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Renewable Energy for Rural Sustainability in Developing Countries

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This article establishes the benefits of applying renewable energy and analyzes the main difficulties that have stood in the way of more widely successful renewable energy for rural areas in the developing world and discusses why outcomes from these technologies fall short. Although there is substantial recognition of technological, economic, institutional, and other supply-side barriers that have generally interfered with success, the household and other stakeholders have been left outside the scope of evaluation. This article first discusses the usefulness of renewable energy for encouraging sustainability in rural, poor areas, analyzes barriers that have often interfered with the promotion and delivery of expected outputs of installed modern energy technology in remote communities, and finally presents findings from a survey on the actual performance state of the renewable energy technology and degree of satisfaction with it.

Keywords: *rural renewable energy technology; developing countries; sustainability; postevaluation; Latin America*

Modern energy forms are an economic good, capable of improving the living standards of billions of people, particularly in developing countries, who lack access to service or whose consumption levels are far below those of people in industrialized countries (Anderson, 2000). By using decentralized energy systems, the high costs associated with transmission and distribution through the national grids can be avoided. The possibility of adopting renewable energy technology (RET) is particularly important in the light of the limited success of conventional rural electrification programs that have been designed to meet energy needs in developing countries (e.g., Anderson, 2000; D. Anderson, Barnes, & Jechoutek, 1996; United Nations Development Programme [UNDP] & EC, 1999). There is, nonetheless, a large unutilized potential to develop energy services in this way. Improvements in energy efficiency apparently have considerable potential to reduce poverty in all of its major dimensions and to facilitate development (UNDP & EC, 1999). Yet, for all this potential to be realized, current problems need to be first recognized and acknowledged to suggest ways to overcome them. After more than 30 years of electricity expansion in rural areas it is time to take stock of the conditions that indicate unintended discrepancies between the potential of energy technology to positively affect poor communities and its actual suspected limited effects.

As part of these efforts, off grid, in many cases renewable technology systems—the most common being diesel-engine generator set, small-scale hydropower, photovoltaic (PV), wind, and small-scale bio-power producing gas—have been installed across the developing world in Latin America, the Caribbean, Africa, and Asia in the past four decades.[1] However, only a minority of the rural population without electricity has access to some form of modern renewable energy services; that is, more than 2.4 billion people worldwide continue to rely fully on traditional fuels to cook (Howells, Alfstad, Victor, Goldstein, & Remme, 2005).

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This article argues that laudable features of RET schemes—such as independence from the national grids, very small associated consumption costs, being benign to the environment, and enabling supply of electricity to poor and geographically remote populations—has not however automatically guaranteed wide expansion and effective performance. Evidence is still needed on what has taken place after installations have been completed; whether the technology fulfills people's needs and priorities; whether the equipment has remained in working order and for how long; whether the population has been trained to respond to technical challenges; how satisfied users are, and what, if any, are the localized environmental consequences of implementing the new systems. In other words, this study explores how sustainable the application of RET has been when applied to rural poor areas in developing countries. Throughout this study the term "sustainable" was thought of as an integrated concept that applied not only to *environmental*, but also to *social, economic*, and *technological* dimensions of energy solutions.

There is wide experience worldwide with RET in rural areas. Appraisal of success and failures of modern off-grid energy technology has, however, moved at a much slower pace than its support and actual expansion in developing countries. A significant drawback to uncover the barriers for their complete success has been the lack of appropriate approaches to gather relevant information and sufficient interest to systematically collect knowledge from users in rural areas. This article reflects on the benefits that may be accrued from renewable energy for the rural poor and then it does two things. It first analyzes the main difficulties that have been encountered in the way of more widely promoting RET in rural areas and presents a number of crucial findings that testify to the performance condition and limited satisfaction degree of users in remote rural areas in Latin America and the Caribbean. This work is part of the U.K. Department for International Development (DFID) awarded research project RESURL (Renewable Energy for Sustainable Rural Livelihoods, 2001-2006) whose objectives were: (a) to develop a method to evaluate existing systems and (b) to design a new multicriteria decision support system for future infrastructure development. This article focuses on the first objective.

