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Design Principles for Renewable Energy Programs in Developing Countries

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OPINION

Design principles for renewable energy programs in developing countries†

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Broader context

This article introduces readers to the concept of energy poverty and the types of renewable energy technologies that can overcome it. It discusses the benefits of solar home systems, residential wind turbines, biogas digesters and gasifiers, microhydro dams, and improved cookstoves and the various mechanisms planners and policymakers have utilized to disseminate these technologies. Then, based on four years of field research studying programs in Bangladesh, China, Laos, Mongolia, Nepal, Sri Lanka, India, Indonesia, Malaysia, and Papua New Guinea, the article presents twelve lessons for how policymakers and development planners can improve future renewable energy projects. These lessons include selecting appropriate technology matched in scale and quality to the energy services communities desire, emphasizing affordability rather than installed capacity, and viewing communities and end-users as active participants in energy production and use rather than passive consumers.

1. Introduction

The United Nations has announced 2012 as the "International Year for Sustainable Energy for All." This proposal attempts to persuade countries, corporations, and other groups to realize three goals by 2030: "universal access to modern energy services, reducing global energy intensity by 40 percent, and increasing renewable energy use globally to 30 percent of total primary energy supply".[1] Two of these targets—universal access and the dissemination of renewable energy systems—occupy bilateral and multilateral development institutions, and are orientated towards eradicating "energy poverty."

"Energy poverty"—traditionally defined as lack of access to electricity and dependence on solid biomass fuels for cooking and heating—remains a persistent global challenge. In 2009 approximately 1.4 billion people lived without access to electricity grids, and 2.7 billion people depended entirely on solid fuels such as wood, charcoal, and dung for their household energy needs.[1,2] This inability to utilize modern forms of energy limits opportunities for income generation and frustrates attempts to reduce poverty,[3] and it also severely impacts the lives and livelihoods of women and children.[4] Furthermore, it contributes to global deforestation and climate change through both traditional greenhouse gas emissions[5] and those from black and brown carbon.[12]

Expanding energy access for rural and increasingly poor communities, moreover, is a daunting task. Those without electricity or dependent on traditional fuels tend to have income levels, purchasing power, and consumption levels far below what private companies and electric utilities typically deem profitable, reluctance further attenuated by the inaccessibility of these communities to national electricity grids.[11] Public officials, like their private counterparts, prioritize investments in urban infrastructure where most of their constituents reside, and they often subsidize grid electricity to existing customers instead of expanding access to rural ones or incorporating off-grid technologies.[11]

Nevertheless, small-scale renewable energy technologies such as solar home systems, residential wind turbines, biogas digesters and gasifiers, microhydro dams, and improved cookstoves provide households and villages the capacity to reduce extreme poverty and advance standards of living.[3] Collaborations enrolling governments as well as businesses, nonprofit organizations, banks, and community based cooperatives have flourished over the past decade to efficaciously expand access to these technologies and the energy services they offer.

This article distills twelve "design principles" or "lessons" from ten such partnerships—six "successes,"‡ four "failures"§—chosen from a sample of 1156 programs (see S1† for a description of the selection process, and S2† for a more detailed description of these ten programs). The author collected original data on these cases from field research

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‡ "Success" refers to a program that met all of its targets, sometimes ahead of schedule, with measurable benefits exceeding costs.

§ "Failure" refers to a program that met none or only a limited number of its targets, often behind schedule, with measurable costs exceeding benefits.

and 441 research interviews over the course of four years, site visits to 90 renewable energy facilities, and focus groups with almost 800 community members across the ten countries (S3† describes these data collection methods more fully).

