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Energy for Sustainable Development: The Energy–Poverty–Climate Nexus

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Additional information is available at the end of the chapter

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Abstract

Worldwide, 1.4 billion people lack access to electricity, and 2.7 billion people rely on traditional biomass for cooking. Most people living in energy poverty—without electricity access and/or using traditional biomass for cooking—are from rural areas of Sub-Saharan Africa, India, and other developing Asian countries (excluding China). At the same time, the poorest people are the most likely to suffer from the impacts of climate change.

Fortunately, innovative, sustainable energy technologies can allow developing countries to leapfrog to low-carbon renewable energy, while at the same time alleviating extreme poverty. Increasing energy access, alleviating rural poverty, and reducing greenhouse gas emissions can thus be complementary, their overlap defining an energy–poverty–climate nexus. Transitioning to more efficient low-carbon energy systems in rural areas can generate greater returns than similar efforts in industrialized areas.

Accordingly, this chapter provides an overview of: a) The linked problems facing developing countries of energy access, poverty, and climate change, and how these problems interact and compound each other. b) Potential renewable energy solutions, including off-grid solar, wind, clean biomass, micro-hydro, and hybrid systems. For each energy option, benefits and challenges will be discussed, along with examples of successful small-scale use in rural areas of developing countries.

Keywords: Sustainable energy, climate change, developing countries, renewable energy, energy–climate–poverty nexus

1. Introduction

Most of the world's people without access to electricity or clean energy are from rural areas of developing countries. At the same time, a person in a developing country is 79 times more

likely to suffer from a climate-related disaster than a person in a developed country, according to the United Nations Development Programme [1].

Fortunately, for developing countries, increasing energy access, alleviating poverty, and addressing climate change can all be accomplished via sustainable energy. In fact, implementing renewable energy in rural areas can generate greater returns in terms of reduced greenhouse gas emissions than similar efforts in industrialized areas. Accordingly, this chapter will provide an overview of the current energy access problem in developing countries and potential innovative sustainable solutions. Off-grid renewable electricity options to be discussed include solar, wind, clean biomass, micro-hydro, and hybrid systems.

2. The Problems

The problems of energy access, poverty, and climate change are intertwined in the developing world. The poor often lack access to energy at all or have access only to inefficient and unhealthy forms of energy. Lack of energy makes it more difficult to address other aspects of poverty, such as lack of education or health care (imagine operating a school or hospital without access to electricity). As the poor gain access to energy, their contribution to climate change will increase, unless they leapfrog to renewable energy technologies. Unfortunately, the poor are the most vulnerable to many impacts of climate change, including increased food insecurity and amplified health risks. These interrelationships that constitute the energy–poverty–climate nexus problem are discussed in more detail below.

2.1. The Energy–Poverty Nexus

Worldwide, 1.4 billion people (20% of the world’s population) currently lack access to electricity, and 2.7 billion people (40% of the world’s population) rely on inefficient and unhealthy forms of biomass [2]. Air pollution levels indoors from 3-stone fires or inefficient stoves using biomass are many times higher than typical outdoor levels, even those in highly polluted cities. The World Health Organization (WHO) estimates that over 1.5 million die prematurely each year from household air pollution due to inefficient biomass combustion [2]. These deaths from cancer, respiratory infections, and lung diseases account for 4% of the global burden of disease—more deaths than those from malaria (1.2 million) or tuberculosis (1.6 million) [1]. Many of those who die are young children, who spend hours each day breathing in smoke from the cookstove [2].

Moreover, in regions where households rely heavily on unhealthy forms of biomass, women and children are typically responsible for fuel collection—a time-consuming and exhausting task. This strenuous work without sufficient recuperation can cause serious long-term physical damage for women. Heavy reliance on biomass can also cause land degradation, including deforestation, and local and regional air pollution [2].

As shown in Table 1, most of the people living in energy poverty—without electricity access and/or using traditional biomass for cooking—are from rural areas of developing countries,

the majority in Sub-Saharan Africa, India, and other developing Asian countries (excluding China) [2]. At current growth rates, about half a billion “energy poor” will be added over the next 20 years [1].

