related upfront costs. Note that  $UEB(RI)_k > UEB(TI)_k$ .

Designers of support schemes can also find out the level of support needed to make an EAP affordable to a household group  $k$  by determining the amount by which the energy-related expenditure under the EAP exceeds the actual energy expenditure at present (without the EAP). The total annual financial support an energy-poor household ( $FS_p$ ) needs to switch to the EAP can be calculated as follows:

$$FS_p = XE_r - XE_{op} \quad (\text{Eq. 9.8})$$

where

$XE_r$  = total annuitized energy-related household expenditure (including upfront, energy and O&M cost) to meet acceptable minimum level of basic energy services with the EAP; and

$XE_o$  = corresponding expenditure of an energy-poor household without the EAP.

The total support needed can be broken down into two components: (i) support for upfront costs, and (ii) support for additional fuel and other operating costs.

The financial support each household needs to meet the upfront cost ( $SUC_p$ ) is calculated as

$$SUC_p = UC_i - UC_o, \text{ when } UC_i > UC_o \quad (\text{Eq. 9.9})$$

where

$UC_i$  = upfront cost per energy-poor household with the EAP; and

$UC_o$  = upfront cost per energy-poor household without the EAP.

Similarly, the level of financial support needed per household for meeting the energy and operating costs ( $SEC_p$ ) is calculated as

$$SEC_p = EC_i - EC_o, \text{ when } EC_i > EC_o \quad (\text{Eq. 9.10})$$

where

$EC_i$  = energy and operating costs per energy-poor household with the EAP; and

$EC_0$  = energy and operating costs per energy-poor household without the EAP.

The total financial support needed to make the upfront cost ( $TSUC_p$ ) under the EAP affordable to energy-poor households is calculated as

$$TSUC_p = SUC_p * NH_p \quad (\text{Eq. 9.11})$$

where

$SUC_p$  = financial support each household needs to meet upfront cost; and

$NH_p$  = total number of energy-poor households.

The total financial support needed ( $TSEC$ ) to make the energy and other operating costs under the EAP affordable to energy-poor households is calculated as

$$TSEC = SEC_p * NH_p \quad (\text{Eq. 9.12})$$

where

$SEC_p$  = financial support needed per household for meeting the energy and operating costs; and

$NH_p$  = total number of energy-poor households.

Often the availability of resources to provide financial support to enhance affordability could be a determining factor to the choice of the financial support scheme among  $FS_p$ ,  $SUC_p$  and  $SEC_p$  as stated in equations 9.8, 9.9 and 9.10.

## Data Requirements

The data required for the affordability assessment include:

- Total number of energy-poor households;
- Total income of household;
- Discount rate;
- Total household expenditure on energy resources;
- Price for energy services;
- Amount of household energy consumption, by fuel type;
- Initial connection cost;
- Cost of devices and equipment (e.g., lamps, electrical wiring, cookstoves);
- O&M cost of equipment;
- Price of nonenergy good or service  $i$ ; and
- Quantity of nonenergy good or service.



# 10 Implementation Issues

## Introduction

To capture the special features of sustainable energy access planning, the SEAP framework calls for seven different assessments, as described in Chapters 3 to 9. This chapter discusses the implementation issues and challenges that developing countries could face in conducting such assessments.

## Implementation Issues Specific to Individual Assessments

### Energy Poverty Assessment

As discussed in Chapter 3, energy-poor households are identified in literature according to several criteria: the minimum level of energy required to meet basic energy services, indexes (e.g., Multidimensional Energy Poverty Index [MEPI] and Total Energy Access [TEA] approach), energy burden, demand analysis, and energy poverty line. The size of the energy-poor household population and the average energy consumption level of these households could both depend on the criteria chosen.

But there is no universally accepted criterion for determining which households are energy poor. Although the criterion based on physical energy needs (or basic minimum energy needs) may appear relatively easier to understand and use, there is no universally applicable value for it. This is because basic energy needs are variously defined in different countries and regions with their climatic, physiographic, socioeconomic or cultural, and other variations. In fact, knowledge of the

threshold value for a criterion that is specific to the country or subnational region covered by energy access planning is an important prerequisite for the assessment of energy poverty under the SEAP framework. Demand assessment based on an assumed value, instead of a nationally appropriate threshold value, could become controversial.

The set of basic energy needs that is most acceptable to a particular group of policy makers and stakeholders, given their country or regional context, should therefore largely dictate the choice of criterion and, by extension, the definition of the energy-poor household population.

