Evaluating Renewable Energy Technology Transfer In Developing Countries: Enabling Factors & Barriers

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Executive Summary: During the past two decades, energy demand in developing countries has reached unprecedented levels, surpassing that of developed countries, particularly in Brazil, China, India, and other growing economies in Asia, Latin America, and Africa (Martinot et al. 2002, Besant-Jones 2006). Through the development of local energy sources and a modern energy infrastructure, nations seek to maintain independence from fossil-fuel-based energy systems that preserve reliance on a small subset of nations, and avoid associated environmental risks created by traditional energy systems. Advancements in renewable energy technologies have lowered costs and increased access to energy in developing countries through many pilot projects. In rural electrification projects, the confluence of potential implementation obstacles, such as liability of price subsidies, low service quality, low collection rates, and low availability, have been well documented as lessons learned for future projects.

Policymakers, both in the host country and international community, must collaborate to foster a suitable political and economic environment that facilitates the success of rural energy pilot projects. Rural electrification projects in many developing countries have demonstrated common keys to success in cultivating a commercially viable market while simultaneously revealing unique characteristics for specific nations. Governments that seek to draw private sector support need to create a legal and regulatory environment that increases private sector participation, which may include various concession models, local microenterprises, and competitive dealer sales to lower the cost of renewable energy systems. This paper examines the development of energy sectors across countries at various stages of growth, and aims to discuss unique enabling factors, barriers to renewable energy investment, and, based on lessons learned from pilot projects, policy recommendations for implementing sustainable projects.

1. Introduction

Ensuring energy access and security in developing countries entails balancing economic, social, and environmental reform, and thus faces immense challenges. Energy access is central to nearly all aspects of welfare, including access to clean water, education, health care, agricultural productivity, and job creation. In the absence of reliable, safe, and clean energy, people are constrained to poor-quality energy sources that are expensive, damage health, limit expansion of opportunities, and negatively impact education and social mobility (Barnes and Floor 1996, Akella, Saini, and Sharma 2009). Roughly 350–400 million households, or 40% of the population of developing countries, do not have access to electricity (Goldemberg et al. 2000). The percent of the population that has access to electricity varies widely at the national level, from 98% in Thailand and 85% in Mexico to only 2%–5% in many countries in sub-Saharan Africa. In between are many middle-income countries such as Brazil, Bangladesh, India, and South Africa, with just 20%–

30% of rural populations having access to electricity (Chaurey 2001, Chaurey and Kandpal 2010, Graham 2001). Energy access is not only essential at the household level, but is also very important to the delivery of basic minimum infrastructure such as hospitals, schools, and industrial applications.

Effective policies will need to be locally designed, since there are substantial differences at both the national and sub-national level. Social and economic reform is needed to simultaneously improve the affordability, availability, and safety of energy access, while reducing the financial risk premium to encourage private sector involvement. Long-term commitments are needed from development partners to scale up energy investments, transfer knowledge, and deploy financing instruments which will leverage private capital. With concrete lessons from numerous case studies, policymakers are armed with a better understanding of the nexus between renewable energy policy design and financing.

2. Renewable technologies

There are wide variations internationally in the level of consumption and the types of energy supply used, based on the country, region, household income level, and available energy sources. Advancements in renewable energy technologies have diversified the range of options available for improving rural energy supply (Anderson and Ahmed 1994). Numerous organizations have developed international programs to increase diffusion of renewable energy technologies, such as the United States (US) Agency for International Development (Wilkins 2010), the United Nations Development Program (Margolis and Kammen 1999), the World Bank (Martinot 2001, Martinot, Cabraal, and Mathur 2001), and the US National Renewable Energy Laboratory (Flowers et al. 1997, Givler and Lilienthal 2005). Largely, these efforts adopt a technology-neutral approach, encompass a wide set of in-country activities, and establish the development of complementary partnerships. The essential activities typically include resource mapping, initiating pilot projects, conducting essential training and outreach, and in-depth analysis of lessons learned and best practices for modeling rural electrification with renewable energy systems. Projects ranged from wind-fossil hybrid systems in Chile, remote wind-solar-diesel hybrid and water pumping projects in Mexico, and rural electrification with PV-diesel hybrid power units in Ghana. In this section, the techno-economic feasibility, unique characteristics, and social impact from existing installations of various renewable energy technologies are studied.