Benefits From Access to Energy and RETs

The role of energy in the life of modern societies occupies a central place in almost every economic sector, social and cultural activity, and in the physical transportation of people and objects. Energy is seen as an irreplaceable ingredient for societies' economic and industrial progress. Energy powers economic growth and access to it is vital if poverty is to be alleviated. But it is very unequally accessed and consumed. The world's richest countries, with about one fifth of the world's population, account for more than half of commercial energy use. Development in large part depends on access to appropriate energy services (e.g., DFID, 2002, 2006; UNDP & EC, 1999; World Bank, 1996).

The main energy demand in rural areas of low-income countries is for cooking and the main source of fuel for satisfying this demand comes from fuel-wood, dung, and other forms of biomass, which are highly inefficient and polluting (World Bank, 2000). This type of fuel is also expensive and requires intensive labor for collecting the wood (World Health Organization, 2000). The use of clean RET in particular could play a major role in national development in terms of job creation and income generation and protecting the local environment (Karekezi & Kithyoma, 2003) simultaneously allowing the "leap-frogging" of fossil fuel-based energy supplies, along the energy-development path.

Expansion of RET could be particularly advantageous to reduce the gap of about 2 billion people, mainly in the developing world, who lack access to any forms of modern energy or have deficient access to it, and still rely on traditional sources of energy (World Bank, 1996). Enabling access to renewable energy services could directly improve the productivity and well-being of millions of people across the developing world—by providing lighting that extends their workday, by powering machines, and by freeing them from the burden of collecting firewood (Biswas, Bryce, & Diesendorf, 2001; Byrne, Shen, & Wallace, 1998; de Janvry & Sadoulet, 2000; Saghir, 2002).

However, technical benefits from the application of energy innovation technologies in poorer areas must be positioned in conjunction with other aspects of sustainability such that societal and environmental improvements may happen at the same time. Therefore, problems and solutions to supplying energy technology to rural areas to improve basic infrastructure services and livelihoods cannot be dealt with in isolation. Hundreds of thousands of renewable systems have been installed throughout rural areas of the developing world (Greenpeace, 2001). Yet, technical and institutional difficulties have prevented their wider expansion, with many obstacles coming from lack of investment, maintenance, high costs, and particularly lack of supporting policy frameworks. Additional institutional difficulties have been created by the international development

agenda giving less precedence toward providing electricity to the impoverished than toward fulfilling other immediate needs.

Poverty and dependence on traditional sources of fuels go hand in hand. As household incomes rise, people normally switch to modern fuels, if these are available. The best schemes for improving rural energy may therefore fail if other policies prevent an overall sustainability and equity approach to economic growth. It has been emphasized that the main principles to creating sustainable energy systems are to improve efficiency of energy use, make more effective use and transformation of conventional fuels, and use renewable sources of energy more widely (UNDP & EC, 1999, p. 5). Furthermore, in the 2002 Earth Summit, it was stated that "Sustainable development is the greatest challenge of our times" (by British Environment Secretary, Margaret Becket, in Vidal, 2002, p. 1).

Decentralized energy systems, particularly systems that use renewable natural sources, can offer a solution and in many cases, the only possible one to supply electricity to isolated areas where the grid cannot reach. RET offers environmental, social, and economic advantages. Energy provision can be a factor in the reduction of poverty in rural areas (DFID, 2002; UNDP, 2000; WEC/FAO, 2000).

Recent interest in RET (e.g., the 2002 Earth Summit, see Lean, 2002; and the REEP initiative, see UK White Paper) has been justified given society's growing unease with several central issues, namely, the future supply of fuel, the effects of severe pollution, global climate change, ill health issues because of use of fuel wood (Eberhard & Van Hooren, 1995; International Energy Agency, 2002), and inequitable distribution of access to energy. RET is an important component in addressing these vital contemporary issues.

Most commonly used renewable energy options for delivering energy in rural areas are small-scale hydropower plant, wind, solar, and bio-gas technologies.

Small hydro plants vary in size (micro, mini, and small) and generate from 100 KW up to 15 MW.

Micro hydro systems are almost always "run-of-river" schemes, which means that the principal energy carrying medium is the natural flow of water; any barrage or dams (if any) are very small, and there is very little or no storage of water. This makes these systems cheaper and less demanding on the natural environment, but their efficiency is lower and because of the lack of a water reservoir, they depend heavily on the hydrological cycle of that location (Paish, 2002).

Another widely used technology is wind power. Wind energy is mainly applied to pumping water, supplying livestock with water, electricity generation, and/or for irrigation (T. Anderson, Doig, Rees, & Khennas, 1999). For example, there are around 1 million mechanical wind pumps in Argentina, with another 350,000 elsewhere around the world, mostly in South Africa (REN21, 2005).

