Annu. Rev. Environ. Resour. 2005. 30:117–44
doi: 10.1146/annurev.energy.30.050504.144228

PRODUCTIVE USES OF ENERGY FOR RURAL DEVELOPMENT

R. Anil Cabraal,[1] Douglas F. Barnes,[2] and Sachin G. Agarwal[1]

[1]Energy and Water, [2]Energy Sector Management Assistance Program, World Bank, Washington, District of Columbia 20433; email: acabraal@worldbank.org, dbarnes@worldbank.org, sashint@gmail.com

Key Words income, health, education, gender equality

■ **Abstract** This review utilizes the Global Environment Facility (GEF) and UN Food and Agricultural Organization (FAO) working definition of "productive uses of energy," which states "in the context of providing modern energy services in rural areas, a productive use of energy is one that involves the application of energy derived mainly from renewable resources to create goods and/or services either directly or indirectly for the production of income or value." The definition reflects the shift toward the aspirations of the Millennium Development Goals (MDGs). Traditionally, the productive uses of energy have been rather narrowly defined. The focus has been on the direct impact of energy use on gross domestic product (GDP) and the importance of motive power for agriculture. This conventional view has some utility in understanding the nature of development at the national and regional level; however, in order to respond to international development goals while maintaining pace with an ever-evolving understanding of what development is, it is important to consider how this traditional thinking may be augmented. The earlier thinking about the productive uses of energy needs to be updated with an enhanced understanding of the tremendous impact that energy services have on education, health, and gender equality. Indeed, a refined understanding of energy use has important public policy implications because scarce resources may be guided into investments that may achieve the desired national or international development goals.

CONTENTS

INTRODUCTION

There is almost unanimous agreement that energy plays a pivotal role in national development. Generally, there is a high degree of correlation between energy use, economic growth, and level of development. In the context of rural development, the traditional view of the productive use of energy is that it is associated primarily with the provision of motive power for agricultural and industrial or commercial uses. For example, motors are used to grind grain, operate power tools, irrigate farmland, and facilitate many commercial activities. It was believed that the motive power made possible by electricity would result in tremendous productivity gains and economic growth, thus transforming the underdeveloped rural landscape. In other words, the emphasis has been on the direct income-generating uses of energy.

The traditional concept of productive uses of energy for rural development needs to be revised for primarily two reasons. First, there is a growing realization that although energy is a necessary condition for rural development, it is insufficient by itself to bring about the desired socioeconomic impact. Second, there is a significant shift in the understanding of what is meant by rural development, especially in the context of the Millennium Development Goals (MDGs) used by the major donors and international development agencies.

The MDGs emphasize not just poverty reduction in terms of income, but they also highlight the importance of improved health, universal primary education, women's empowerment, and gender equality. The very goals of development are to raise incomes of the poor and also to ensure that they are educated and healthy, and treated equally. Thus, an enhanced understanding of what is a productive use of energy must take into account not only the direct impact of energy on raising incomes, but also the indirect impacts that energy can have on education, health, and gender issues.

TRADITIONAL VIEW OF PRODUCTIVE USES OF ENERGY

For rural development, energy was, and in some cases still is, looked at as having two distinct uses: residential and productive. Residential uses of energy are expected to positively impact the rural quality of life or improve rural living standards (1, 2). The productive use of energy in rural areas is expected to result in increased rural productivity, greater economic growth, and a rise in rural employment, which would not only raise incomes but also reduce the migration of the rural poor to urban areas.

With respect to agricultural production, electricity would be used principally to provide motive power for agriculture-based industries and would power farm machinery, such as water pumps, fodder choppers, threshers, grinders, and dryers. This would result in the modernization of agricultural production. Electricity would bring an increase in irrigation, which in turn would result in an increase in the amount of required labor. The generous output of these modernized farms would provide inputs to large commercial enterprises such as rural cooperative sugar factories.

Another example includes the use of electricity as a source of driveshaft power and lighting, which is suitable for rural industries, for example, machine shops. In the past, a common belief was that once a rural region was provided with electrical service and access to modern energy, rural industries would expand and the quality of rural products would improve. Over the long run, the availability of modern energy services would provide significant indirect social benefits such as greater equity and improved quality of life. In short, if energy was used for productive applications, it would transform an underdeveloped agrarian economy. Not surprisingly, the process has proved to be more complicated (3–5). One example of this is India.

India has a long history of supporting rural electrification for productive uses, in recognition of the potential benefits for the country in terms of poverty alleviation and food self-sufficiency. A major component of India's rural electrification program since the late 1960s has been to promote electricity for irrigation pumping by heavily subsidizing agricultural electricity rates (6, p. 13). Since then, 13 million pump sets have been put in use for irrigation by Indian farmers. Partly owing to the high prices of other pumping alternatives such as diesel, and partly owing to the constrained capacity of the State Electricity Boards, today there are substantial waiting lists for irrigation pump-set connections in most Indian states.

Thus, this program in India has been relatively successful in promoting productive uses—particularly in the form of irrigation. However, electricity use by households has not kept pace with its use for irrigation pumping, and it is estimated that only about 44% of rural households actually have electricity in their homes. Bangladesh, by contrast, has witnessed a more balanced approach toward rural electrification. The rural electrification program in Bangladesh stressed both residential as well as productive uses of energy and has met with reasonable success (7, 8).

Lack of adequate electricity for households has important gender implications as well. Because agriculture and cultivation are usually male domains (with homes being female domains), the traditional definition of productive use of energy has an inherent gender bias (9). This bias is evident in the rural marketplace as well. Even in rural areas where households have access to electricity, markets stock leisure items such as televisions and radios but not labor-reducing modern cooking appliances for women. Because men serve as the decision makers in households, the market tends to cater to their needs over women's (10).

In Indonesia, a survey of a relatively wealthy rice-growing region found that the rate of growth of pump sets was low and that most irrigation continues to be successfully accomplished through traditional, gravity-fed methods. Furthermore, the price of kerosene and diesel in Indonesia was heavily subsidized, making it less attractive for those farmers who used diesel pumps to switch to electricity. Thus, experience suggests that there are many different ways to promote productive uses of energy. This has important consequences not only in shaping the program but also in producing the types of benefits needed for rural areas.

EMERGING VIEW OF PRODUCTIVE USES OF ENERGY

The view that the productive use of energy for rural development is primarily one of motive power is now changing. There are several reasons for this change. First, some recent studies have documented that lighting for rural nonfarm businesses actually improves productivity and provides additional income for rural people (11). Secondly, there is growing evidence that electricity use in rural homes is related to an improvement in education levels (12). And, because there is a well-documented relationship between lifetime earnings and education, a use of energy that positively impacts education can be considered productive (13). For instance, one study that stresses the value of human capital in development states, "The main engine of growth is the accumulation of human capital—or knowledge—and the main source of differences in living standards among nations is a difference in human capital. Physical capital plays an essential but decidedly subsidiary role" (14).

Finally, access to modern energy services can lead to improvements in health. Although there are very few studies examining the relationship between electricity and health, there is a growing body of literature on indoor air pollution and its impact on both morbidity and mortality (15, 16). And because people who are unhealthy cannot work as much as people who are healthy, surely improved health will lead to higher incomes. Thus, the uses of energy in homes or businesses, which can have a positive impact on social development in many contexts, are also productive.

In June 2002, the Global Environment Facility (GEF) and the Food and Agricultural Organization (FAO) held an expert workshop on the productive uses of renewable energy (17). The fact that the traditional concept of productive uses as motive power for farms is under scrutiny was revealed as the assembled international experts grappled with developing a working definition of productive uses. In the end they settled on the following definition: "In the context of providing modern energy services in rural areas, a productive use of energy is one that involves the application of energy derived mainly from renewable resources to create goods and/or services either directly or indirectly for the production of income or value" (17).

It should be noted that the above definition is specifically for renewable energy; however, it can apply to energy derived from all sources. The workshop

participants admitted that the meaning of productive uses of energy in the context of human development is difficult to establish. They felt that a use of energy that is instrumental in bringing about an increase in income is clearly a productive use. They also felt that the use of energy for increasing education and/or life expectancy is also a productive use; however, the impact that energy can have on these two is an indirect one. They argued that educated and healthy people will possess greater potential for income generation than a comparatively unhealthy and uneducated people. Thus, uses of energy to enhance education and life expectancy should be considered productive uses.

However, some argue that applications of energy for home lighting and entertainment cannot be considered as productive applications, because even though they improve the quality of life, their linkages to the Human Development Index are less obvious and almost impossible to quantify. In a review of renewable energy markets Martinot et al. (18) use a definition similar to the one developed by the GEF/FAO workshop. Both not only include the uses of energy that have a positive impact on income generation, but also include the uses of energy for indirect social benefits such as education and health. Finally, K. Kapadia, in an unpublished World Bank paper (19), cites three primary reasons for the emphasis on productive uses of energy: maximization of the economic and social benefits, catalyzed by access to energy; facilitation of the Millennium Development Goals; and improving the economic sustainability of rural electrification projects and renewable energy markets.