2. Technology and policy options

First, however, it is necessary to briefly summarize how off-grid renewable energy systems function in developing countries, and how they are promoted. For readers unaware with such technologies, the typical solar home system (SHS) consists of a solar photovoltaic (PV) module generally ranging from 10 Watts-peak (Wp) to 150 Wp, battery, charge controller, and lamp. Larger systems often have the capacity to connect televisions, radios, and other electric appliances.[3]

Household scale wind turbines operate similarly to their horizontal-access commercial counterparts but in smaller capacities. These devices convert the flow of air into electricity, and are most competitive in areas with stronger and more constant winds, such as locations near the coast or in regions of high altitude. Household turbines generally possess an upwind rotor directly matched to a variable speed electric generator. Passive aerodynamic techniques regulate the modulation of electricity, rotor speed, and orientation.[3]

Biogas is an energy fuel produced through the anaerobic digestion of animal, agricultural, and domestic wastes. These forms of organic waste and water typically enter a vessel where they are left to ferment and decompose, producing both biogas as well as digested slurry that can be turned into an organic fertilizer. Smaller-scale two- to three-cubic meter biogas plants tend to be used in homes and communities, suitable for providing gas and heat for cooking three meals a day for an average sized family. Commercial scale systems exist as well, with these larger units offering enough gas to meet the energy needs of neighborhoods, restaurants, tea stalls, and bakeries.[3]

Microhydro dams utilize low-voltage distribution systems and simpler designs that often have a natural river intake, de-sanding basin, masonry lined canal, forebay, penstock, powerhouse, short tailrace, and electronic load controller. By "micro" the author refers to what is commonly discussed as either "mini," "micro," and "small" hydro units ranging from 5 kW to 10 MW of installed capacity.[3]

The three basic components of any cookstove are a combustion chamber where wood or charcoal are burnt with air; a heat transfer area, where hot gases actually warm pots and cook; and a chimney which removes hazardous gases outside the cooking area. Though the term "improved" is certainly subjective, the most common "improved" models are one-, two-, and three-mouthed clay cookstoves which cut fuel use by half and have chimneys that create a smoke-free cooking environment, improving air quality within the home.[3]

The policies and models employed by institutions and governments to promote these five technologies can vary significantly. A "cash model" refers to when customers purchase the product paying the full cost. It is most commonly applied to SHS and small hydro schemes, and the owners of such technologies are usually moderately wealthy private individuals and in some cases communities or public organizations.[10]

A "credit model" refers to when local dealers sell their products to rural clients on credit against collateral or personal guarantees. It is commonly applied to SHS, biogas units, and improved cookstoves. Payment is done in installments, and this type of partnership has high installation expenses due to the transaction costs associated with acquiring credit and high to medium quality products. This model also excludes poor families without the ability to provide collateral.[10]

A "mixed finance model" is when governments provide a fixed subsidy and the balance is born by villagers or private firms. It is most commonly applied to microhydro schemes and SHSs, with ownership residing either with individuals or the community. The model requires high quality products from prequalified companies, and it has relatively high installation costs due to lengthy quality assurance procedures.[10]

A "donation model" is one where the technology is transferred to the community as a gift, usually from a private entity (part of their corporate social responsibility program) or a development donor. It has been utilized for all types of renewable energy with varying degrees of quality and installation cost.[10]

A "fee for service" model is one where renewable energy technology is owned, operated, and maintained by a supplying company, but the customer pays regular fees for using it. It, too, has been utilized for all types of renewable energy with varying degrees of quality and installation cost.[10]

3. Principles for policymakers and practitioners

The diversity of these models does not tell us, however, which one or combination of them works best, or how they might be improved. Based on qualitative analysis of the data summarized in S1–S3,† this section presents twelve broader lessons for energy policymakers, development practitioners, and scholars. Table 1 provides an overview of these lessons and their interlinked factors.

First, programs expanding access to renewable energy can lead to higher living standards, lower fuel consumption or fuel prices, improved technology, and other benefits. The most prominent of these advantages is improved health, given that more than 1.6 million people die each year from premature mortality due to the solid combustion of biomass, half of which are children, many of those young children under the age of five.[13] The most successful programs generate these gains with a positive cost benefit curve; that is, their benefits far exceed their costs. Nepal's Rural Energy Development Program (REDP), for example, delivered \$5.70 in household benefits for every \$1 expended.[6] In Sri Lanka, the Energy Services Delivery Project (ESDP) catalyzed a matching investment from the private sector three times its budget.[7] By contrast, the failed Teachers Solar Lighting Project in Papua New Guinea spent \$3 million and ended up distributing only a single SHS unit.