Solar energy. Recent developments in solar photovoltaic (PV) systems have dramatically increased the accessibility for small-scale applications. Currently, solar PV can be less expensive when considered across a lifetime cost basis, and is more reliable than grid energy or diesel generators for small-scale applications (Wade 1991). Many successful pilot projects have illustrated that solar PV can uniquely provide reliable energy access for a wide array of basic welfare needs, such as in-home and street lighting, distribution and access to clean drinking water, community-based cell phone and internet network availability, refrigeration for medical supplies, and various industrial applications (Posorski 1996, Nieuwenhout et al. 2001, Van Campen, Guidi, and Best 2000). However, high initial investment costs of the systems pose a significant barrier for rapid deployment of solar PV, even with subsidies (as financed in government programs in India (Chaurey 2001, Chaurey and Kandpal 2010, Bhattacharya and Jana 2009), Mexico (Huacuz and Martinez 1995, Huacuz et al. 1994), and Chile (Jadresic 2000)). Currently, battery banks and charge controllers are often the most costly component in the entire installation; lowering this cost should be a top research priority.

In rural areas of developing countries, the main use of energy in households is for cooking. For example, in rural India cooking constitutes approximately 80% of the total household energy consumption (MNES 1994). Bio-fuels such as fuel wood, charcoal, crop residues, and dung are the conventional energy source in rural areas. The burning of these bio-fuels contributes to indoor air pollution and has been strongly linked to many health issues (Besant-Jones 2006). Moreover, the collection of fuel wood is often done by women and children, which takes time away from other productive pursuits such as studying and income-generating endeavors (Saghir 2005, Barnes and Toman 2003). More recently, solar energy technologies, such as solar water heaters and cookers, have been advancements in alleviating these problems. The advent of utilizing solar energy for lighting and cooking still requires a wider availability of parts, and higher efficacy to supplant traditional fuels (Smith et al. 2005, Pohekar, Kumar, and Ramachandran 2005).

Wind energy. Wind power is the most mature renewable energy technology worldwide. According to the International Energy Agency, the total installed capacity worldwide stood at 318,000 MW in 2013, about 15% of which was in developing countries. India has 20,150 MW of installed wind power capacity, which leads the developing world (Martinot et al. 2002). This boom in wind power development can be attributed to special tax policies established in the 1990s that allowed private power developers to recover the full investment costs of wind farms in the first year of operation, i.e. accelerated depreciation (Graham 2001, Givler and Lilienthal 2005). China also has a growing wind turbine market; in the 1990s, several Chinese companies began to produce large-scale (200–300 kW) wind turbines as joint ventures or under license to foreign companies. To stimulate domestic manufacturing industries, the Chinese government has set mandatory regulations that all new wind farms must comprise a minimum of 40% local components (Byrne, Shen, and Wallace 1998). Also, the market for small wind turbines has significant growth in Inner Mongolia for household-scale wind power applications (Lew 2000). A socioeconomic assessment of small household-scale wind turbines in Inner Mongolia discovered numerous social benefits: households purchased appliances such as refrigerators, rice cookers, and electric heaters to improve living conditions and save time, particularly for women. Also, television and radio have served as a resource for language instruction and information on commodity pricing, weather, and the latest farming methods and practices (Martinot et al. 2002).

Energy storage. The intermittent nature and variability of renewable energy sources has led to concerns regarding reliability of energy systems. The incorporation of energy storage, typically in the form of battery banks, allows for the installation of hybrid systems (such as combined PV-wind), and permits energy to be collected and utilized at any time to eliminate the gap between energy resource availability and preferred time of use. One of the main examples is lighting, which is used generally during nighttime when solar energy is not available. High-quality lighting can extend productivity beyond daylight hours. This is especially true for an electric lamp, which provides 100-200 times more lumens than a kerosene lamp. In particular, the following social development impacts may be expected: higher levels of lighting can improve income-generation activities, such as keeping a store open for longer hours or making a home business more productive. Also, access to safe and clean lighting increases study hours for school-going children, which can increase their educational achievements (Foley 1992, Van der Plas and de Graaff 1988) while women gain time for themselves or to extend income generating work into the evening hours (Bose 1993, Reiche, Covarrubias, and Martinot 2000). Residential and public lighting increases safety within the community - again, children and women profit most (Narayan et al. 2000).

3. Institutional aspects

Institutional aspects, such as governmental programs, serve a crucial role in cultivating the appropriate political and financial environment needed for the success of rural energy pilot projects. Governments that wish to involve the private sector need to create a legal and regulatory environment that increases private sector participation. Government support must also include serving as the link between economic and social reform. Many studies state that the regular maintenance and monitoring of local energy projects is critical to program success, which requires in-country knowledge and reach that often only the government possesses (Urmee, Harries, and Schlapfer 2009, Liebenthal, Mathur, and Wade 1994). Some common public sector programs are discussed, in terms of various mechanisms, political and economic environment, and measured effectiveness.