Region	Number of people lacking access to electricity (millions)	Number of people relying on the traditional use of biomass for cooking (millions)
Africa	587	657
<i>Sub-Saharan Africa</i>	585	653
Developing Asia	799	1937
<i>China</i>	8	423
<i>India</i>	404	855
<i>Other Asia</i>	387	659
Latin America	31	85
Developing countries*	1438	2679
World**	1441	2679

*Includes Middle East countries.

**Includes Organisation for Economic Co-operation and Development (OECD) and transition economies.

Table 1. Number of people lacking access to electricity and relying on the traditional use of biomass for cooking, 2009 (million) [2]

Improving access to cost-effective, sustainable energy technologies is critical for addressing poverty in developing countries [1]. Although improving energy access is not one of the 8 globally agreed Millennium Development Goals (MDGs), it is a cross-cutting issue that directly impacts achievement of the goals [1]. More and better energy services are needed to end poverty, hunger, educational disparity between boys and girls, the marginalization of women, major disease and health service deficits, as well as environmental degradation [1, 2]. Without modern energy services, basic social goods such as health care and education are more costly in both real and human terms, and economic development is harder to perpetuate [1]. A clear correlation exists between energy and the Human Development Index (HDI) [3]. As the International Energy Agency and United Nations state, “Access to modern forms of energy is essential for the provision of clean water, sanitation and healthcare and provides great benefits to development through the provision of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunication services” [2].

For the 1.4 billion people that lack access to electricity, they either live in locations too remote to be connected or cannot afford the fee to connect [4]. For locations that are off-grid, fossil fuels are often unaffordable due to the cost of delivery to remote locations [5].

2.2. The Energy–Climate Nexus

The climate change problem is largely a fossil fuel problem. According to the Intergovernmental Panel on Climate Change (IPCC) 2007 report, at least 57% of greenhouse gas emissions

globally stem from burning of fossil fuels [6]. For carbon dioxide (CO₂), the most important anthropogenic greenhouse gas, 74% of emissions are due to combustion of fossil fuels [6]. When fossil fuels are burned for energy, the carbon stored in them, originally from biomass such as algae, is emitted almost entirely as CO₂. These fossil fuels include coal, oil, and natural gas, which are burned in electric power plants, automobiles, industrial facilities, and other sources.

2.3. The Poverty–Climate Nexus

The poorest people in the world are the most likely to suffer from impacts of climate change. According to the United Nations Development Programme (UNDP), a person in a developing country is 79 times more likely to suffer from a climate-related disaster than a person in a developed country [2]. The poor are especially vulnerable to the impacts of climate change, including reduced agricultural productivity and increased food insecurity; heightened water stress and insecurity; rising sea levels and increased exposure to climate disasters; loss of ecosystems and biodiversity; and amplified health risks [1]. According to the Human Development Report (HDR) 2007–2008, failure to address climate change will consign and trap the poorest 40% of the world's population, some 2.6 billion people, in downward spirals of deprivation [7]. Providing energy access will help poor areas adapt in the face of a changing climate [8].

Reductions in greenhouse gas emissions must include both developed and developing countries, including those with significant numbers of people living in poverty. According to the U.S. Environmental Protection Agency (EPA), greenhouse gas emissions from developing countries are expected to exceed those from developed countries in 2015 [9]. According to Casillas and Kammen [8], every dollar spent on the transition to more efficient low-carbon energy systems in rural areas has the potential to produce greater carbon mitigation returns than in more industrialized areas.

3. Potential Solutions

Since the problems of energy access, poverty, and climate change are interrelated in developing countries, solutions can be designed to solve all 3 problems simultaneously. Innovative sustainable energy technologies can allow developing countries to leapfrog to low-carbon renewable energy, while at the same time alleviating extreme poverty. Increasing energy access, alleviating poverty, and reducing greenhouse gas emissions can thus be complementary, their overlap defining an energy–poverty–climate nexus solution.