Second, effective programs typically begin with pilot programs or with feasibility assessments before installing systems and scaling up to larger production or distribution volumes—such as Grameen Shakti starting near Dhaka

Table 1 Twelve lessons and 42 factors associated with successful renewable energy development programs[a]

Lesson	Factor	Bangladesh	China	Laos	Mongolia	Nepal	Sri Lanka	India	Indonesia	Malaysia	Papua New Guinea
Net beneficial energy access	Expanded access to energy services	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Job creation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Lowered fuel consumption/prices	✓	✓			✓	✓				
	Improved technological quality	✓	✓			✓	✓				✓
	Reduced morbidity and mortality			✓			✓				
	Fewer greenhouse gas emissions	✓			✓	✓				✓	
Appropriate technology	Feasibility studies	✓	✓	✓	✓	✓	✓				
	Scaling up	✓	✓				✓				
	Service rather than technology orientation	✓	✓	✓	✓	✓	✓				
	Technical standards and certification		✓		✓		✓				
	Cultural sensitivity	✓	✓	✓	✓	✓	✓				
Community commitment	Community ownership/operation/participation	✓	✓	✓	✓	✓	✓				
	Minority/gender empowerment	✓		✓		✓					
	Monetary contributions (cash, savings, collateral)	✓	✓	✓	✓						
	Non-monetary contributions (time, labor, land, materials)					✓	✓				
Awareness raising	Marketing and promotion	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Demonstration	✓	✓		✓	✓	✓				
After-sales service	Product guarantees/warranties/buy back	✓		✓	✓						
	Training/funds for maintenance	✓	✓	✓	✓	✓	✓				
Income generation	Classes in productive end-use	✓	✓	✓	✓	✓	✓		✓	✓	
	Scholarships	✓									
Institutional diversity	Involvement of non-state-actors/private sector	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Polycentricity	✓	✓	✓	✓	✓	✓				
	Cost sharing	✓	✓	✓	✓	✓	✓				
	Avoidance of corruption					✓					
Affordability	Provision of credit/microcredit/ESCO "fee-for-service" model	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Revenue collection	✓		✓		✓	✓				
	Support for manufacturing/industry		✓		✓						
	Lower programmatic costs	✓	✓			✓					
Capacity building	Institution building	✓	✓	✓	✓	✓	✓				
	Outsourcing			✓							
	Improved business practices (accounting, auditing, revenue collection, marketing)		✓		✓	✓	✓				
	Self-sufficiency	✓	✓		✓	✓	✓				
Flexibility	Diversity of eligible technologies	✓	✓	✓	✓	✓	✓				
	Follow-up project		✓	✓		✓	✓				
	Promotion of both grid/off-grid systems			✓	✓	✓	✓				
	Adjusted targets/extended deadline		✓	✓		✓	✓	✓	✓	✓	✓
Evaluation and monitoring	Independent evaluator	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Penalties for noncompliance	✓	✓		✓	✓	✓				
Political support	Policy integration	✓	✓	✓	✓	✓	✓			✓	
	Dedicated or experienced implementing agency	✓	✓	✓	✓	✓	✓				
	Project champion/political leadership	✓	✓	✓	✓	✓	✓				

[a] *Note:* S2† provides descriptions of each program.

before expanding to the rest of the country. They select technologies that are appropriate for local communities, matched in both scale and quality to the energy services needed, such as smaller SHS units for poor households or biogas digesters near farms. Failures tended to do the opposite: they restrict eligibility to a single technology or a predetermined size, with only one type of SHS being promoted in Indonesia and Papua New Guinea, and the Small Renewable Energy Power (SREP) program in Malaysia actually excluding wind turbines. Furthermore, successful programs often possess culturally sensitive dissemination efforts, opposed to those in Malaysia where communities felt alienated by the program and in Papua New Guinea where they felt threatened by it.