Solar PV technology is another widely applied renewable technology found in rural areas. The effectiveness of a solar PV cell depends on the fair amount of sunlight it collects to convert it into electricity. Developing countries in general are endowed with considerable quantities of sunlight per year making PV applications more favorable in these regions than in colder and cloudier climates. Globally, the market development of the PV industry has witnessed an impressive growth, largely owing to the growth in grid-tied PV systems (Maycock, 2005).

RETs have improved and their costs have been reduced during the past 10 years. However, little is actually known and there are still uncertainties about the degree of success of renewable energy applications as they operate in the poorest parts of developing countries. This article explores whether clean, modern off-grid and small-scale technologies may have contributed among the poor to users' quality of life by providing a reliable and lasting service, helping to break their cycle of poverty, and protecting their local natural environment.

Method

Two main approaches to assess the subject were applied; a literature review and fieldwork survey. The article first discusses the difficulties most often found in the expansion of RET by drawing on informative studies to identify the barriers often found in the way of RET success in rural areas by generating two main categories, the macro and the micro barriers to RET. Selected findings are then presented in relation to the extent of modern energy installations found in rural areas that sought to assess the current performance state of rural energy systems and users' satisfaction with them. The results are drawn on a large household survey in 35 rural communities in Colombia, Cuba, and Peru.

Whereas most existent approaches to address these issues have focused on the technical and economic aspects of energy development, the methodology was multidisciplinary and participatory and drew heavily on

expert assessment. The ex-post evaluation addressed technical and nontechnical aspects to assess the degree of failure and success of RET in remote rural areas.

The sections below discuss the outstanding macro and micro barriers followed by a description and a discussion of the fieldwork approach, its application in three countries, and fundamental findings and their interpretation.

Macro and Micro Barriers of RET in Rural Poor Areas

Effective supply of and access to energy in poor rural areas has been interfered by numerous factors. However, little work has directed attention to difficulties that users have encountered locally.

Research on rural energy is, in fact, research on the technological, economic, and managerial *problems* during the course of exploitation and/or consumption of energy for sustainable development. This problem's literature may be approached through a macro and a micro perspective that classifies the obstacles that have emerged as part of advancing electrification with RET in remote areas. Whereas macro barriers refer to difficulties that originate at the structural level of society and technology and include such aspects as government policies and restricted access to funding, micro barriers spring from users' conditions generally associated with poverty and geographic isolation. Therefore, obstacles that originate in the higher national and international spheres are the macro barriers; the other difficulties that targeted populations also face constitute the micro barriers. There are links between macro and micro barriers and users could be said to be directly and indirectly affected by the two types of barriers. The article however analyzes only the direct impacts, and for clarity, the barriers had been classified in the two main mentioned groups: macro and micro barriers. The main focus of this article is on the analysis of difficulties which can best be understood as originating at the micro level, which will follow a brief discussion of central economic, technological, and managerial macro barriers.

The Macro Barriers

Lack of both investment and national governments' policies that promote connection of small-scale energy systems to the national grids have deterred a more generalized spread of RETs in rural areas.

The greatest macro problem is financial (Reddy & Painuly, 2004; Sadrul Islam, Islam, & Rahman, 2006). A most concerning issue is finding organizations and companies that are willing to invest in RETs. Lack of technology is no longer a barrier to the widespread use of RE products; the biggest obstacle is finding companies and institutions that are willing to invest in them (Cone, 2000). These institutions tend not to be the private sector: The public sector instead has to make up the shortfall (Cone, 2000). The perception among investors of RET that they have large commercial risks tends to hamper investment, whereas high interest rates can be off-putting even for keen investors.

According to Karekezi and Ranja (1997), the main economic obstacle to implementing RE projects is the absence of low-cost, long-term financing. Most RE technologies, having limited operating costs, suffer from high investment costs and a low volume of sales. Economic and Social Commission for Western Asia (ESCWA, 1999) claims that the challenge is thus to promote a market that will achieve high volumes and low costs. Also, when RE technologies are set against conventional options a number of obstacles emerge: the comparatively high capital cost of installing RE systems; an absence of accountability studies of social and environmental benefits related to RE technologies; and a lack of accumulated experience with long-existing systems in similar conditions that could be used to validate economic evaluations (ESCWA, 1999).