Although all of the above-mentioned reasons for choosing the definition of productive uses are extremely pertinent, they preclude a broader understanding of what is meant by development. Amartya Sen (20) stresses the importance of thinking of development as the process of expanding the real freedoms that people enjoy. Specifically, he notes that the growth of individual incomes is important "as *means* to expanding the freedoms enjoyed by the members of the society." In addition, he provides a wide list of freedoms, e.g., political freedom, opportunities to receive basic education, opportunities to receive health care, and freedom to participate in the labor market. It is often asked, he says, whether these freedoms are indeed conducive to development. This question, however, unfortunately misses the point that these very freedoms represent what development aims to achieve.

In the context of energy, many of the uses of energy that are seen as consumptive (e.g., home lighting or television) in fact may be uses that help achieve the goal of freedom allowed by development. For instance, television viewing is considered traditionally as a consumptive or unproductive use of electricity. However, a recent study in Bangladesh revealed that women in households with electricity were much more aware about gender equality issues than women in households without electricity. Furthermore, these women cited the television as their chief source of information for gender equality-related knowledge (7). In the discussion above on the definition of productive uses of energy, energy projects that have a positive impact on education and health are included because improved health and education increase people's incomes. A broader understanding of development would suggest that improved health and education are goals and ends in themselves.

This is not to suggest that an emphasis on income generation is misplaced. However, if the only productive uses of energy are those that facilitate income generation, then any use of energy which does not must therefore be an unproductive use. Although energy professionals and specialists may understand that "productive uses of energy" is mere substitute nomenclature for "income-generating uses of energy" and does not in any way pass a value judgment on the "unproductive uses of energy," some may mistakenly believe that only energy projects that increase income are valuable. Thus, it may be worthwhile to consider revising the nomenclature for income-generating uses of energy from "productive uses of energy" to what they really are, namely, "income-generating uses of energy."

Quantifying the impact of energy services on human development is not easy. However, a lack of quantitative data does not suggest the absence of a relationship but rather the need for further analysis and research. The next section discusses the impact that modern energy services can have on achieving the development goals in rural areas of developing countries.

LINKING OF ENERGY WITH DEVELOPMENT GOALS

The energy sector has a significant and productive role to play in achieving the goals related to income and poverty, education, health, and gender issues. More than half of the world's population and more than 70% of the world's poor are found in rural areas (21). Energy access can have a substantial positive impact on rural growth and livelihoods. In terms of economic development, it provides the basis for improving productivity by facilitating income generating activities and improving the business climate. In terms of human development, the energy sector can assist in reducing child mortality, maternal mortality, and other diseases by facilitating better health services. It can also encourage the development of higher literacy rates, gender equality, and women's empowerment. It is not surprising that a number of statistics show a very strong association between increasing commercial energy consumption and human welfare.

The MDGs (22) adopted by the UN member states commit the international community to human development and are key to sustaining social and economic progress in all countries. These goals are now almost universally accepted as a framework for measuring developmental progress. The MDGs seek to (23) eradicate poverty and hunger; achieve universal primary education; promote gender equality; empower women; reduce childhood mortality; improve maternal health; combat HIV/AIDS, malaria and other diseases; ensure environmental sustainability; and develop a global partnership for development. The UN Millennium Project, which offers a practical plan to achieve the MDGs, has also recognized the importance of energy services. It has mentioned the provision of electricity for all schools and hospitals as one of the quick-win interventions that can be implemented immediately and has the potential to bring vital gains in well-being to millions of people (24). Table 1 is a modified version of Kapadia's diagram, which depicts the association between energy and the MDGs (19).

TABLE 1 The linkages between energy, productive applications and the Millennium Development Goals (19)

Technology/fuel type	Appliances powered	Productive applications	Millennium development goals
Grid:	Light bulbs	Heating & cooling:	Eradicate extreme poverty and hunger:
Fossil/renewables	Radios	Ice making	Increasing productivity of businesses owned by or that employ the poor
Minigrids:	Televisions	Refrigeration of medicine	Facilitating establishment of businesses that employ the poor
Diesel generators	Refrigerators	Water heating	Lowering costs of energy
Small hydro	Air conditioners and fans	Processing:	Achieve universal primary education:
Small wind	Stoves and ovens	Drying for food, spices	Increasing literacy and time for reading because of improved lighting
Biomass—combustion/ gasification	Pumps	Production of sugar and silk	Increasing household income and decreasing time spent on collecting traditional fuels increases time for children to spend on education and increases likelihood of school attendance
Hybrid–diesel with PV/wind/biomass	Motors	Grain and saw mills	Promote gender equality and empower women:
Stand alone systems:	Heaters	Textile dyeing and weaving	Reducing time and efforts to gather wood/biomass
Solar PV	Boilers	Water related:	Improving access to information (via radio, television)
Biogas		Desalination	Improving standards of living
Diesel generators		Pumping for irrigation and potable water	Improve maternal health and reduce child mortality:
Microhydro		Purification	Reducing respiratory illness because of cleaner fuels
Shaft/mechanical energy:		Energy production and conversion:	Improving delivery of health care
Wind		Battery charging	Reducing household accidents like burns or poisoning
Water wheels		Gaseous and liquid fuels	Reducing fertility
Heat energy (community scale):		Lighting:	Combat HIV/AIDS, malaria, and other diseases:
Biogas		For community centers, health clinics, schools, workshops and homes	Reducing incidence of food and water-borne illnesses due to increased boiling of water and refrigeration of food
Biomass—combustion/ gasification		Communication:	Ensure environmental sustainability
Solar thermal		Distance education	Develop a global partnership for development
Heat energy (household scale):		Internet	
Liquefied petroleum gas		Telephone	
Biogas		Video	
Solar thermal		Miscellaneous:	
Passive solar design		Brick making	
		Carpentry	
		Electric fences	
		Environmental monitoring	
		Fish hatcheries	
		Handicraft production	
		Power medical equipment	
		Sewing	
		Welding	

Energy and Poverty

Energy services can help reduce poverty and raise incomes in a variety of ways. The traditional thinking about the productive uses of energy considers only the impacts on farm incomes by substituting machines for animal and human labor. However, energy services impact incomes in other ways too, such as saving time and resources, indirect benefits due to lighting and communication, and numerous other positive impacts on the nonfarm business environment. An expanded definition of the productive uses of energy would provide a greater emphasis on these benefits of energy.

Electric-powered farm equipment has tremendous benefits for rural farm incomes. As discussed above, farm machinery, such as water pumps, fodder choppers, threshers, grinders, and dryers, increase average yields per acre, improve cropping intensities, are more dependable, increase cost efficiency and productivity, decrease labor time consumed, increase areas for cultivation, and result in higher crop growth. Several studies have documented these benefits (25, 26).

One such study in India (25) demonstrates that the addition of an electric pump to a typical farm without electricity can result in an approximate income gain of about 11 thousand rupees (Rs) annually. This compares quite favorably to the farmers' electricity expenses (excluding electric pump capital expenditures), which average between 2 and 3 thousand rupees per year. Given existing agricultural subsidies, an irrigation pump appears to be a good investment for most small, medium, and large farmers with available groundwater resources. As indicated in Table 2, the same may not be true for marginal farmers, who gain only about 5600 Rs, as this sum may not cover capital costs. Therefore, it is quite reasonable that most of the farmers in this group have not yet invested in irrigation.

Apart from raising farm incomes, modern energy services can improve the more informal aspects of rural incomes by reducing much of the necessary daily drudgery that pervades the lives of the rural poor. For example, the rural poor spend a considerable amount of time each day collecting fuelwood, dung, and water. Because biofuels are a poor source of energy (particularly for an activity such as cooking), they consequently have to be collected in large quantities. If the rural poor had access to improved stoves and modern cooking fuels, this time could be spent on income-generating, educational or other activities.

On the extreme end of the spectrum, studies in South Indian villages have revealed that families spend 2–6 hours each day collecting 10 kilograms of wood over distances of 4–8 kilometers (27). A survey in the Himalayas (27) found that although the hilly areas of Nepal provided an abundant supply of fuelwood, women still had to spend more than an hour each day collecting biomass (28, 29). The survey also revealed that the amount of time they were able to spend on agricultural activities was reduced likewise (compared to other people who were not dependent on these fuels). Surveys in Africa have shown similar results (30). Some evidence from India suggests that even if households continue to cook using biomass fuels, lighting enables timesaving food preparation (31). Table 3 illustrates the amount of time and effort families spend gathering fuelwood each day.