### Demand Assessment

Under the SEAP framework, the energy demand of energy-poor households and that of non-energy-poor households must be defined separately. For both categories of households, information about average energy consumption per household, number of households, and average income per household, by income category, is required. Overall, national-level data are more likely to be available; data on the subnational regions may be harder to find. In areas without electricity access, estimates of the likely demand for electricity will then have to be based on proxy data on the average household demand in each income category in already electrified areas that are otherwise similar to the area to be electrified. Electricity access planning requires monthly or seasonal demand profiles of electricity consumption in the area where energy access is to be provided. Again, if the area is completely unelectrified, then a proxy demand profile of electricity consumption in electrified areas that are otherwise similar to the target area may have to be considered.

## Resource Assessment

An assessment of energy resources in the geographic area where an EAP is being planned is essential for understanding their economic potential and costs. A sound, spatially disaggregated energy resource database cataloging temporal availability patterns over different periods in a year must therefore be developed. The lack of such data can often make it difficult to find cost-effective solutions for energy access and weaken the credibility of proposed solutions.

## Cost Assessment

The cost assessment component of the SEAP framework mainly identifies the cleaner-energy technology and resource options that would minimize the total resource cost to society of providing energy access to all. The total cost here consists of the supply- and demand-side costs associated with such access over the planning horizon. Ideally, therefore, an integrated resource planning model should be used in the cost assessment to identify the mix of supply- and demand-side technologies (and energy resources) that will keep down the total resource cost. The model can also provide energy supply- and demand-side cost information that forms part of the energy burden estimates for the affordability analysis.

Most of the cost assessment tools for electricity planning that now exist determine the minimum cost of the electricity supply-side options for a given level of electricity demand and do not consider explicitly the choice of demand-side or end-use technologies. The supply-side cost, however, depends on the demand for electricity, which in turn depends on the choice of the technologies used on the demand side. Using a supply system model, rather than an integrated cost assessment model, could make the cost assessment more tedious and time consuming, as electricity demand would have to be modified for each set of technologies considered on the demand side, with the supply system model running each time.

## Sustainability Assessment

There are different approaches to obtaining the overall sustainability index. The sustainability ranking of different technology options considered for energy access planning can therefore vary depending on the approach chosen.

But as the purpose of the sustainability assessment is to determine the relative sustainability of the options and to put together a short list of relatively more sustainable options to be considered in an EAP, those variations in ranking should not matter.

## Benefit Assessment

Some benefits of an EAP will not be too difficult to gauge. The decrease in emissions of indoor air pollutants and GHGs can be estimated from consumption data and emission factors for the fuels and technologies used; the reduction in human drudgery and the time saving due to avoided consumption of biomass fuels, from primary information about biomass use in the target area, and the time spent and distance traveled for biomass collection; the increase in energy security resulting from the replacement of imported fossil fuels, from survey data on the amount of fossil fuels (e.g., kerosene for lighting) used in the absence of an EAP or from secondary information.

On the other hand, for benefits related to improvements in education, health, productivity, and employment generation, among others, relevant data are not likely to be available in areas that have no access to cleaner-energy services. In such cases, proxy data for a typical household from an area with energy access but with otherwise similar characteristics could be used.

## Affordability Assessment

The affordability assessment entails identifying households that spend more than a predetermined acceptable share of their income on energy. However, as mentioned in Chapter 9, no universally accepted value for the maximum acceptable level of energy burden exists. It has to be determined as an energy policy variable following a detailed analysis in the context of the country concerned. Another issue has to do with the generally larger share of free fuels such as biomass in energy consumption in some areas, leading to a low or underestimated share of energy expenditure, and a low energy burden. That possibility should be taken into account in the assessment.

The affordability assessment also helps in the design of financial support schemes for the energy poor. Both subsidy and nonsubsidy (such as soft loans) schemes

could be involved. But the effective provision of support schemes could depend on the existence of low-cost lending facilities for end users (informal financing, microfinancing, etc.).

## Other Implementation Issues

### Sustainable Energy Access Planning Toolkit

The present framework provides the conceptual basis for sustainable energy access planning. Its wider use would, however, depend greatly on the availability of an easy-to-use practical toolkit to guide and facilitate the assessments under the SEAP framework. Although some toolkits for electrification programs exist at present—Enable and Motivate Sustainable Power (EMPower) is one of them—the types of assessments and technology options they deal with are limited.<sup>28</sup> Sustainable energy access planning and program development would benefit to a great extent from having a user-friendly integrated toolkit that covers all the components of the SEAP framework.