Third, effectual programs encourage community ownership and participation in projects—they reject the "donor gift" model and never give away technologies for free. Sometimes successful efforts target minority groups in rural areas (such as female heads of household or children). Mongolia's Rural Energy Access Project and China's Renewable Energy Development Project (REDP) created technical centers near rural communities so that they would become more active in maintaining their systems. Laos's Rural Electrification Project devolved decision-making authority to village elders who formed their own electricity cooperatives. Microhydro projects in Nepal and Sri Lanka relied on voluntary land donations for the construction of canals, penstocks, powerhouses and distribution lines, and they asked villagers to contribute labor for civil works.

Fourth, prosperous programs have strong marketing, promotional, and demonstration efforts, ensuring that users and members of the public understand project goals and learn about renewable energy technology. Such efforts often include the printing and dissemination of colorful sales catalogs and educational brochures, physical displays of products in shops or within potential communities, and targeted advertising campaigns that occur in newspapers, on radio shows, or (more rarely) in television commercials. Bangladesh's Grameen Shakti orchestrates community demonstrations for SHSs, biogas digesters, and improved cookstoves on request, and the REDP in China, REAP in Mongolia, the REDP in Nepal, and the ESDP in Sri Lanka all sponsored "road shows" where program officials, vendors, and bankers journeyed to rural communities to display technologies to prospective clients. By contrast, promotional efforts in our four failures were extremely limited, with Indonesia's National SHS project leaving it unfunded and up entirely to dealers, who couldn't afford to do it and had no experience regardless, and Papua New Guinea's demonstration efforts confining themselves to displays in bank branches that teachers rarely patronized.

Fifth, successful programs seek to protect consumers and provide after-sales service and customer support. Sometimes this occurs through the creation of product guarantees, warranties, and assurances to repurchase systems if communities become connected to the grid; in other cases programs can offer free training sessions or maintenance. The REAP in Mongolia, for example, funded the establishment of more than 60 after-sales service call centers throughout the country and backed their SHS and wind systems with strong warranties. The Village Energy Security Project in India, by comparison, saw roughly half its biogas units break down within two years after implementation due to lack of maintenance and confusion within villages over maintenance responsibilities.

Sixth, effective programs match energy services with generating income, direct employment, and educational training. Grameen Shakti in Bangladesh offers a scholarship competition for the children of customers. It also subsidizes collegiate degrees in science, engineering, and related areas for employees that dedicate themselves to long-term employment within the company. Similarly, the REDP in China educated nomadic herders about how their SHS could provide lighting to keep herds together during storms and electrical energy to power milk separators and recharge mobile phones. In Nepal, the REDP coupled its promotion of microhydro dams with the agricultural processing needs of communities.

Seventh, worthwhile programs allocate roles and responsibilities among different institutions and actors. This facilitates the diffusion of risks and an "institutional heterogeneity" that can motivate actors to keep tabs on each other, ensuring performance benchmarks are met. Usually, these institutions operate at multiple geographic scales, making them what governance scholars have called "polycentric".[8,9] Fruitful programs from our sample also tended to share costs between government and intergovernmental institutions, private sector participants, and the communities themselves.

Eighth, almost all successful case studies offered financial assistance through microcredit financing, low-interest loans, or the leasing out of systems according to an energy service company (ESCO) model. They focused intently on making energy services affordable rather than meeting targets for installed capacity or numbers of systems sold. The implication is that programs should first consider affordability, and then ask "What's the most we can provide for the low cost that households can afford?", whereas there may be a tendency to instead ask "What's the most capacity we can install?" without regard for what it would cost. The most effective programs also saw their programmatic and technological costs fall over time, due largely to the creation of economies of scale, technological learning, and improved competition. Juxtapose this with the four failures which saw SHS costs rise in Indonesia, solar retailers go bankrupt in Papua New Guinea, and expensive delays, opposition from the national utility TNB, and quality assurance problems in Malaysia.

Ninth, successful programs all had robust capacity building components. Some dedicated their efforts towards improving financial management and revenue collection; others, such as the REP in Laos, outsourced key components to overseas experts; still others directed their attention to research grants, software and data collection techniques, and the marketing and awareness campaigns mentioned above. Some successes, such as Nepal's REDP, spent a *majority* of project funds on capacity building; some failures, such as Malaysia and Indonesia, spent *nothing* on capacity building or dedicated 90 percent of project funds to technology, respectively.