TABLE 2 Impact of irrigation with electricity on farm income in six states, India, 1996 (25)

	Sample size		Farm income (rupees per year)		Farm size (ha)[a]	Irrigated area (ha)	Predicted net income gain from irrigating rain-fed farms with electric pumps		
	All farms	Percent of farms with electricity	Rainfed farms	Electric pump farms	All farmers	Electric pump farmers	Percent income gain	Rupee income gain	Rupee income gain per kWh
Large farmer	617	20.3	31,849	60,210	7.565	3.305	45	14,205	3.71
Medium farmer	253	18.6	14,573	33,336	2.501	1.655	81	11,804	3.24
Small farmer	702	13.0	15,479	27,925	1.531	1.277	54	8,343	2.32
Marginal farmer	1,189	6.1	9,514	12,890	0.552	0.558	59	5,604	2.39
Average	2,761	12.2	15,911	37,426	2.547	1.928	68	10,867	3.18

[a]The farm sizes are as follows: large farms are greater than 3 hectares (ha), medium farms are 2–3 ha; small farms are 1–2 ha; and marginal farms are less than 1 ha.

TABLE 3 Time spent gathering fuel, early 1980s (33)

Country	Average hours per day	Explanation of work
Southern India (6 villages)	1.7	Women contribute 0.7 hours; children contribute 0.5
Guajarat, India	3.0	In family of 5, 1 member often spends all his/her time on it
Nepal	1–5	Often 1 adult and 1–2 children collect fuelwood
Tanzania	8.0	Traditional women's work
Senegal	4–5	Often is carried about 45 km
Niger	4–6	Women sometimes walk 25 km
Kenya	3.5	Women do 75% of fuel gathering
Ghana	3.5–4	One full day's search provides wood for 3 days
Peru	2.5	Women gather and cut wood

Time is not the only precious resource that is wasted by the rural poor owing to a lack of modern cooking fuels. Using dung and crop residues as a fuel reduces the amount available for use as a fertilizer for growing crops, thus reducing income from crops. The dung used as fuel in India would be worth US$800 million per year if it were used as fertilizer (32, 33).

Also, the importance of lighting and the many benefits that it provides is oftentimes ignored. Without lighting, livelihood activities cannot be continued beyond daylight hours, thereby reducing the total number of productive hours available. If the rural poor had access to lighting, they could work in the evenings and nights. For example, some poor Indian households that operate small cottage industries increased their income by 10 Rs per day using light to extend their productive hours after nightfall (34). In Indonesia (35), solar home systems provided lighting, which not only had a direct impact on income-generating activities such as office and store hours but also on activities related to household chores.

Another often overlooked impact is the facilitation of information and communication technologies. Rural energy services allow farm and nonfarm sectors access to modern communication, enabling them to receive accurate and current market prices. Lack of adequate information hurts sound business decision making and lowers income. For example, telephones in rural Thailand have enabled farmers to check prices in Bangkok regularly, significantly increasing their profits (34). Also, in India, the "*e-choupal*" initiative has succeeded in providing farmers with access to Internet-enabled computers, which helps them obtain current information on market prices and good farming practices and allows them to order agricultural inputs. This initiative has resulted in improvements to the quality of their produce and also ensures that they receive better prices for their produce (36).

All of the above-mentioned benefits of improved energy services result in an improved business environment for small farm and nonfarm businesses. An example of the links between productivity and electricity is provided by a recent study in the Philippines, which found that small home businesses were more active in areas with electricity and made a greater contribution to family income than those in areas without electricity (see Table 4). Overall, 25% of households with electricity operated a home business, compared to about 15% of the households without electricity (12). The businesses with electricity, furthermore, were more productive than those without electricity. Most of these businesses were small general stores.

Bundling the delivery of electricity with other services or coordinating rural electrification with other development programs has been shown to magnify its effect on income (37). A household survey in India, for instance, revealed that while both education and electricity can result in higher nonfarm income, when the two services are delivered together the effect is amplified by as much as 2.3 times (or 25,000 Rs of annual household income) (6). The traditional definition of productive uses of energy does not take into account these types of synergies.

Education

Modern energy services can have a positive impact on the time children spend at school and also improve the quality of the schools and the teaching. Electricity also provides lighting for rural homes, which increases the number of hours children have to study. In fact, children in rural areas are often unable to go to school because they must perform household chores and/or income-earning activities. For example, collecting cooking fuel can be an important component of a child's daily household chores; and if children are in school, they are unable to assist the household in this activity. Similarly, children may be involved in certain income-generating activities. This income could be vital to the economics of the households, thus acting as a disincentive for the parents to send their children to school.

As discussed above, lack of access to modern cooking fuels in rural areas forces villagers, often girls, to spend considerable amounts of time collecting firewood. If there is access to modern cooking fuels or better stoves (38, 39), then children need not spend hours every day collecting firewood and can take courses at school instead. In Morocco, road improvements made butane more affordable. This reduced the need for girls to collect firewood, giving them more free time and opening up new opportunities for education, work, and other activities (34).

A comprehensive survey in India was able to quantify the complex relationship between electricity and education (25). Although the positive influence of rural electrification on education is fairly well established, it was found that one of the main benefits of electricity is a very high amount of quality light compared to that provided by kerosene. This high quality light in the evening creates an atmosphere in which reading is possible for adults and children, who can more easily pursue their studies.

TABLE 4 Percentage distribution of households in the Philippines with the presence of a home business, 1998 (12)

	Mountain provinces		Nueva Ecija		Batangas		Camarines Sur		Total sample		
Home business status	**NE[a]**	**E**	**NE**	**E**	**NE**	**E**	**NE**	**E**	**NE**	**E**	**All households**
No	96.0	80.6	89.4	74.4	84.2	79.2	81.9	66.7	85.2	75.3	77.5
Yes	4.0	19.4	10.6	25.6	15.8	20.8	18.1	33.3	14.8	24.7	22.5
Valid N (thousands)	5.89	12.4	10.0	51.1	4.3	79.1	30.7	37.7	51.0	180.3	231.2

[a]NE, nonelectrified; E, electrified.

Furthermore, the likelihood of having electricity is directly related to the level of education and the level of income (see Table 5). Households in the rural energy sample with low levels of income earn about 13 thousand rupees per year and only 30% of them have electricity. This contrasts with close to 30 thousand rupees annually for the more than 80% of households that have electricity and have an adult with a high school education.

Particularly interesting was the finding that with every year of education, electricity seems to have a greater impact on income compared to those households without electricity. In other words, the combination of electricity and education has a greater effect on income than each variable taken separately. This finding has potentially important policy implications because it implies that education and electricity are mutually supporting programs.

Providing education without electricity is not going to have as much impact as providing education with electricity. Similarly, providing electricity by itself without schools or other educational facilities will not have as much impact as having both of them present in a community. This is supported by a study in Peru that found the bundling, or joint provision, of services was very important in creating positive impacts and increasing returns. To illustrate, the study found, in an analysis of identical households, that those households with access to basic services such as electricity and water "had a significantly higher growth rate of per capita consumption than households that did not have such access" (37).

Rural schools throughout the developing world typically lack electricity and clean fuels. Many development assistance programs will pay to build school houses and provide books, teaching materials, and basic furniture, but electricity is rarely part of the package. With modern energy, these schools can much better serve the needs of students and their families by providing space heating, clean water, good meals, and educational facilities that include decent lighting, audio/visual equipment, computers, and information and communication facilities. The use of electricity, modern fuels, and thermal energy services for schools is described in a detailed manual (40) from the National Renewable Energy Laboratory.

Electricity and clean water are also essential services if schools are to offer decent living and working conditions for teachers. Retaining qualified teachers in remote rural areas is a challenge. For example, there is an ongoing crisis in teacher retention faced by the Papua New Guinea Department of Education and the various Provincial Divisions of Education. At present, there are approximately 36,000 primary, elementary, and secondary school teachers posted throughout the country. Over 90% of the teachers are in rural locations and serve the predominantly rural population. Most primary and elementary school teachers have little or no provision for power supply. Primary schools in particular typically do not have electricity or communications, and teachers posted to these schools and their families suffer from a lack of basic amenities. Not surprisingly, poor teacher retention directly contributes to low levels of access to education and poor educational outcomes.

TABLE 5 Relationship between education and income in rural India, 1996 (25)

	Yearly income (Rs)		Percent of households with education level		Yearly income (Rs)	
Years of education[a]	**No electricity**	**With electricity**	**No electricity**	**With electricity**	**Total households**	**Total households sampled**
0	13,794	18,472	70.8%	29.2%	15,160	702
3	17,531	18,184	67.4%	32.6%	17,744	577
6	19,726	24,861	50.7%	49.3%	22,259	821
9	19,907	30,233	31.9%	68.1%	26,936	1588
12	24,604	38,279	17.6%	82.4%	35,867	720
14+	31,158	55,350	11.9%	88.1%	52,477	640
Average	18,622	34,214	39.9%	60.1%	27,999	5048

[a]Years of education: 0, illiterate or literate but no formal schooling; 3, primary (1–4 Std); 6, middle (5–7 Std); 9, high school (8–10 std); 12, higher sec (11 & 12 std); and 14+ = graduate/LLB, B. Ed. MA, Technical (Dr., Eng., ITI Diploma, etc.).