Furthermore, there is little assistance for those interested in investing in RE technologies. Investors face competition from other small-scale industries for loans from banking institutions, whereas energy sector subsidies has been distorting (Kartha & Leach, 2001). That is, energy efficiency and renewable technologies are disadvantaged by the massive subsidies with which governments support the fossil fuel and nuclear industries. In addition, the tariff system in many regions is often based on cross-subsidy principles to enable the rural population to have access to electricity (ESCWA, 1999). Many Eastern and Southern African countries' pricing policies, such as distorted taxes on RET and thus high initial costs, continue to be a major barrier to RET development and dissemination (Karekezi & Ranja, 1997; Takase, 1997). The high initial cost barrier is frequently insurmountable (Kartha & Leach, 2001).

The development of RE technologies has often suffered from a lack of appropriate institutional underpinning (Reddy & Painuly, 2004; Wolde-Ghiorgis, 2002). The absence of core, specialized institutions for RE in some countries and the limited coordination of activities in others have hampered the formulation of appropriate strategies to promote the use of RE in different applications and to follow up its implementation. Adequate legislation and incentive schemes can

be effective tools for the promotion of RE (ESCWA, 1999). Yet, energy policy making has focused most strongly on fossil fuels and hydro-electricity, and research and development have also been similarly focused—at the expense of renewable technologies (Hall & Mao, 1994; Takase, 1997). Such explains why there has been so little supportive data on renewable energy resources.

In the African region, for example, the major obstacles to the wider deployment of large-scale biomass energy power generation have been institutional (Karekezi & Ranja, 1997). Oil and power sector companies usually have had a de facto or de jure monopoly on production and distribution of energy, making it difficult for RE technologies to penetrate the market (Karekezi & Ranja, 1997). In Kenya, solar equipment still continues to be highly taxed, which has hindered its promotion, and has consequently maintained it as a preserve of a select privileged few (Jacobson, 2007; Karekezi & Ranja, 1997). Also in Cameroon, although solar home systems have gone some way to meeting electrification needs in some rural areas, the market penetration of such systems has remained low. This is partly because of lack of promotion within Cameroon itself, and partly because of national fiscal and customs policies that constrain the import of the mostly foreign equipment. In fact, institutionalized subsidies in the conventional energy sector can be distorting, poorly targeted, and unsustainably expensive, creating a barrier to rational energy choices (Kartha & Leach, 2001). The absence of institutional arrangements to widen the access to modern energy services has frequently characterized the condition of people living in poverty (UNDP & EC, 1999).

The Micro Barriers

In addition to the obstacles mentioned above occurring at the higher levels of decision making, the other less well-recognized hurdles had come into play once the technology had been implemented. Main factors that have militated against the sustainability of clean and decentralized technologies in rural poor areas refer to equipment, maintenance and cost, information, remoteness, poor information, and gender bias.

At a micro level the lack of practical support for users of modern off-grid technology in remote rural areas can be a difficult barrier to overcome because of, for example, a lack of local manufacturers of the required equipment or its spare parts (ESCWA, 1999; Sadrul Islam et al., 2006; Taele, Gopinathan, & Mokhuts'oane, 2007). Should a market grow, the number of manufacturers could be expected to increase, but this will only happen after a certain point in the expansion of the industry. In the meantime, spare parts have only been available from distant manufacturers and suppliers, making it difficult to establish the market required to stimulate local manufacturing interest.

Remoteness is typically associated with greater poverty and fewer livelihood options. It thus often makes sense to target remote locations rather than those places already well integrated both on the national grid and into diverse economic activities to promote development (Ellis, 2002). By the 1990s however, the lack of income in rural areas has meant that domestic PV lighting has been installed predominantly in urban areas, despite the considerable potential for its use in both (Diphaha & Burton, 1993).

One of the problems of using solar systems in remote areas is that usually no one local has been trained in repair (Cone, 2000) and much-needed technical expertise has been severely lacking. An example of this could be found in Botswana, where there was no formal training available for PV technicians with the result that there were few skilled personnel sufficiently qualified to install or maintain PV systems and consequent failure of the systems (Diphaha & Burton, 1993). In general, solar energy technologies require from users a minimum of maintenance skills for their successful use, and before these skills become commonly available, problems are bound to arise. A common problem has been that the implementation and running of solar technologies cut across existing lines of demarcation among government departments, causing difficulties in areas such as equipment maintenance. This problem has been solved almost by chance in India, where the popularity of the bicycle has led to a profusion of bicycle mechanics whose abilities have apparently been transferred to the energy field. In other nations, where there is no such existing source of mechanical knowledge, the problem remains critical (Wood, 1994).