As mentioned above, according to the article published by Casillas and Kammen [8] recently in *Science*, transitioning to more efficient low-carbon energy systems in rural areas can generate greater returns than similar efforts in industrialized areas. Urban cities of developing countries may have access to electricity for lighting. Rural areas typically lack access altogether; hence, the need in these areas is the greatest [9]. Access to electricity in rural areas, even at modest consumption levels, can dramatically improve a community's quality of life. For example,

electric lamps can allow children to study at night, and radios and cellular phones can greatly improve communication pathways [10]. This section will accordingly focus on renewable energy solutions for rural areas of developing countries.

Centralized electrification requires massive amounts of capital [10]. The dispersed nature of houses and low potential demand create little incentive for power companies to provide access to rural areas. In addition, extending the grid may be unrealistic due to transmission line costs or hard terrain [5]. Thus, in rural areas, off-grid and mini-grid solutions make the most sense. Such systems can consist of a single home or several small homes and businesses. The systems can be incremental and scalable and applied to many different conditions and environments [10]. Off-grid and mini-grid options for renewable electricity include solar, wind, clean biomass, and micro-hydro. These options for renewable power will be discussed in more detail below.

3.1. Solar Power

Solar energy is abundant in many locations in the developing world [5]. Many regard it as the most promising renewable source for developing countries [5, 11, 12]. The use of solar energy produces no on-site air pollutants [although pollutants are typically generated in the process of manufacturing photovoltaics (PV) cells].

Solar energy can be utilized in two ways: direct heat energy for various purposes (heating water, heating space) and direct current electricity generation using PV system. Electrical energy can be used immediately to pump water for irrigation or for refrigeration, lighting, or other purposes; alternatively, it can be stored in a rechargeable battery for later use [5]. This can help solve problems associated with its intermittency [12].

Individual houses can have their own PV system for lighting and small appliances, such as radio and mobile phone charging. A village can benefit from a larger PV system, with a micro-grid structure.

3.1.1. Solar Challenges

The primary barrier to widespread implementation of the solar PV technology is its cost, due to the high cost of the silicon base material and associated manufacturing processes [1]. In addition, production of solar cells currently requires sophisticated and expensive manufacturing facilities and highly trained personnel, which may not be available in developing countries. Nicole Kuepper, a Ph.D. student, won the Eureka Prize for Young Leaders in Environmental Issues and Climate Change for developing a simple, inexpensive way of producing solar cells in a pizza oven. The process uses a low-cost inkjet printing process, aluminum spray, and a low-temperature pizza oven, meaning that the solar cells can be made without high-tech environments or high-cost inputs [1].

Solar water heaters (SWHs) are relatively expensive to install (\$500–\$2100), although the initial investment can be recovered through future electricity savings [1]. For many families in rural areas, the purchase of a solar lighting set, even for lighting service only, is so hard that a

systematic approach has to be designed, which enables them to pay only for the lighting service received instead of owning the whole hardware [5].

3.1.2. Solar Success Stories

Solar lanterns. Typically, solar-powered lanterns use solar energy to charge a battery that powers a solid-state light-emitting diode (LED), the most efficient lighting technology on the market. One solar lantern, the Mighty Light, costs around US\$ 45 and lasts up to 30 years. It has replaced polluting dangerous kerosene lamps for thousands of households in Afghanistan, Guatemala, India, Pakistan, and Rwanda [1]. As of November 2010, around 9000 versions of a solar lantern called the “solar tuki” had been installed in Nepal [1].

Solar home systems. A solar home system is a PV system with capacity of 10–40 Wp (peak Watts). By 2007, Grameen Shakti had installed 100,000 solar home systems to power lights, motors, pumps, televisions, mobile phones, and computers in Bangladesh [1].