### Capacity Development

The capacity of local planners to adopt and use the SEAP framework for energy access planning would also determine the extent of its applicability at the national level and in the subnational regions. Adequate capacity for wider and effective application of the SEAP framework should therefore be developed at both the national and subnational levels.

### Database and Primary Data Collection

As stated earlier, lack of relevant data can hamper the implementation of the SEAP framework in some areas, especially where there is no access to cleaner energy (e.g., electricity) at present. In the short term, available secondary information about typical households in electrified areas that are otherwise similar to the target area may have to make up for the lack. A longer-term strategy could be to establish a sound database of information about the household economic and energy use characteristics of typical areas in different subnational regions. Such a database would make it unnecessary to spend time and financial resources on household surveys each time a different target area is chosen for energy access planning. The database would be an asset for SEAP.

<sup>28</sup> For example, the EMPower toolkit is available for the large-scale development of solar power (mainly solar photovoltaic and concentrating solar power), but it does not include energy poverty, sustainability, and affordability assessment. For details, see <http://empower-ph2.com/EMPowerToolkit/>

# Appendix 1 Data Requirements

Data	Type of Assessment						
	Energy Poverty	Energy Demand	Resource	Cost	Sustainability	Affordability	Benefit
Demographic Data							
Population (Rural/Urban)	√	√		√	√		√
Number of Households	√	√					√
Household Productivity Level		√					√
Household Size					√		√
Population Growth Rate		√					
Socio Economic Data							
Electrified and Unelectrified Households	√	√		√	√	√	√
Household Income	√	√			√	√	√
Gross Domestic Product		√					
Income Elasticity		√					
Population Elasticity							
Price Elasticity							
Discount Rate				√		√	
Household Expenditure	√					√	√
Numbers of Educational, Health, and other Community Institutions		√					√
Average Study Hours (Electrified and Unelectrified)							√
Average Number of Hospital Visits (Electrified and Unelectrified)							√
Energy Data							
Fuel Consumption per Household by End Use (Cooking, Lighting, etc.) and Fuel Type	√	√		√	√	√	√
Basic Minimum Energy Requirement	√	√					
Energy Consumption by Fuel Type	√	√		√		√	√
Price of Energy		√		√	√	√	√
Specific Electricity Consumption per Activity Level		√					

continued on next page

Appendix 1 table continued

Data	Type of Assessment						
	Energy Poverty	Energy Demand	Resource	Cost	Sustainability	Affordability	Benefit
Economic Potential for Energy Resource				√	√		
Type of Fuel Used	√				√		
Daily Load Profile				√			
Share of Renewable Energy in Electricity Supply					√		
Income Spent on Fuel and Electricity	√				√	√	√
Amount of Energy Imported					√		√
Hours of Electricity Supply					√		
Resource Data							
Fuelwood (Source, Production, Amount, Time Spent)			√	√	√		
Agriculture Residue (Source, Time, Amount)			√	√	√		
Animal Waste (Number of Cattle Owned, Amount of Waste Produced, Time Spent)			√	√	√		
Hydropower (Head, Discharge, Distance Form Load Center, Potential)			√	√	√		
Solar Energy Potential			√	√	√		
Wind Energy Potential			√	√	√		
Forest Area			√		√		
Technology Data							
Type of End Use Device Used for Cooking, Lighting, Heating, etc.	√	√		√	√		
Efficiency of End Use Device		√		√	√		
Types of Electrical Appliances Used	√						
Power Rating of Devices		√					
Time of use		√		√			
Life of Technology				√	√		√
Technology Cost (Investment, O and M)	√			√	√	√	√
Transmission and Distribution Loss				√	√		
Reliability and Durability of Technology				√	√		
Price and Quantity of Nonenergy Goods	√					√	√
Emission Factor and Global Warming Potential							√

Source: Authors.

## Appendix 2 Multidimensional Energy Poverty Index Approach

The Multidimensional Energy Poverty Index (MEPI) approach involves the following steps:

- Identify the dimensions of energy poverty in terms of service demand and define the “deprivation cut off” for each dimension in the case of an energy-poor person.
- Define the value of relative importance of a person’s deprivation from a predefined energy service in energy poverty when a certain predefined condition for the dimension is not satisfied. This is expressed in term of a weight attached to the dimension in measuring energy poverty.
- Derive the deprivation matrix  $g$ , whose element  $g_{ij}$  expresses the measure of deprivation related to dimension  $i$  of person  $j$ . The cutoff level for deprivation related to a dimension of MEPI is expressed in terms of whether or not a set of conditions are met. If the defined set of conditions for a dimension are met i.e., when a person is considered deprived from a particular service demand, in this case the deprivation count is expressed by the energy poverty weightage assigned for the deprivation of the service demand. Otherwise it is set equal to zero. Thus,

Set  $g_{ij} = w_j$ , when the deprivation conditions for dimension  $j$  hold in the case of person  $i$ .