An example of how this problem is being addressed is the proposed World Bank and GEF-assisted Teacher's Solar Lighting Project in Papua New Guinea that will provide a modest financing package, making the purchase of solar lighting kits affordable for teachers and eventually for health workers and the general public. It is intended to improve delivery of education in rural Papua New Guinea through longer retention of teachers posted to remote areas. The project will provide the financial remediation necessary for the PNG Teachers Savings and Loan Society to offer long-term (five-year) fixed-rate loans that make purchase of a Solar House Lighting kit by school teachers possible (41).

Electric lights in schools and homes permit evening study and classes. These greatly encourage adult education because adults are busy during the day. Educated adults, especially women, ensure educated children (42). Lighting also allows for a reduction in household accidents such as paraffin poisoning and burns associated with other commonly used fuels such as kerosene. According to some estimates, in Sri Lanka, one person dies every two days as the result of burn injuries associated with unsafe bottle lamps (43).

A study in the Philippines examined the social and economic impact of rural electrification (12). The most important finding was the clear link between electricity and education. Rural households perceived electricity to be important for children's education because it improved study conditions during the evening (see Table 6 for details). This was borne out by the increased number of hours spent by both children and adults reading in rural homes, where electricity was available. Children from electrified households gained about two years in educational achievement over children from nonelectrified households. A household survey in Vietnam produced similar results (44).

Distance education (45, 46) is widely used in secondary schools (grades 7–9) throughout Mexico. The *Telesecundaria* program provides education to children who live in rural and indigenous communities where access to modern education services is limited. The educational program uses 16-minute televised lessons transmitted from Mexico City via the EDUSAT satellite. Rural teachers use the broadcast in combination with related texts and other teaching materials for a total educational segment of 48 minutes. The television sets are used for about 2 hours during each school day. Both grid electricity and photovoltaic (PV) power systems are used to ensure reception by all communities.

TABLE 6 Electricity and education in Philippines and Vietnam (12, 44)

	Strongly agree	Agree	Neutral/no opinion	Disagree	Strongly disagree
Philippines: In my house it is easy to read in the evening					
No electricity	11%	30%	20%	36%	3%
Electricity	31%	54%	11%	3%	1%
Vietnam: Having electricity is important for children's education					
All households	55%	40.5%	3.5%	1%	0%

The Mexican program is not just about energy; it is a comprehensive distance education program developed over more than three decades, and it is a major initiative in bringing the possibility of universal primary and secondary education to Mexico. Other developing countries are using various energy-enabled methods for distance information and education, including both low-cost radio (e.g., Mali) and television. The integration of modern energy with schools and effective curricula is emerging as an essential approach to achieving improved education in rural areas of developing countries.

The evidence of correlation between electricity and education is strong, but we must caution that the difficult issue of causality has not been fully resolved. There is fairly strong evidence that electricity is related to improvement in school attendance, literacy, and level of education, but this could be caused by the decision of educated households to adopt electricity as well. These are issues that require further investigation and may be assisted by the inclusion of energy questions in national multisector surveys, a topic addressed below.

Health

Rural social and economic development depends significantly on the state of health of the population. For rural people to be productive farmers, fishermen, and workers, they must be healthy and well nourished. As mentioned previously, it can also be argued that better health has an intrinsic value and, irrespective of its impact on income generation, is a desirable goal. Indeed, energy has a significant role in improving public health in rural areas. Modern energy services improve health service delivery, increase access to safe drinking water, provide clean fuels that reduce indoor pollution, and can make available various communication tools (e.g., radio, television, and the Internet), which can be utilized effectively against AIDS and other diseases.

Rural health clinics are the front line against disease and in the promotion of health in rural communities. Yet few rural health clinics in the developing world have access to electricity, modern fuels, clean water, or telecommunications. Provision of electricity, heat, and kerosene or liquefied petroleum gas (LPG) to rural health clinics allows cleaner and safer environments, power for operating lights, water pumping and heating, sanitation, sterilization of medical equipment, medical refrigerators, other laboratory equipment, and telecommunications equipment. Handbooks (47) are available that provide detailed information on the electrical and thermal (e.g., clean fuel) requirements of rural health posts, together with information on alternative means for providing the required energy services.

Without electricity for lighting, it is difficult to present health and medical information to local families and communities at night (when the men are back from the fields); yet providing such information and education is central in the war against the triple pandemic of HIV/AIDS, malaria, and tuberculosis. Deaths at birth can be reduced with improved delivery conditions, such as proper lighting. In the absence of a good lighting source, doctors are unable to perform operations at night or even examine patients (48). In health clinics, energy makes it possible

to refrigerate vaccines (49) (e.g., measles and tetanus toxoid vaccine) and operate medical equipment (50, 51). Telecommunications equipment is essential in contacting physicians and in locating and obtaining emergency sources of medicines (e.g., antisnakebite serums).

Without electricity and fuels, such as kerosene or LPG, for rural health clinics and the residences of nurses and doctors, it is extremely difficult to attract, much less hold, trained health workers in rural areas. In Ghana, a primitive rural primary health care facility in the community of Binde (52) evolved into a district hospital with the introduction and expansion of electricity (primarily from PV systems) and use of LPG for heat and sterilization. As of May 1998, 170 rural clinics in the remote mountain regions of Cuba (53) were electrified with PV systems. These systems have reportedly increased the quality of life and decreased the infant mortality rate in those areas. All the systems include lights, a vaccine refrigerator, and other medical equipment, such as electrocardiographs and x-ray machines. Because each clinic has a live-in doctor, the systems include a television and radio.

It is for some of these reasons that maternal mortality rates tend to be lower in urban areas than in rural areas in most parts of the world because urban residents have easier access to appropriate medical services. One study illustrates the beneficial effects that electricity can have on an area's infant mortality rate. As seen in Figure 1, the infant mortality rate in electrified Bangladesh households was 4.27%, whereas nonelectrified households in electrified villages and nonelectrified villages experienced rates of 5.38% and 5.78%, respectively. For further perspective, the infant mortality rate in households with electricity is 25% less than the national average (5.7%) and 35% less than the national rural average (6.6%). The study's estimates show that if access to electricity is expanded to 100% of rural households, the annual number of infant deaths that could be avoided would number roughly 36,818, i.e., a savings of 101 infant deaths everyday (7).

Access to modern energy services also can improve access to clean water, and this, in turn, can make a significant difference in the fight against all kinds of diseases (54). Energy allows the use of mechanized pumps to tap water from deep wells, and energy can be used to boil or filter available water resources to make it safe for drinking. Energy for pumping and treating raw water provides numerous health benefits for communities as well. And, by reducing the cost of boiling water, access to modern cooking fuels not only improves hygiene but also reduces deaths from diseases such as diarrhea.

Exposure to biomass smoke is a significant cause (55) of health problems, such as acute respiratory infections, chronic obstructive lung diseases, lung cancer, and pregnancy-related outcomes (56). Indoor air pollution affects children and women the most. In fact, indoor air pollution is estimated to kill 2 million women and children every year: There are about 500,000 deaths in India, roughly the same in China, with the other million in other developing countries (57). It is also estimated that indoor air pollution causes 500 million incidences of illness each year among women and children in India alone (58). In Nepal and India, studies of women exposed to biomass smoke—but who did not smoke themselves—found that their death rate from chronic respiratory disease was similar to that of heavy smoking males (59).

TABLE 7 Comparison of indoor pollution levels from open fire, *plancha*, and liquefied petroleum gas (LPG) stoves in the Guatemalan Highlands (59)

Type of stove	$PM_{2.5}$[a] ($\mu g/m^3$)	PM_{10}[a] ($\mu g/m^3$)	CO (mg/m^3)
Indoor concentrations of pollutants			
Open fire	527	717	5.9
Plancha	96.5	186.3	1.4
LPG stove	56.8	210.2	1.2

[a]$PM_{2.5}$ and PM_{10} are particulate matter with an aerodynamic diameter less than 2.5 microns and 10 microns, respectively.

The exposure to smoke is quite high in households that cook with biomass fuels in traditional stoves. For instance, a study in the Guatemala highlands (see Table 7) indicates that households using open fires for cooking have average particulate exposure levels of over 700 micrograms per cubic meter of air over a period of 24 hours. For households with an improved stove (*plancha*) or those that use LPG, the exposure levels are 100 to 200 micrograms per cubic meter. As a reference, this level can be compared to the United States Environmental Protection Agency's recommended maximum exposure level of 50 micrograms. Therefore, developing country households that used open fires or three stone stoves have very high levels of exposure to particulates.