SELCO of India is an organization successfully installing solar home and business systems to provide electricity for lighting, SWHs, solar inverter systems (for use in communications and computing), and small business appliances. Since 1995, SELCO has been providing solar energy solutions to underserved households and businesses in India, based on the ideas that poor people can afford sustainable technologies, poor people can maintain sustainable technologies, and social ventures can be run as commercial entities [1].

Community solar systems. Community solar PV systems are commonly used for pumping water for drinking and irrigation. The solar panel may vary between 130 Wp and 40 kWp. The Promethean Power project promotes a version of community solar systems using concentrated solar thermal power rather than PV. The system, which can be manufactured locally, concentrates solar thermal energy to heat a fluid refrigerant. The solar thermal system is combined with a unique microscale generator adapted and scaled to suit the needs of underserved communities. The heated fluid expands through a rotary vane turbine (an automobile power-steering pump) to make mechanical energy that spins a generator (an automobile alternator). Massachusetts Institute of Technology (MIT) is installing the systems in Lesotho in Africa [1].

3.2. Wind Power

Like solar, the fuel source for wind power is free and unlimited. The use of wind turbines to generate electricity via a generator produces no on-site air pollution, although a small amount of emissions is produced during manufacture of the turbines. One life-cycle assessment found that off-grid wind turbines reduce greenhouse gas emissions by 93%, compared to off-grid diesel power generation systems [13]. An additional advantage is that wind turbines are simple mechanical systems that can be easily maintained and repaired [10].

3.2.1. Wind Challenges

One of the challenges associated with wind power is its intermittency. Researchers are developing solutions to this problem for off-grid wind systems. Short term, the electrical

energy generated by the turbine can be stored in a battery [14]. Researchers have developed controllers that maximize capture of wind energy and avoid battery overcharge [15, 16]. Other researchers have proposed a hybrid energy storage system that can provide uninterrupted power, according to simulations. In the hybrid storage system, a battery is used for short-term energy storage, and a water electrolysis hydrogen system is used for long-term energy storage due to hydrogen's high mass energy density and very low leakage [17].

Another challenge is selecting an appropriate location for the turbine, due to the highly localized nature of wind. Low-cost anemometers may help alleviate this problem, but time must be spent to collect a sufficient amount of data [10]. Areas particularly suited to wind power because of their typical high wind velocities include coastlines, high ground, and mountain passes [12]. Wind power does not need water, so it is suitable for dry areas.

A third challenge is the need for a tower, so that the turbine is at least 10 m above the nearest obstacle. The tower itself could cost more than the wind turbine. Researchers are examining towers made from bamboo and other common and low-cost materials [10].

3.2.2. Wind Success Stories

The cost of commercially available wind turbines is several thousand US dollars per kilowatt, which is out of reach for most rural residents of developing countries [10]. Low-cost wind turbines with timber blades have been demonstrated successfully in Nepal [18]. Low-technology wind turbine generators, which can be made by people with limited technical skills, no advanced machining equipment, low capital cost, and limited exotic materials, have also been demonstrated [10]. The low-technology wind turbine was constructed in a joint effort by the IEEE Power & Energy Society Community Solutions Initiative and the Puget Sound Professional Chapter of Engineers Without Borders, USA.

3.3. Clean Biomass

Biomass sources in rural areas include human excrement, animal manure, and agricultural wastes. Biomass can be burned directly to produce heat energy or electricity via a microturbine, or it can be degraded by anaerobic microbes to produce biogas. Although burning biomass in inefficient cookstoves contributes to illness via indoor air pollution, as described above, biomass can be burned using clean technologies or used to generate clean-burning biogas. Biogas, typically 60–70% methane, can be used directly in natural gas-powered appliances or burned to generate electricity via a microturbine and generator [19]. It is expected that microturbines powered by biogas might eventually be competitive with diesel engines for village-scale power applications, with relatively low maintenance costs, high reliability, long lifetimes, and low capital costs [1]. Fuel cells might ultimately prove able to generate power at village scales from biogas, at very high efficiencies [1].