And  $g_{ij} = 0$ , when the deprivation conditions do not hold for person  $i$ .

- Calculate the total deprivation count of person  $i$  as

$$c_i = \sum_{j=1}^d g_{ij}$$

with  $d$  representing the number of dimensions (or service demands) considered for energy poverty measurement.

- Define a cutoff level for the total deprivation count to identify energy poor. A person  $i$  is defined as energy poor if the weighted deprivation count,  $c_i > k$ .

Set  $c_i(k) = 0$ , if  $c_i(k) \leq k$

$c_i(k) = c_i$ , if  $c_i(k) > k$

- Find the total number of energy-poor people (i.e., total no. of people with  $c_i > k$ ). Let  $q$  denote the number of energy-poor people. Compute the head count ratio  $H$  of the energy-poor people as

$$H = \frac{q}{n}$$

where  $n$  = total population.

The head count ratio  $H$  represents the incidence of multidimensional energy poverty.

- The intensity of multidimensional energy poverty ( $A$ ) is calculated as

$$A = \sum_{i=1}^n \frac{c_i(k)}{q}$$

- Finally the multidimensional energy poverty index is expressed as:

$$\text{MEPI} = H \cdot A$$

## Appendix 3 Total Energy Access: Minimum Standards

Energy Service	Minimum Standards
Lighting	300 lumens for a minimum of 4 hours per night at household level
Cooking and water heating	1 kg of wood fuel or 0.3 kg charcoal or 0.04 kg LPG or 0.2 litres of kerosene or biofuel per person per day, taking less than 30 minutes per household per day to obtain
	Minimum efficiency of improved solid fuel stoves to be 40% greater than a three-stone fire in terms of fuel use
	Annual mean concentrations of particulate matter ( $PM_{2.5}$ ) < 10 $\mu\text{g}/\text{m}^3$ in households, with interim goals of 15 $\mu\text{g}/\text{m}^3$ , 25 $\mu\text{g}/\text{m}^3$ and 35 $\mu\text{g}/\text{m}^3$
Space heating	Minimum daytime indoor air temperature of 18°C
Cooling	Households can extend life of perishable products by a minimum of 50% over that allowed by ambient storage
	Maximum apparent indoor air temperature of 30°C
Information and communications	People can communicate electronic information from their household
	People can access electronic media relevant to their lives and livelihoods in their households

Source: Practical Action (2012).

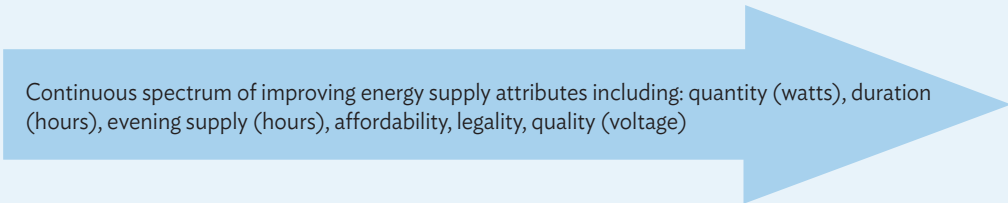
## Appendix 4 Energy Access Index

Energy Supply	Level	Quality of Supply
Household fuels	1	Collecting wood or dung and using a three-stone fire
	2	Collecting wood and using an improved stove
	3	Buying wood and using an improved stove
	4	Buying charcoal and using an improved stove
	5	Using a modern, clean burning fuel and stove combination
Electricity	1	No access to electricity at all
	2	Access to third party battery charging only
	3	Own low-voltage DC access for home applications
	4	240 V AC connection but poor quality and intermittent supply
	5	Reliable 240 V AC connection available for all uses
Mechanical Power	1	No access to mechanical power. Hand power only with basic tools
	2	Mechanical advantage devices available to magnify human/animal effort
	3	Powered (renewable or fossil) mechanical devices available for some tasks
	4	Powered (renewable or fossil) mechanical devices available for most tasks
	5	Mainly purchasing mechanically processed services

Source: Practical Action (2010).