There is strong evidence of causal linkage between biomass combustion emissions and acute respiratory infections in children (60, 61). Children are particularly vulnerable because they spend a lot of time indoors close to the women who are doing the cooking. A study in the Gambia, for example, examined the health of 500 children under five years old. It found that girls, who were carried on their mother's backs as they cooked in smoky huts, were six times more likely to develop acute respiratory illness than other children (62). World Health Organization figures indicate that 20% of the 10.9 million deaths of children under five years old in 1999 were due to acute respiratory infections. In Bangladesh, a study found that a child's exposure to indoor pollution could be halved simply by increasing their time spent outdoors from 3 to 6 hours per day and by concentrating this outdoor time during peak cooking periods (63).

Information and communication facilities also play a crucial role in improving health. Rural health clinics benefit from radio-telephone communications capabilities, including single-side-band radios, two-way radios, cellular phones, and satellite phones. In Cuba, clinic electrification resulted in significant health improvements in local communities. However, owing to the remoteness of clinics, doctors had no way to communicate with ambulances or hospitals. Radio communications were added to each clinic. Of the 170 clinics, 130 have radiotelephones, allowing them to communicate with hospitals in the larger towns. The radiotelephones have already saved numerous lives and have been used for many purposes, including during hurricanes and floods to request ambulance or helicopter assistance; to inform relatives of the condition of a patient in a hospital; to inform hospitals

about the status of vaccination campaigns; to ask for specific medicines needed by the clinic; and to solicit help from medical specialists. Importantly, the communications equipment adds only slightly to the cost of the total PV system.

Apart from having direct impacts on health (as described by the examples above), energy services also provide indirect impacts on improving health by increasing literacy, reducing malnutrition, and promoting women's empowerment. For instance, a rise in women's literacy and education has a strong impact on reducing child mortality, maternal mortality, and HIV/AIDS. Educated women take better care of children and increase a child's chances of surviving. Grant in "The State of the World's Children" (64) has shown the relationship between female literacy rate, contraceptive prevalence, the crude birth rate, and the maternal mortality rate. The higher the female literacy rate, the lower is the maternal mortality rate. The education of young people merits the highest priority in a world afflicted by HIV/AIDS because education is the most effective—and the most cost-effective—means of prevention (22).

Increased energy access can have an indirect impact on reducing malnutrition. About 95% of staple foods need cooking before they can be eaten. Thus, lack of access to energy may render some, otherwise edible, products inedible and increase hunger. Malnutrition plays a role in more than half of all child deaths. Experts agree that malnutrition leaves many women unable to meet the physical demands of pregnancy (65).

Gender Equality and Women's Empowerment

Lack of women's empowerment has a direct impact on women's health issues. It is not an exaggeration to say that a maternal death is the outcome of a chain of events and disadvantages throughout a woman's life (66). A UNICEF publication (67) titled *The Lesser Child* highlights the disadvantages of being born a female. For example, girls are likely to be breast fed less often and for a shorter period of time than boys, resulting in malnourishment from the beginning of their lives. They also are subjected to heavy work both within and outside the house at an early age and, when ill, are less likely to receive medical help. Energy services in rural areas can have a significant impact on women's empowerment (one of the MDGs), thus indirectly impacting women's health issues too.

Energy projects are often seen as having no impact on gender equality (68), however, as it is assumed that energy services impact men and women in similar ways. This assumption does not reflect reality in most developing countries. Consequently, several energy projects have not been as successful as they should have been because they failed to recognize the differences in energy usage patterns between men and women (69).

As a matter of fact, rural markets in developing countries often do not provide appliances that cater to women's needs. Although these markets stock leisure items such as televisions as well as video and audio players, they do not provide labor-saving cooking devices for women, e.g., mixers, grinders, and cookers. One of the reasons this occurs is that men are the decision makers; hence, markets are biased

TABLE 8 Hours spent on nonincome-earning activities each week in winter (70, p. 111)

	Gaozui		Zhaoshan		Xiapai	
Gansu	**Men**	**Women**	**Men**	**Women**	**Men**	**Women**
Cooking	1.1	11.9	2.5	12.6	2.7	18.8
Gathering fuel	1.4	9.6	2.8	4.6	1.2	2.7
Fetching water	2.4	2.2	1.1	0.6	1.0	1.7
Washing clothes	0.6	2.1	0.4	1.8	0.4	3.6
Feeding livestock	3.5	2.8	6.7	2.2	4.2	2.3
Grazing sheep	0.5	1.6	5.3	2.4	3.3	1.2
Feeding pigs/chickens	0.0	2.1	0.3	3.7	0.1	3.1
Cleaning house/yard	0.0	2.5	0.4	3.6	0.4	4.3
Gathering dung	0.0	0.8	0.4	1.6	0.1	0.1
Total	9.5	35.6	19.9	33.1	13.4	37.8

toward goods that serve their interests. Women benefit from televisions and radios too, but many of the labor-saving devices that are of greater benefit for women are not considered a priority (10).

Many of the benefits that stem from modern energy services disproportionately benefit women more than they benefit men (31). This is largely true because it is women and girls who spend the most amount of time and effort cooking, collecting water, and collecting fuelwood and other biomass resources (see Table 8 for an example). Thus, any improvement in energy access will disproportionately benefit them. By reducing the time women must spend cooking and collecting water, electricity allows women and children to spend more time on educational, social, and income-generating activities. This additional time can have a dramatic effect on a woman's level of education, health, economic opportunities, and involvement in community activities (70).

Limited access to modern energy remains an issue of gender equity in much of the rural developing world because 70% of all poor are women. A study of the impact of electricity on rural women in India showed that women from households with electricity had more time for leisure activities than women from households without access to electricity. There also is evidence that suggests the probability that a woman will read is very strongly related to the presence, or absence, of electricity in the home. In fact, regardless of income level, virtually no reading takes place in households without electricity.

The Indian experience was mirrored in Mali (71), where modern energy services derived from a multifunctional platform project showed that after the implementation of the project women were spending less time milling cereals and dehusking rice. They also were generating greater revenue from the sale of agricultural goods

and foodstuffs and were producing and consuming greater amounts of rice. Perhaps most relevant to the subject of women's empowerment is that the total proportion of girls completing primary school increased as did the girl-to-boy ratio in primary schools. Additionally, from a health perspective, the number of prenatal visits that women made to health clinics also increased.

The successful integration of renewable energy with economically productive uses in the rural Philippines is providing income to many women at a small coconut development cooperative (72). This enterprise employs 200 families; 90% of the employees are women. Not only have employees doubled their household incomes, but previously unemployed rural women are now earning a regular income and, in many cases, have become the principal wage earners. Rural women have been empowered by becoming bona fide (with voting privileges) members of the local coconut cooperative. The Philippine Government and others are supporting replication of this activity in other coconut growing areas of the Philippines.

In Bangladesh, a study revealed that women in households with access to electricity were much more aware of gender equality issues than women in houses without access to electricity. Barkat's case study of Bangladesh (7) provides a "women's knowledge score of gender equality issues" for electrified and nonelectrified households in electrified villages and nonelectrified houses in villages without electricity. Figure 2, demonstrates the effect of electricity on women's empowerment through a combined knowledge score based on three indicators: (*a*) women's freedom in mobility, (*b*) participation in the family decision-making process, and (*c*) knowledge about gender equality issues. Women in households with electricity had a higher empowerment score (0.662) than women in nonelectrified households in both electrified and nonelectrified villages (0.533 and 0.499, respectively).

The same study also found that poor women in electrified households were more knowledgeable (79%) about gender equality issues than even the rich in the nonelectrified villages (64%). This indicates that household access to electricity can greatly improve a poor woman's knowledge of gender issues.

Figure 3, illustrates the sources women in both electrified and nonelectrified households use to acquire knowledge about gender equity issues. Barkat notes that, "Electricity has contributed spectacularly to knowledge-building about selected gender equality issues" (7). Indeed, his statement is validated by Figure 3, which shows that 64% of women in electrified households reported television as their main source of knowledge about these issues.

It can be concluded reasonably, therefore, that women in electrified households, compared to those without, are more aware and knowledgeable about the selected gender equality issues and that electricity (via television) can play an important role as a primary source of this knowledge. This has important implications for the definition of productive uses of energy. In the traditional thinking about productive uses of energy, use of energy for television is considered a leisure or nonproductive use. However, if watching television encourages gender equality and gender equality is one of the goals of development, then energy used for television is energy used productively.

Public lighting improves women's safety and encourages evening community and commercial activities. Clean cooking fuels minimize indoor air pollution and the associated morbidity and mortality of women. Women are at greatest risk from indoor air pollution because of their gender roles, household responsibilities, and behavior (e.g., cooking and spending a lot of time indoors). Modern energy services (e.g., from multifunctional platforms) can increase agricultural productivity and women's incomes. Electricity and fuels for lighting, refrigeration, entertainment, and a host of other purposes permit women to develop small enterprises and increase their income and social power (9).