Anaerobic processes that produce methane from waste solve 2 problems at once: waste and energy. Anaerobic processes provide some of the simplest and most practical methods for minimizing public health hazards from human and animal wastes. Pathogens such as schistosome eggs, hookworm, flat/tape worm, dysentery *Bacillus*, poliovirus, *Salmonella*, and

Bacillus for paratyphoid are destroyed. A residence time of 14 days at $>35^{\circ}\text{C}$ in a small-scale system in a developing country can provide 99+% removal of pathogens, with the exception of roundworm [20, 21].

In addition, the solid residue from anaerobic waste treatment processes is a valuable fertilizer, which is stabilized and almost odorless. This fertilizer is especially a benefit in developing countries, due to its potential to boost crop yields.

3.3.1. Biomass Challenges

Ideally, energy should be produced from biomass that is not edible and that cannot be grown in places where edible crops could be grown, so that competition between uses of crops for energy and food does not become an issue. Producing energy from wastes avoids this issue.

Because of limits on the amount of land accordingly available for growing plants that can be used for energy, bioenergy cannot be viewed globally as the sole replacement or substitute for fossil fuels, but rather as one element in a broader portfolio of renewable energy sources [1]. In rural locations in developing countries without current access to electricity, however, biomass can provide a transformative local power source.

3.3.2. Biomass Success Stories

An improved biomass cookstove designed by Prakti Design Lab to meet the cooking requirements of rural households is around 40% percent more fuel efficient than traditional cookstoves and emits 70–80% less smoke [1].

In Senegal, proliferating invasive aquatic plants are being transformed into combustible pellets that can be used for cooking, replacing wood and charcoal. By impacting lake water quality, the plants' proliferation caused an increase in waterborne diseases. The plants are also created problems for fishermen, by jamming their nets, and farmers, by reducing access to water for livestock. Local fishermen and farmers will be recruited as plant removers, and 20 additional local workers will be hired and trained to manage the pellet production process. Based on capacity production of the compaction machine (4,000 kg/week) and a local price of US\$ 0.28/kg, the pellets could generate income of about US\$ 1,120/week for the local population [1].

3.4. Micro-Hydro

Micro-hydro systems use the natural flow of water to yield up to 100 kW output of electrical energy [22]. Simplicity, efficiency, longevity, reliability, and low maintenance costs make these systems attractive for rural development [23]. Like solar and wind, the fuel source for micro-hydro power is free, and the use of hydro-powered turbines to generate electricity produces no on-site air pollution.

Unlike large hydroelectric plants, micro-hydro systems do not require a dam and reservoir, which minimize their environmental damage. A portion of the river's flow is diverted to the micro-hydro intake. A settling tank may be used to allow silt to settle out of the water. A screen or bars screen out floating debris and fish. The water then flows through a channel, pipeline,

or pressurized pipeline (penstock) to the powerhouse, which houses a turbine or waterwheel. The turbine turns a generator to produce electricity [22]. A variety of turbines may be used, including a Pelton wheel for high head, low-flow water supply, or a propeller-type turbine for low-head installations [24, 25].

3.4.1. Micro-Hydro Challenges

Micro-hydro systems obviously are limited to locations with a stream or river. The flow volume must be sufficient to supply local energy needs. In addition, a sufficient quantity of falling water must be available, which usually means that hilly or mountainous sites are best. A drop of water elevation of at least 2 ft is required or the system may not be feasible; the water does not “fall” enough distance to produce enough head [22, 24]. Another limitation is that the distance from the stream or river to the site in need of energy may be considerable [23].

The power produced may fluctuate depending on how much water is flowing in the stream or river and the velocity of flow [23]. Energy can be stored in batteries, so additional reserve energy available for time of low generation and/or high demand. However, because hydro-power resources tend to be more seasonal than wind or solar resources, batteries may not be able to provide enough energy storage for summer or other seasons with severely limited water flow. Integrating the hydropower with a hybrid wind or solar system can help in areas where water flow is highly seasonal.