## Appendix 5 Multitier Framework

**Table A5.1 Multitier Framework for Household Electricity Access**

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Electricity Services	None	Electric lighting, radio, mobile phone charging	Tier 1 + multibulb lighting, air circulation, television	Tier 2 + rice cooking, water heater	Tier 3 + refrigeration, mechanical loads	Tier 4 + electric cooking, space heating and cooling
Energy Supply Attributes	 <p>Continuous spectrum of improving energy supply attributes including: quantity (watts), duration (hours), evening supply (hours), affordability, legality, quality (voltage)</p>					
Possible Electricity Supply Technologies	None	Solar lantern, rechargeable batteries, home system, minigrid, grid	Rechargeable batteries, home system, minigrid, grid	Home system, minigrid, grid	Home system, minigrid, grid	Home system, minigrid, grid

Source: World Bank/ESMAP and IEA (2013) and Practical Action (2013).

Table A5.2 Multitier Framework for Household Cooking Solutions

Tier	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
Household cooking solution attributes	<div>Continuous spectrum of improving energy supply attributes including: quantity (watts), duration (hours), evening supply (hours), affordability, legality, quality (voltage)</div>				
Possible Energy Supply Technology	<div>Traditional cookstoves +Solid fuels</div>	<div>Improved cookstoves with solid fuels</div>	<div>Advanced cookstoves with solid fuels</div> <div>Kerosene cookstoves</div>	<div>Gaseous fuels such as LPG, natural gas, biogas</div>	<div>Electric</div>

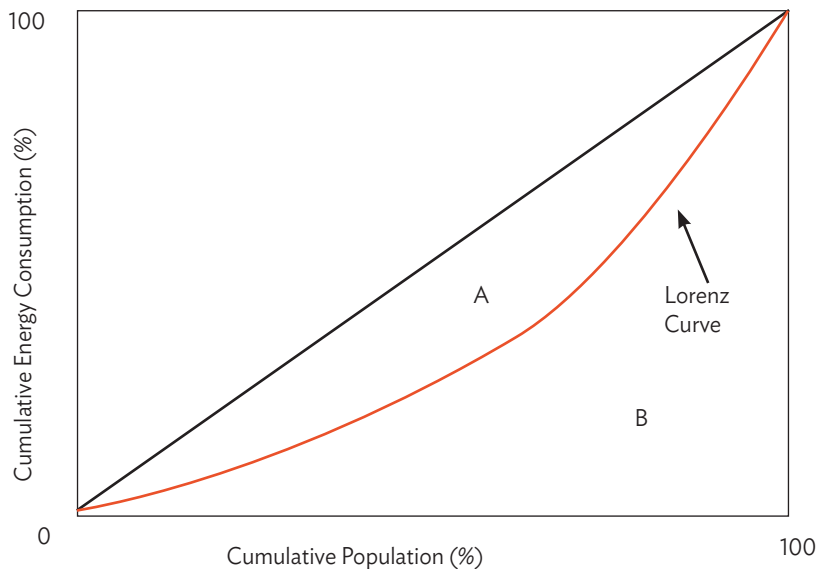
Source: Practical Action (2013).

## Appendix 6 Energy Inequality

The method for assessment of energy inequality is based on calculation of an “energy Gini coefficient,” which is derived from a Lorenz curve for residential energy consumption. The Lorenz curve for energy distribution represents a ranked distribution of the cumulative percentage of the population on the abscissa versus the cumulative percentage of residential energy consumption distributed along the ordinate axis (Figure A6.1). The energy Gini coefficient is a quantitative measure of energy inequality. It shows the difference between a uniform distribution and the actual distribution of residential energy consumption. The energy Gini coefficient is obtained from the energy Lorenz curve as the ratio between the portion of the area enclosed by the diagonal line and the energy Lorenz curve (i.e., area A) and the total area below the diagonal line (i.e., the sum of areas A and B). Thus in reference to Figure A6.1,

Energy Gini coefficient ( $G_e$ ) =  $A/(A+B)$

**Figure A6.1: A Lorenz Curve for Residential Energy Consumption**



Source: Authors.