In conclusion, an updated approach to the productive uses of energy would emphasize that energy services should be part of a suite or package of rural infrastructure services that together can provide a base for substantial economic and social development. For instance, it was found in Peru that when the infrastructure includes electricity, water, and other development programs the various parts actually work together rather than separately to promote economic growth (37). The result is that the causal effects of electricity and other energy services are sometimes hard to disentangle from other causes. However, this is really an empirical issue for further research rather than an argument against the relationship between energy and rural productivity.

EFFECT ON PUBLIC POLICY

The most obvious impact of considering all the productive uses of energy is to realize that even though the MDGs do not explicitly mention energy, without the provision of energy services, the MDGs cannot be achieved (see Table 1 for MDG linkages). This has strong implications for public policy. Development strategies, whether formulated by the developing countries themselves or by international development institutions, must include a greater role for rural energy. In the past, energy was either assigned a marginal role or not mentioned at all in important strategy documents. Such an approach will only serve to repeat the mistakes of the past.

Energy services also cannot be thought of in isolation. Changes in the understanding of the productive uses of energy for rural development have meant that public policy also must consider the following: An emphasis on simply providing electricity coverage in rural areas without adequate forethought to opportunities for business development and poverty reduction is not only undesirable, but in the long run is unsustainable as valuable resources will be wasted. Moreover, promotion of productive uses, in addition to its poverty reduction impacts, can also improve the efficient utilization of energy infrastructure. For example, a rural electrification project in Indonesia included a component to promote rural business services by targeted marketing interventions and price incentives and also addressed information constraints and business needs of small enterprises in rural areas. The rural business service program demonstrated that these promotional efforts led to better daytime utilization of utility electricity generation and distribution assets. In fact, the program supported 66,000 rural enterprises and led to an increase in

employment of 22,000, as well as an increase in electricity consumption by these enterprises of 180 GWh/year (73).

Energy services, to be most effective, have to be applied in a way that they improve the delivery of services from various other sectors such as health, education, information, and communication. This in turn has several implications. To a certain extent, the work on productive uses of energy has overconcentrated on the role of electricity. This is not to diminish the importance of electricity, but to improve maternal health, for example, improved cook stoves and modern cooking fuels are needed to reduce indoor air pollution. Also, it is important that public policy recognizes the interdependence of the various sectors by employing a multisectoral approach. For example, in the case of India, this suggests that the rural electrification program should have a broader focus—one that seeks to improve not only the supply and quality of electricity to households, businesses, and farms, but also to improve access to services (6).

This broader focus implies that within the developing countries, as well as in the international development institutions, development professionals need to have greater cross-sectoral interaction and competence. Energy professionals need to provide greater outreach by engaging planners and implementers within other sectors. By doing so, this will help ensure that an understanding of the important role of energy in delivering services ranging from health to education to communication is held among all professionals across all sectors (71, 73).

Although energy professionals often maintain that their colleagues from the health and education sectors, for example, do not grasp the importance of energy services, more often than not they themselves are guilty of not having made an attempt to understand the education and health sectors. To be sure, it is of critical importance that a better understanding of the linkages between energy and other sectors be found. In spite of anecdotal evidence, there is a lack of sufficient quantitative data on this aspect. However, it is important to emphasize that the lack of quantitative data does not indicate the absence of linkages but rather only indicates the need to study these linkages further.

Thus, it is important to improve and systematize the collection of information on uses of energy and its impact on income generation, health, and education (86). Often, energy is represented only by a handful of questions in national multisector development surveys. As a consequence, it is difficult to establish or understand the relationship between energy, productive uses, and development because there are few national surveys that contain information about energy and other social indicators such as health and education.

CONCLUSION

In light of the increasing emphasis on the importance of education, gender, and health for development, the energy practice needs to reevaluate its view on productive uses of energy. The emphasis on motive power that leads directly to increasing incomes is an important component of energy and productive uses. However, in

this review, we argue for a much broader approach. The very purpose of development is to create a world full of healthy, educated, and socially equal people. Although income generation is an important means toward this goal, it must be recognized that any use of energy that contributes toward education, health, and gender equity should be considered a productive use of energy.

The ways in which energy contributes to the improved productivity of rural populations are both many and varied. Energy services can improve the delivery of health and educational services by providing lighting, refrigeration, heating, and modern communication. New energy services can reduce the amount of labor-intensive time that rural women and children spend on collecting fuelwood and performing household chores. This extra time can be used on more productive activities, including the pursuit of educational, income-generating, and leisure activities. Improved cooking fuels and stoves can alleviate health problems—and even reduce deaths—related to indoor air pollution from traditional ways of cooking with biomass. Generally, everyone agrees with the notion that healthy people are more productive.

Broadening the definition of productive uses of energy is important for a better understanding of how energy is related to development. Even motive power is a means to an end and not an end in itself. Machines must be used by educated and healthy people to be effective in promoting development and improving income. Also, energy in the context of failing schools, poor health facilities, and poor water supply will not lead to development. However, without energy there are limits to any type of growth in rural areas. This suggests an urgent need to examine the critical linkages between energy and women's empowerment, education of children and adults, health, and income generation without past preconceptions of the productive uses of energy.

ACKNOWLEDGMENT

We would like to thank John Sottong for his editorial contributions and help in preparing the manuscript.

LITERATURE CITED

1. Barnes DF. 1988. Electric power for rural growth. In *How Electricity Affects Rural Life in Developing Countries*, pp. 1–39. Boulder, CO: Westview
2. Bose S. 1993. Introduction: technical transformations and the rural economy. In *Money, Energy and Welfare: The State and the Household in India's Rural Electrification Policy*, pp. 1–3. New Delhi, India: Oxford Univ. Press
3. Mason M. 1990. *Rural electrification: a review of World Bank and USAID financed projects*, World Bank Backgr. Pap., Washington, DC
4. Schramm G. 1993. Rural electrification in LDCs as a tool for economic

development: facts and fiction. *OPEC Rev.* 17(4):501–17
5. Wasserman G, Davenport A. 1983. Power to the people: rural electrification sector summary report. *AID Program Eval. Rep. 11*, US Agency Int. Dev., Washington, DC
6. World Bank, South Asia Energy, Infrastruct. Unit. 2004. *Access to Electricity: Strategy Options for India*, pp. 1–56. Washington, DC: World Bank
7. Barkat A. 2003. *Rural electrification and poverty reduction: case of Bangladesh*. Presented at NRECA Int. Conf., Sustain. Rural Electrif. Dev. Ctries.: Is it Possible, Arlington, VA
8. Barkat A, Rahman M, Zaman S, Podder A, Halim S, et al. 2002. Economic and social impact evaluation study of the rural electrification program in Bangladesh. *Rep. to Natl. Rural Electric Coop. Assoc. Int.*, Dhaka, Bangladesh
9. Barnes D, Sen M. 2004. The impact of electrification on women's lives in rural India. *Energia News* 7(1):13–14
10. Sen M, Barnes D. 2004. Gender and rural electrification, viewing electrification through a gendered lens. *Energia News* 7(1):1–3
11. Siddhi P. 2000. *Making solar affordable to the poor*. Presented at Village Power 2000, World Bank, Washington, DC
12. Energy Sector Manag. Assist. Program. 2002. Rural electrification and development in the Phillipines: measuring the social and economic benefits. *ESMAP Rep. 255/02*, World Bank, Washington, DC
13. Dahlin B. 2002. *The impact of education on economic growth: theory, findings, and policy implications*, Duke Univ. http://www.duke.edu/∼bgd3/bgd0202.pdf
14. Lucas R. 1993. Making a miracle. *Econometrica* 61:251–72
15. Desai MA, Mehta S, Smith KR. 2004. *Indoor Smoke from Solid Fuels: Assessing the Environmental Burden of Disease*, ed. Prüss-Üstün A, Campbell-Lendrum D, Corvalán C, Woodward A. (WHO Environ. Burden Disease Ser. 4) Geneva: World Health Organ. http://www.who.int/quantifying_ehimpacts/publications/en/Indoorsmoke.pdf
16. Smith K. 1993. Fuel combustion, air pollution exposure, and health: the situation in developing countries. *Annu. Rev. Energy Environ.* 18:529–66
17. White R. 2002. GEF-FAO Workshop on Productive Uses of Renewable Energy: Experience, Strategies, and Project Development, June 18–20, *Workshop Synth. Rep.*, UN Food Agric. Organ., Rome, Italy
18. Martinot E, Chaurey A, Lew D, Moreira JM, Wamukonya N. 2002. Renewable energy market in developing countries. *Annu. Rev. Energy Environ*. 27:309–48
19. Kapadia K. 2004. *Productive uses of renewable energy: a review of four Bank-GEF projects*. World Bank, Washington, DC. http://ist-socrates.berkeley.edu/∼rael/kamal.pdf
20. Sen A. 1999. Introduction. In *Development as Freedom*, pp. 1–11. New York: Anchor
21. World Bank. 2004. *The Little Green Data Book*, p. 8. Washington, DC: World Bank
22. World Bank. 2004. *Millennium development goals.* http://www.developmentgoals.org
23. UN. 2004. *UN Millennium development goals.* http://www.un.org/millenniumgoals/
24. Sachs JD. 2005. *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. London: Earthscan
25. Barnes DF, Fitzgerald K, Peskin HM. 2002. *The Benefits of Rural Electrification in India: Implications for Education, Household Lighting, and Irrigation*, Draft manuscr. Washington, DC: World Bank
26. Surendra TS. 2000. *Solar Photovoltaic Water Pumping: A Permanent Solution to the Small Farmers' Problems*. Hyderabad, India: Polyene Film Ind.
27. Dep. Int. Dev. 2002. The importance of increasing access to energy services. In

Energy for the Poor: Underpinning the Millennium Development Goals, p. 9. London: Dep. Int. Dev.