3.4.2. Micro-Hydro Success Stories

The main micro-hydro programs in developing countries are in mountainous regions, such as Nepal (around 2,000 installations, including both mechanical and electrical power generation) and other Himalayan countries [25]. In South America, micro-hydro programs are located in countries along the Andes, such as Peru and Bolivia. Smaller programs have been initiated in hilly areas of Sri Lanka, the Philippines, China, and elsewhere [25]. In a variety of locations, micro-hydro systems have been shown to increase employment opportunities in rural areas, which encourage young people to stay in the villages rather than drifting to the cities [25].

Maher et al. [26] describe the successful implementation of pico hydro (<5 kW) systems in two communities in Kenya. Costs for these systems were considerably less than comparable PV or auto battery systems. The systems were constructed locally using available materials and community labor.

3.5. Hybrid Systems

According to a report issued in 2010 by the International Energy Agency, UNDP, and United Nations Industrial Development Organization, combining solar, wind, biomass, and mini-hydro into an integrated/hybrid system supplying a mini-grid is probably the most promising approach to rural electrification [2]. A combination of technologies in an integrated system can promote reliability. A small backup generator may be operated on diesel, biogas, or biodiesel [5]. Hybrid village electrification systems have been implemented in various countries, including China, India, Ghana, South Africa, and Tanzania [1]. A number of studies have

examined the feasibility of various kinds of hybrid off-grid systems: wind–diesel [14, 27], wind–solar [28, 30], wind–PV–diesel [31–33], hydro–PV–wind [34], wind–hydrogen [35], and solar–wind–biomass–hydro [36].

4. What Now? Next Steps

At the global level, a new development paradigm—a pro-poor global climate change agenda—should be embraced. National climate change adaptation and mitigation strategies should be directly linked with poverty reduction and sustainable development goals [1].

To ensure that every person in the world benefits from access to electricity and clean cooking facilities by 2030, the International Energy Agency, UNDP, and United Nations Industrial Development Organization estimate that investment of \$36 billion per year will be required. To meet the more ambitious target of achieving universal access to modern energy services by 2030, an additional cumulative investment of \$756 billion, or \$36 billion per year, is needed. Although this sounds like a large number, it represents only 0.06% of average annual global gross domestic product (GDP) over the period. The resulting increase in primary energy demand and CO₂ emissions would be modest: in 2030, global electricity generation would be 2.9% higher, and CO₂ emissions would be only 0.8% higher [2]. Given that the up-front cost of new energy technologies is prohibitively expensive for poor communities, targeted financing and incentives are needed so that low-income communities, households, and entrepreneurs can invest in new energy technologies.

Students and young entrepreneurs in collaboration with nongovernmental organizations (NGOs) have done some of the most innovative work in new low-cost sustainable energy applications. Such partnerships should be promoted. The World Bank's Development Marketplace Grants, for example, provide global recognition and seed funding for creative ideas, technologies, and services that matter for development, so that they may grow and replicate.

5. Summary

The problems of energy access, poverty, and climate change are intertwined in the developing world. The poor often lack access to energy at all or have access only to inefficient and unhealthy forms of energy. As the poor gain access to energy, their contribution to climate change will increase, unless they leapfrog to renewable energy technologies. Unfortunately, the poor are the most vulnerable to many impacts of climate change, including increased food insecurity and amplified health risks. Access to energy can reduce their vulnerability to climate change impacts.

Fortunately, increasing energy access, alleviating rural poverty, and reducing greenhouse gas emissions can all be complementary, their overlap defining an energy–poverty–climate nexus.

Solar, wind, biomass, and micro-hydro systems have all been used successfully in various locations to provide off-grid renewable power to rural areas. Each has advantages and drawbacks, depending on the particular location. Combining solar, wind, biomass, and mini-hydro into an integrated/hybrid system supplying a mini-grid is probably the most promising approach to rural electrification.

Providing universal access to modern energy services by 2030 would cost only 0.06% of average annual global GDP during the period. What else could be a more worthwhile investment?

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