From a technology perspective, if an RE system does not have a diesel backup or the natural resource is scarce, or the equipment efficiency is limited, the costs may be excessive. If system components, especially the battery bank, are sized for the worst possible case, the system will be oversized at all other times (Ghosh, 2002).

The costs of maintenance are higher when the trained engineers who are called to repair the installed energy equipment have to travel long distances. The operating costs also increase as a result of poorly maintained equipment. These costs can be significantly reduced if the service personnel are local

(Allderdice & Rogers, 2000). Maintenance costs for local users therefore may rise significantly in addition to the initial purchase cost, which, as mentioned above, is already a deterrent for investors.

Another barrier that has interfered with the success of modern energy technology has been limited information of various technology options among potential users that can lead to problems such as the choice of unsuitable equipment (Diphaha & Burton, 1993). Also, often the governments, utilities firms, bankers, donors, and investors involved in the development of RE projects are not fully aware of the benefits its development can bring. There has been a distinct lack of information, communication, and coordination among these different sets of people (ESCWA, 1999). This has led to a lack of information available to rural communities, reducing their ability to make informed choices.

Recently there has been an increase of interest in the gender bias in energy issues. Women in poor communities spend more time and effort on energy-related activities than their male counterparts, and men may not be prepared to invest capital in a technology that will primarily affect women, for example a biogas plant that will provide gas for women's cooking (Biswas et al., 2001). Women and children tend to suffer more of the ill effects attributable to poor energy solutions, such as smoke inhalation from cooking (UNDP & EC, 1999). The unpaid work done by women in nonmarketed and subsistence activities is unrecognized and undervalued. Thus much of the economic analysis of energy issues does not take account of the work done by the women, nor does it accurately measure the benefits that improved energy provision can bring. It is generally the men who make the decisions about adopting new technology. These factors can severely distort decision making about adopting new technologies, in both economic and social terms.

In summary, factors that do not circumscribe directly to the technology, policy, or economics, albeit these are of great importance as seen above, but originate at the users' level have also intervened on the success and failure of energy development. Addressing those in more detail, and through appropriate policies, promises to improve the prospects of promoting RET and of its effectiveness.

Assessment of RET in Rural Areas

The RESURL Post-Evaluation Survey (RESURL-Post-E)

A main aspect of the fieldwork carried out by RESURL in 2003 to postevaluate the current conditions of RET in rural areas consisted of a large household survey, the RESURL-Post-E—Renewable Energy for Sustainable Rural Livelihoods–Post Evaluation. It sought (a) to elucidate the type of technology used; (b) to investigate the performance status of such modern RET systems in rural poor communities; and (c) to assess energy uses and lack of service, local skills, satisfaction, participation, and costs.

The survey addressed the full-energy menu consisting of solar, diesel, micro-hydroelectricity, biogas, firewood, wind, and even grid-connection. It focused on technical and nontechnical aspects of energy development in isolated rural areas, or the micro barriers, in terms of social, financial, human, physical, and natural assets.

The overall aim of this postevaluation study was to find out what is the current functional status of energy equipment survey and assess the factors that may contribute to effective, viable, and sustainable energy in rural areas using a multidisciplinary and participatory perspective. Three large studies were carried out in difficult-to-access poor rural communities of Cuba, Colombia, and Peru.

The three criteria for selecting case study regions within each country were poverty, geographic location, and energy status. Two different regions were surveyed in each country. The size of the population in each community varied. The survey was applied to at least 50% of the population in each community. In Cuba, the study took place in the Escambray high and low mountains, in the province of Santa Clara. In Peru the survey was undertaken in two regions, in the Andes Province of Cajamarca in the north and in the jungle Province of Ucayali. In Colombia two regions were studied, the Chocó on the Colombian Pacific coast, and the inland Andean district of Antioquia. Three baseline data sets were obtained for each country. Overall 35 remote communities were visited and 900 households were surveyed in total. Additional information was gathered through semistructured interviews with representatives of local institutions, community leaders, and regional policy makers, from leaders and other significant people—but these are not the focus of the current article.