28. Int. Food Policy Res. Inst. 1995. Feeding the world to 2020: What role will women play? *2020 Vision News Views*, UN Food Agric. Organ., Rome, Italy, Oct. http://www.ifpri.org/2020/newslet/nv_1095/nv_1095a.htm
29. Kumar SK, Hotchkiss D. 1988. Consequences of deforestation for women's time allocation, agricultural production, and nutrition in hill areas of Nepal. *Int. Food Policy Res. Inst. Res. Rep. 69*, Washington, DC
30. World Bank. 1996. The rural energy situation. In *Rural Energy and Development: Improving Energy Supplies for Two Billion People*, p. 21. Washington, DC: World Bank
31. Energy Sector Manag. Assist. Programme. 2004. *The Impact of Energy on Women's Lives in Rural India*, p. 59. Washington, DC: World Bank
32. Int. Energy Agency. 2002. Energy and poverty. In *World Energy Outlook 2002*, p. 7. Paris: Int. Energy Agency
33. Njie N-I. 1995. Energy's role in deforestation and land degradation. In *Energy as an Instrument for Socio-Economic Development*, ed. J Goldemberg, TB Johansson, p. 5. New York, NY: UN Dev. Programme
34. World Bank. 2003. *Infrastructure Services*: *The Building Blocks of Development*, pp. 5–9. Washington, DC: World Bank
35. Yayasan DD. 2003. The development impact of solar home system in the Province of Lampung. *Rep. for World Bank/GEF-Assist. Indonesia Sol. Home Syst. Project*, Jakarta, Indonesia: Gov. Indonesia
36. Bhatnagar S, Dewan A, Torres MM, Kanungo P. 2003. *E-Choupal: ITC's Rural Networking Project. Part of the Empowerment Case Studies project.* Washington, DC: World Bank Poverty Reduct. Group
37. World Bank. 1999. Poverty and Social Development in Peru 1944–1997, World Bank Country Study. *World Bank Rep. 19651*, Washington, DC
38. Kammen DM. 1995. Cookstoves for the developing world. *Sci. Am.* 273:72–75
39. Barnes DF, Openshaw K, Smith KR, van der Plas R. 1994. *What makes people cook with improved biomass stoves? A comparative international review of stove programs*. Tech. Pap. 242, Energy Ser. World Bank, Washington, DC
40. Jiminez AC, Lawand T. 2000. *Renewable Energy for Rural Schools*. Golden, CO: US Natl. Renew. Energy Lab.
41. World Bank. 2005. Teacher's solar lighting project, *GEF Project Brief*, East Asia Pac. Region Energy Min. Sector Unit., World Bank, Washington, DC
42. Lloyd CB, Blanc AK. 1996. Children's schooling in sub-Saharan Africa: the role of fathers, mothers, and others. *Popul. Dev. Rev.* 22(2):265–98
43. *Sunday Observer*. 2001. No rise in bottle lamp accident victims. Sept. 23. Sri Lanka
44. Res. Inst. 2001. Survey design, methodology, and survey instruments for rural electrification impact evaluation study in Vietnam. *TERI Project Rep. 2001RP41*, Res. Inst., New Delhi, India
45. Estrada RQ, Brown T. 2003. Telesecundaria: students and the meanings they attribute to elements of the pedagogical model. *Mex. J. Educ. Res.* 8(17):221–43
46. Calderoni J. 1998. *Telesecundaria: using TV to bring education to rural Mexico.* Educ. Technol. Tech. Notes Work Pap. Ser.: Vol. 3, No. 2, World Bank, Washington, DC
47. Jimenez AC, Olsen K. 1998. *Renewable energy for rural health clinics*. US Natl. Renew. Energy Lab. http://ww.nrel.gov and http://www.gvep.org/content/article/detail/8505
48. Brenneman A, Kerf M. 2002. *Infrastructure & Poverty Linkages: A Literature Review*, pp. 24–30. Washington, DC: World Bank

49. Fay M, Leipziger D, Wodon Q, Yepes T. 2003. *Achieving the Millennium Development Goals—A Multi-sectoral Approach Revisited*, p. 7. Washington, DC: World Bank
50. Olsen K. 2000. *Renewable energy for rural health clinics and schools*. UN Conf. Energy. http://www.un.org/events/energy2000/speaker/olson/sld003.html
51. Martinot E, Chaurey A, Lew D, Moreira JM, Wamukonya N. 2002. Renewable energy market in developing countries. *Annu. Rev. Energy Environ.* 27:309–48
52. World Bank, Glob. Environ. Facil. 1996. *Renewable energy-based electricity for rural social and economic development in Ghana*. http://www.gefweb.org/wprogram/1096/ghana.doc
53. Stone L. 1998. Revolutionary health care PV-powered. *Home Power* 66:50–52
54. World Health Organ. 2005. *Water, sanitation, and health*. http://www.who.int/water_sanitation_health/publications/facts2004/en/
55. Bruce N, Perez-Padilla R, Albalak R. 2002. The health effects of indoor air pollution exposure in developing countries. *Rep. WHO/SDE/OEH/02.05.* World Health Organ., Geneva, Switz.
56. Ezzati M, Saleh H, Kammen DM. 2000. The contributions of emissions and spatial microenvironments to exposure to indoor air pollution from biomass combustion in Kenya. *Environ. Health Perspect.* 108(9):833–39
57. Ramani KV, Heijndermans E. 2003. *Energy, Poverty, and Gender: A Synthesis*. p. 38. Washington, DC: World Bank
58. Energy Sector Manag. Assist. Program. 2002. India, household energy, indoor air pollution, and health. *ESMAP Rep. 261/02*, World Bank, Washington, DC
59. World Bank. 2005. *Directions in Development: Environmental Health and Traditional Fuel Use in Guatemala*. p. 6. Washington, DC: World Bank
60. Kammen DM, Bailis R, Herzog AV. 2002. *Clean Energy for Development and Economic Growth: Biomass and Other Renewable Energy Options to Meet Energy and Development Needs in Poor Nations*, p. 12. New York: UN Dev. Programme/Gov. Morocco
61. Parikh J, Laxmi V. 2001. Biofuels, pollution and health linkages: a survey of rural Tamil Nadu. *Econ. Pol. Wkly.* 36:4125–38
62. World Bank. 1996. *Rural Energy and Development: Improving Energy Supplies for Two Billion People*. p. 21. Washington, DC: World Bank
63. Dasgupta S, Huq M, Khaliquzzaman M, Pandey K, Wheeler D. 2004. *Who Suffers from Indoor Air Pollution? Evidence from Bangladesh.* p. 21. Washington, DC: World Bank
64. Grant JP. 1991. *The State of the World's Children*. New York, NY: UNICEF
65. Popul. Inf. Program. 1994. Causes of maternal deaths, *Popul. Rep*, *Ser. M, Vol. XXII (1)*. Johns Hopkins Univ., Baltimore, MD. http://www.infoforhealth.org/pr/m12/m12chap2_1.shtml
66. Motashaw ND. 1997. Root causes of maternal mortality: infancy to motherhood. *J. Fam. Welf.* 43(2):4–7
67. UNICEF. 1990. *The Lesser Child*. New York, NY: UNICEF
68. Parikh J, Smith K, Laxmi V. 1999. Indoor air pollution: a reflection on gender bias. *Econ. Pol. Wkly.* 34(9):539–44
69. UN Dev. Programme. 2004. *Gender & Energy for Sustainable Development: A Toolkit and Resource Guide.* New York, NY: UN Dev. Programme
70. Inst. Dev. Stud., Univ. of Sussex. 2003. *Energy Poverty and Gender: A Review of the Evidence and Case Studies in Rural China*. p. 111. Washington, DC: World Bank
71. Porcaro J, Takada M, eds. 2005. *Achieving the Millennium Development Goals: The Role of Energy Services, Case Studies from Brazil, Mali and the Philippines*. New York, NY: UN Dev. Programme
72. Manapol P, Weingart J, Lilley A, Walt R.