Tenth, a recognition that programs will need to be flexible in the technologies they include is a common element among our successes. Planners appreciated that programs had to take into consideration

Table 2 Three paradigms of energy development

	Donor gift paradigm (1970–1990s)	Market creation paradigm (1990s and 2000s)	New "Sustainable Program Paradigm" (mid-2000s)
Actors	One, usually a government or just one development donor	Multiple government agencies and/or multilateral donors	Multiple public, private, and community stakeholders
Primary goal	Technology diffusion	Market and economic viability	Environmental and social sustainability
Focus	Equipment, often single systems	Multiple fuels (*e.g.* "electricity" or "fuelwood")	Energy services, income generation, institutional and social needs and solutions
Standardization	Little standardized between projects	Some standardization	Standardized with certificates, testing regimes, and national standards
Implementation	One time disbursement	Project evaluation at beginning and end	Continuous evaluation and monitoring
After-sales service and maintenance	Limited	Moderate	Extensive
Ownership	Given away	Sold to consumers	Cost-sharing and in-kind community contributions
Awareness raising	Technical demonstrations	Demonstrations of business models	Demonstrations of business, financing, institutional, and social models

unexpected circumstances and adjust to rapidly changing situations. This criterion is common to both our successes and failures, which saw targets revised to accommodate unexpected alterations in program performance, ongoing civil wars and political crises, and natural disasters.

Eleventh, having dispassionate, objective, and independent actors evaluate the performance of projects is important, as well as strict penalties for poor performance. Grameen Shakti, China's REDP, Mongolia's REAP, Nepal's REDP, and Sri Lanka's EDSP all had firm fines for the violation of programmatic standards. Such programs also emphasized the necessity of commercial viability. For example, the UNDP and World Bank mandated that only microhydro schemes in Nepal with better than average capacity factors and financial rates of return would receive programmatic support.

Twelfth, though difficult to measure, programs meeting their targets tended to have political support and resilient project champions. Sometimes this took the form of a dedicated implementation agency, such as Nepal's Alternative Energy Promotion Center or Sri Lanka's Sustainable Energy Authority. In other cases, such support came with the harmonization of national policies, such as project sponsors for the ESDP in Sri Lanka changing the constitution so that villages and microhydro companies could sell electricity to the grid. In still other cases, such as Grameen Shakti, close ties to prominent political figures such as U.S. President Bill Clinton and the Nobel Laureate Muhammad Yunus enabled access to a wider array of grants and financial support.

4. Conclusions

These lessons show that, designed properly, renewable energy development programs can be effective at meeting national and programmatic targets for electrification and access, sometimes ahead of schedule and below cost.

We know, for example, that the inclusion of multiple stakeholders in program design, implementation, and evaluation can enhance the speed, scale and scope of renewable energy commercialization. The involvement of women's groups, multilateral donors, rural cooperatives, local government, manufacturers, nongovernmental organizations and other members of civil society, and even consumers, can increase both the performance and legitimacy of partnerships. They improve performance since input from multiple stakeholders can accelerate feedback; they improve legitimacy since programs with a broader base of support, and community involvement, are less likely to be opposed, protested, or even attacked physically during civil wars and internal conflicts.

We know that effectively distributing renewable energy technologies in developing countries requires a transition in how many policymakers and practitioners think about project and program organization. Effective programs tend to focus on affordable energy services for rural communities rather than technologies. They focus on capacity building, demonstration, maintenance, and awareness in addition to supplying technical equipment. They contemplate political, institutional, social, and cultural needs alongside economic and financial ones.

Practitioners, and those interested in energy development, could start by shifting how they conceive of energy technology and program structure to focus on the "Sustainable Program Paradigm" in Table 2.

Lastly, and perhaps most importantly, we know that investments in renewable energy bring benefits that far exceed their costs. In some cases these include improvements to household income and standards of living, in others productivity and community development. In others they bring technological reliability and quality, and reductions in cost. In still others they encompass significantly reduced greenhouse gas emissions and rates of deforestation. Investments in renewable energy technologies and programs represent one of those rare cases where not only households and small enterprises benefit, but also companies, regulators, and society at large.

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