Algebraically, following Jacobson, Milman, and Kammen (2005), if population groups are defined and ordered in an increasing order of energy consumption, the Gini coefficient for energy consumption can be expressed as:

$$G_e = 1 - \frac{\sum_i (Y_{i+1} + Y_i) (X_{i+1} - X_i)}{2 \sum_i Y_i (X_{i+1} - X_i)} \quad (\text{Eq. A6.1})$$

where

$X_i$  = the cumulative share of energy consumption by all households up to group  $i$  in total energy use,  
and

$Y_i$  = the cumulative share of all households up to group  $i$  in total population

Another variant of the expression to calculate energy Gini coefficient at a national level (when district level data are available on energy consumption per capita) is:

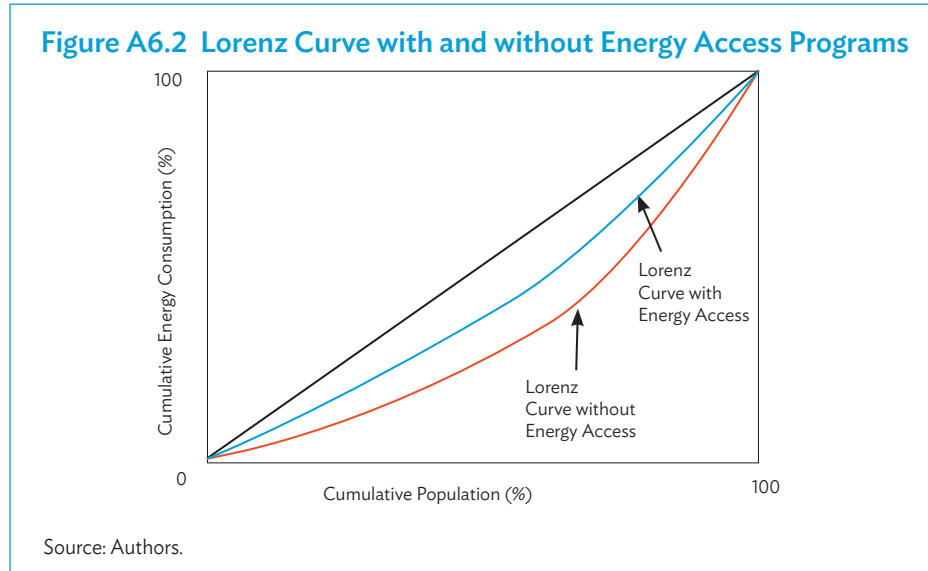
$$G_e = \left[ \frac{2}{N \sum_{i=1}^N e_i} \sum_{i=1}^N i \cdot e_i \right] - \left(1 + \frac{1}{N}\right) \quad (\text{Eq. A6.2})$$

where,  $N$  is the number of districts and  $e_i$  is the per capita energy consumption of the  $i_{th}$  district, ordered by per capita energy consumption (Clarke-Sather et al. 2011). This approach can also be adopted to calculate  $G_e$  at a district or subdistrict level.

As an energy access program at the national or subnational level is likely to affect the distribution of residential energy consumption in the population, the level of decrease in energy Gini coefficient with such program would indicate an improvement in the distribution of residential energy use in the population. Figure B shows Lorenz curves with and without an energy access program. Formally, the decline in energy inequality (i.e., improvement in the distribution of energy consumption across the population) with an energy access program could be estimated in terms of percentage change in energy inequality index ( $\Delta G_e$ ). This is shown by:

$$\Delta G_e = \frac{G_{e,o} - G_{e,i}}{G_{e,o}} \quad (\text{Eq. A6.3})$$

where,  $G_{e,i}$  and  $G_{e,o}$  represent energy Gini coefficients with and without an energy access program, respectively.



A similar method can also be used to calculate electricity Gini coefficients in order to assess the benefit of an electricity access program in terms of improvements in the distribution of electricity consumption by households at a country or sub-country level.

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\* ADB recognizes “China” as the People’s Republic of China.

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# **Sustainable Energy Access Planning**

## *A Framework*

Sustainable energy access planning, unlike traditional energy planning, gives primary importance to the energy demand of both poor and nonpoor households, the need to make cleaner energy services more affordable to the poor, the costs of both supply-side and demand-side access options, and the sustainability of technology and resource options. As such, this type of energy planning contributes to low carbon development and achievement of Sustainable Energy for All objectives. This report presents a framework for sustainable energy access planning that planners and policy makers can use to design cost-effective clean energy supply systems that both poor and nonpoor can sustainably access to meet at least the minimum amount of energy for their basic needs. The report discusses the multidimensional assessments involved in this type of planning, as well as their interlinkages and implementation issues.

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**ASIAN DEVELOPMENT BANK**

6 ADB Avenue, Mandaluyong City

1550 Metro Manila, Philippines

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