The energy questionnaire was applied to the head of the family, or the person present at the time of the survey. The survey aimed that female and male heads were represented equally. The application of the questionnaire took between 25 and 35 minutes. Most questions in the questionnaire were close-ended. Only a few questions were open-ended and requested a more detailed response by the interviewee. The large surveys in the three countries were not undertaken simultaneously but close in dates to each other between 2002 and 2003.

Table 1. Renewable Energy Systems in Remote Locations: the RESURL-Post-E Survey, Cuba, Colombia, and Peru, 2003

Survey	Cuba	Peru	Colombia
Number of villages or communities	14	7	14
Total households	300	300	300
Renewable energy technologies in other premises	Schools, clinics	Clinics, shops	Clinics, shops
Remote locations	Mountains	Andes, Rain forest	Coast, Rain forest
Households using decentralized and traditional energy approaches			
Micro hydro	40	120	94
Solar panels	18	100	35
Traditional	132	80	147
Hybrid	124	2	23

Postevaluation of Renewable Energy in Rural Communities of Three Countries

Neither the degree of success or the current performance state of energy installations in isolated rural areas were known by the focal country authorities. In this article the focus of study was the identification in the studied communities of existing modern energy systems as opposed to traditional fuel, fuel used for cooking, reasons for not having access to modern clean energy, users' degree of satisfaction, technical skills, participation, and energy service costs.

The findings showed widespread dissatisfaction among users of existent energy provision systems. For example, in Peru there were practical issues such as cloudy days inhibiting solar panel use, humidity damaging equipment, improper maintenance, and use of batteries causing solar panels to malfunction; 90% of solar panels in one project were not working.

In addition, the research procedure itself provided economic, technical, environmental, and organizational information. Less evidence emerged on the economic impact of RET on rural livelihoods as, despite the huge potential of clean technology in this sphere, little has been officially established to exploit it. One primary factor for limited outcomes has been the short life span of the technology that resulted as a consequence of the barriers that users encounter in rural remote areas. A significant barrier has been the lack of technical capability of local users to maintain modern equipment. This is a significant problem that emerges with PV installations in the Peruvian jungle, and compounded the difficulties they experienced already because of the defective quality of the batteries when bought. Intermittency and lack of reliability in the micro-hydro service for economic activity create further problems for users in mountainous areas in Cuba and in the Peruvian Andes. The yielding of such information was essential for explaining the lack of success of current systems.

Specifically, surveys uncovered some of the barriers that most often interfered with effective provision of energy in these regions. Essential findings are summarized in Tables 1 and 2. Although most places had some form of modern energy technology, it clearly emerged that the population continues to heavily rely on traditional fuels such as fuel wood and charcoal for such basic activities as cooking. Solar panels were used in schools in Cuba.

Analysis of the 35 remote rural communities studied (in Cuba, Peru, and Colombia) shows that four types of decentralized energy systems are dominant in remote areas (e.g., micro-hydro plants, solar panels, traditional firewood, and hybrid systems). Also, not every technology is equally satisfactory, and maintenance barriers in particular have prevented long-term functioning of the systems.

The state of the systems and users' degree of satisfaction with clean energy systems was related to the type of technology. In all three countries, micro-hydro was the most reliable local energy generator, whereas solar panels were not delivering as expected because of maintenance deficiency.

For the most, users of PV equipment were found to lack basic information about how to maintain and repair it; in the case of micro-hydro plants, technical capacity was limited to very few individuals. No awareness of other technology options, or of the environmental impact of energy development was registered. This lack of technical skills, and high costs involved in maintenance, are the main and most difficult issues preventing sustainable systems.

The beneficial potential of energy emerged on two fronts: livelihoods improvement, by providing essential service for basic health care installations, primary

Table 2. Renewable Energy Technology Installations, the RESURL-Post-E Survey, Cuba, Colombia, and Peru, 2003