2004. *Bioenergy conversion for sustainable rural enterprise in the Philippines*. Presented at World Renew. Energy Congr. VIII, Denver
73. Cabraal RA. 2000. Indonesia second rural electrification project. *Implement. Complet. Rep. 20676*, World Bank, Washington, DC
74. Dep. Int. Dev. 2002. *Energy for the Poor: Underpinning the Millennium Development Goals*, p. 22. London, UK: Dep. Int. Dev.

NOTE ADDED IN PROOF

Disclaimer

The findings, interpretations, and conclusions expressed in this article are entirely those of the authors and should not be attributed in any manner to the World Bank, to its affiliated organizations, or to members of its Board of Executive Directors or the countires they represent. The World Bank does not guarantee the accuracy of the data included in this article and accepts no responsibility whatsoever for any consequences of their use.

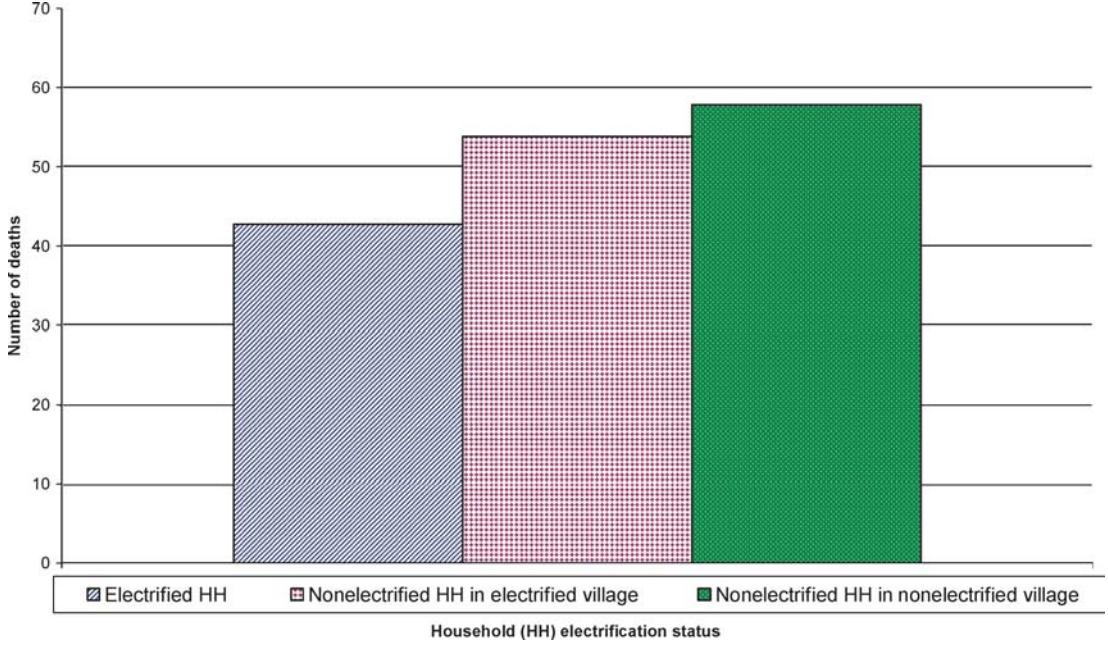

Figure 1 Infant mortality rates in Bangladesh by household (HH) electrification status (per 1000 live births). (Modified from Reference 7 and reprinted with permission.)

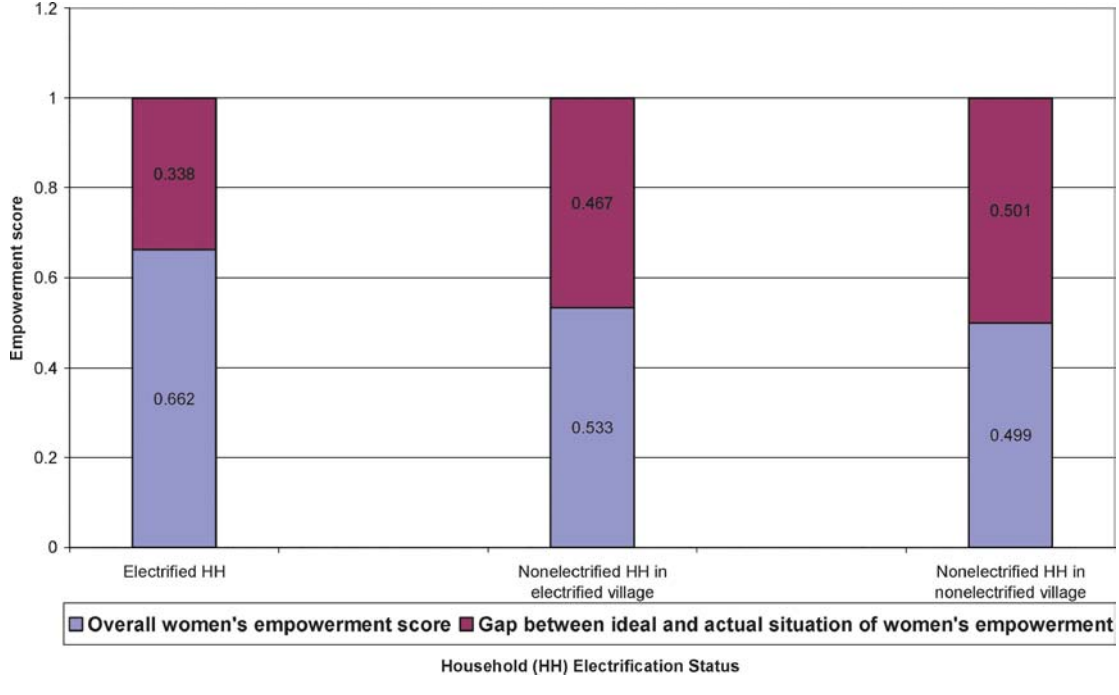

Figure 2 Overall women's empowerment score by household (HH) electrification status. (Modified from Reference 7 and reprinted with permission.)

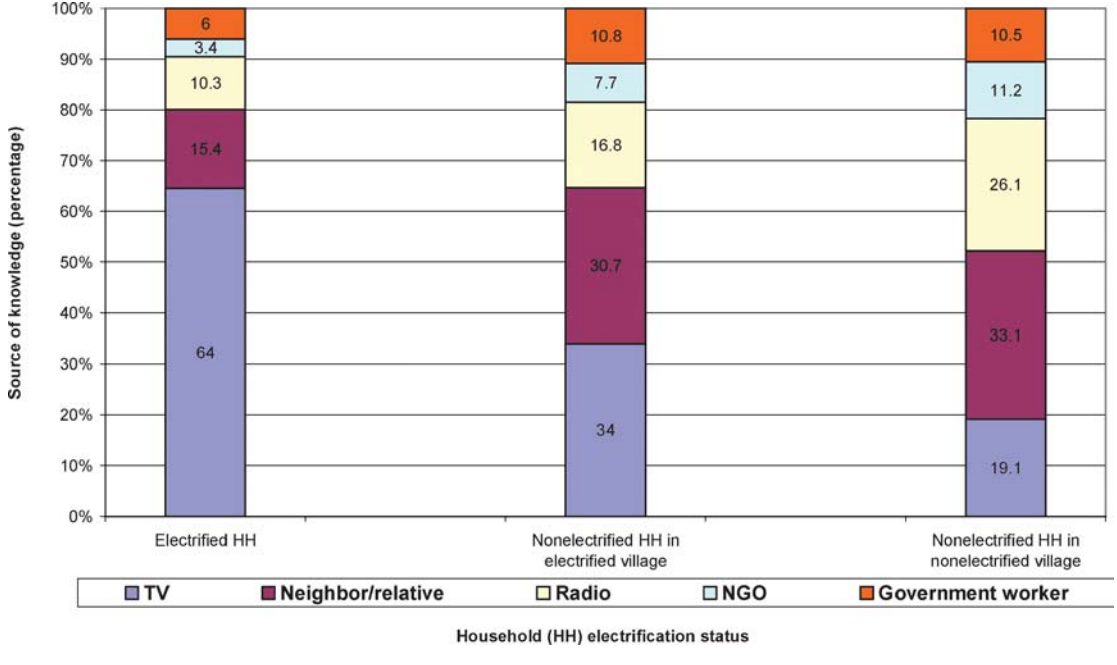

Figure 3 Share of major sources of knowledge among women about selected gender equality issues. Abbreviations: HH, household; TV, television; and NGO, nongovernment organization. (Modified from Reference 7 and reprinted with permission.)

Annual Review of Environment and Resources
Volume 30, 2005

CONTENTS

IV. Emerging Integrative Themes

Indexes

Errata

An online log of corrections to *Annual Review of Environment and and Resources* chapters may be found at http://environ.annualreviews.org