Postevaluation Indicator	Developing Countries		
	Cuba	Peru	Colombia
Energy options and location	Mountains: traditional (i.e., fuel wood; 42%), hybrid (40%), micro hydro (12%), solar panels (6%), particularly in schools and health clinics	Andes: micro hydro plants (40%), solar panels (33%), remote locations in Amazon, traditional fuel wood (26%), hybrid systems (1%)	Coast and rainforest: traditional (49%): firewood and kerosene, micro hydro (31%), solar panels (12%), hybrid systems (8%)
Fuel used for cooking	Traditional (44%): firewood, grid	Traditional (27%): firewood, kerosene, and gas	Traditional (49%): firewood and kerosene
Main reason for lack of, or deficient, access to energy or deficient energy services	Need of technical maintenance	Lack of administration	Lack of both support from authorities and economic resources
Users' degree of satisfaction with current energy option	Satisfied (60%)	Satisfied (40%)	Mainly unsatisfactory (<40%)
Existing local technical skills	Low	Low	Low
Users' participation in energy-related decision making	Yes, through community leaders	Yes, through municipal authorities and families (as consumers)	Yes, through community leaders
Women's participation in energy decision making	Yes, considered very important	Just as family members	Just as family members
Average monthly cost of energy services	10 to 20 Cuban pesos (about £0.50)	25 soles (about £4.06)	10,000 to 25,000 Colombian pesos (about £2.28)

Note: n = 300 households per country.

schooling, and entertainment, reducing excessive drinking particularly among men and the youth; by enabling the possibility of new and old agricultural activities such as coffee-grain drying. However, this possibility was generally not materialized because of defective energy equipment.

Conclusion

The difficulties encountered on the way of implementing RET in remote rural areas of developing countries do not change the fundamental fact that RETs represent a most advisable and appropriate way to provide energy to these areas. RETs offer the possibility of improving sustainability at local levels and enhancing the conditions of groups of users. For more than 3 years the RESURL project studied the barriers and successes of renewable energy development in remote areas of Cuba, Peru, and Colombia. The findings make evident the fact that access to energy can significantly improve users' quality of life. However, unless a strong institutional framework is supporting the energy program, and technical skill is available, the gains are short-lived.

Most often, problems with RET and sustainability have been addressed through the design of guidelines for future implementation of energy systems (e.g., Byrne et al., 1998; Nfah, Ngundam, & Tchinda, 2007; Nguyen, 2007), and/or by recognizing the different types of barriers, usually cost-related macro barriers, that have impeded wider expansion and sustainability in a specific country or in general (e.g., Forcano, 2001; Mahmoud & Ibrik, 2003; Painuly, 2001; Vera, 1992). But these approaches have mostly been aimed at the supply side of RET. Gathering experience from local sources about whether and why energy services have been abandoned, are malfunctioning, or are inappropriate has been a lesser interest. This is particularly important for three reasons. One is that having promoted the installation of modern

energy equipment has not always resulted in lasting effectiveness. The other reason is that electricity generation should not have been considered the final objective, but rather an intermediate product to achieve something else, the value of which is determined by the uses to which it is put. Therefore, information gathered from user groups could be of great relevance to both improve the chances of reliable and durable energy services in the future and to enhance policy decisions. The fieldwork also indicated that it is important to have an appropriate methodology to approach the "problem" to collect relevant information.

The study reveals that application of social science approaches to technology matters provide an important window on how communities and other stakeholders recognize barriers and opportunities, define priorities, and interpret technological and political trends, so as to illuminate the mistakes of the past and to make better use of existing energy technology. Effective and lasting energy provision in rural poor areas depends, nonetheless, on the vital input of engineers and other technical professions. If these total aspects are not captured, the conflicts and problems may not find a durable solution.

For energy technology to better fulfill its potential to improve local livelihoods and reduce rural poverty, national policy mechanism should promote sustainable development in remote areas including the use of technology with indigenous energy sources. Equally important is to create local institutional networks that support energy services.

Making postevaluation studies available, and providing a tested survey method as this study did, facilitates the chances of improvement of existing installations. Application of such types of methods is recommended for other countries where similar situations may not be uncommon. The current study was also implemental for the second objective of RESURL, which was to draw lessons from postevaluation assessment for designing a decision-support system of technologically and socially sustainable future energy provision in rural poor areas.

Note

1. Solar systems have been distributed in Kenya (150,000), China (100,000), Zimbabwe (85,000), Indonesia (60,000), and México (40,000). About 150,000 photovoltaic and wind systems have been fixed in health clinics, schools, and other community buildings. And more than 45,000 micro hydro plants supply electricity to more than 50 million people in China. Also, millions of stoves designed to improve energy efficiency from traditional biomass sources have been distributed (Greenpeace, 2001).

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