Tariff design. One of the most common policy instruments used in support of renewable energy technologies is the feed-in tariff. The premise of the feed-in tariff is to give financial security to power producers through fixed tariffs for power from renewable energy sources over a set period of time (approximately 10–20 years in most schemes). This reduces financial risk and creates a foundation for long-term investment planning, since revenues are known and guaranteed in advance (Besant-Jones 2006). The tariffs are usually distinguished depending on the renewable energy technology. They exceed the levelized cost of electricity paid by consumers and ideally allow investors to recover the capital cost of the system and receive an equitable return on investment. The additional costs due to the higher tariffs are passed on to all power consumers in the form of a premium per kilowatt hour. Generally, tariffs are renegotiated and adjusted over time to prevent consumers from paying unreasonably high prices and to allow flexibility for learning curves as technology matures. However, these adjustments must be predictable to preserve investment certainty.

Tax incentives and subsidies. Tax incentives or subsidies for particular renewable energy technologies, such as solar PV, have also been widely designed and implemented. However, in order to reach cost parity, subsidies alone are not sufficient; therefore, taxes are typically increased on competing fossil fuel systems to allow renewables to become more competitive in the market. More specifically, carbon taxes or cap and trade systems are examples of schemes that internalize the cost of negative externalities on the environment and sustainability caused by fossil fuel usage. Some of the fundamental aspects of establishing regulatory models are how to set tax incentives, how much of a subsidy to provide, and the frequency of revision and renegotiation. For the poorer segments of the rural population, both subsidies and tariffs are often discussed in terms of customer affordability and willingness to pay (Martinot and Reiche 2000).

Concession model. In recent years, the concession model has been receiving attention for rural off-grid electrification because of its hybrid approach to mitigating market risks and regulatory rights. Concession/regulation type approaches to rural electrification have been tested by the World Bank in Argentina, Benin, Bolivia, Cape Verde, and Togo (Reiche, Covarrubias, and Martinot 2000, Martinot and Reiche 2000). In comparison to typical service delivery models such as licensing and dealerships, which foster competition in the market, the concession model permits only a few bidders to contend for exclusivity to serve the market. Concessions will then be committed to providing electricity services, as requested by customers, and will collect a monthly fee-for-service over a long period (in the pilot project in Argentina, 15 years is the first formulation). Concession models hinder a completely free market, but aid in offsetting financial risk, lengthy return on investment, and low returns.

Donor aid. Although donor efforts are rarely sustainable and are incapable of scaling with projected growth of electricity demand in developing countries, donor aid has proved vital for allowing renewable energy to initially penetrate the market, and demonstrate technical and economic feasibility for reduced fiscal risk of private investment. For instance, although private dealers have now provided most solar home systems in Kenya, the market was initially seeded by donor programs in the 1980s (Duke, Jacobson, and Kammen 2002, Nieuwenhout et al. 2000). According to Jacobson, "donor programs allowed PV modules and system components to become known and available in Kenya...and provided a basis for the development of local capacities in component assembly and in the installation, repair and maintenance of PV systems" (Jacobson 2007).

Donor aid is entirely driven by social motivations, and serves as an exploratory tool on the economic viability of the electricity market. As an example, South Africa is an unpredictable market, with a high number of company start-ups and closures (Bugaje 2006). Outside of government programs, dealer sales have been low due to lack of affordability and consumer expectations of eventual universal grid access; therefore, donor aid becomes the primary driver of rural electrification projects (Banks and Schäffler 2006). While multilateral and bilateral aid levels are generally constrained by budgetary difficulties in donor countries and are unlikely to rise substantially in the future, it is a critical ingredient to investigate consumer needs, implicitly survey market viability for private investment, and ultimately improve the livelihood of communities with access to renewable energy.

4. Private sector framework

The mounting shortfalls of the conventional forms of utility company revenues, government subsidies, and public and private foreign loans are reasons for the development of new business practices in the power sector finance. Also, with the unprecedented growth of electrification in developing countries, electrical equipment suppliers in the industrial countries detected the opportunity to capitalize on the burgeoning markets (Liming 2009). Project financing has many advantages, such as independent power projects (IPPs) and domestic enterprises, but additional reorganization will be required to draw resources on the scale needed to achieve long-term commercial viability. In order to achieve this, governments need to establish conditions that are attractive for viable rural entrepreneurship and grid-based power investments that incorporate renewable energy. Commercial banks, multilateral organizations, and other public lenders need to provide business finance to entrepreneurs, credit to consumers, and project finance to grid-based power developers. Financing schemes can range from microfinance, consumer credit, or revolving funds. The augmented role of private financing entities necessitates a symbiotic role between the public sector and official aid agencies.

Technology demand. According to Martinot et al., the largest existing markets for PV systems, in number of potential households, are India (450,000), China (150,000), Kenya (120,000), Morocco (80,000), Mexico (80,000), and South Africa (50,000) (Martinot et al. 2002). The solar PV market in India has been largely propelled by an established government program of subsidy, tax, and financial incentives that was initiated in the 1980s (Chaurey and Kandpal 2010, Gmünder et al. 2010). Solar home system installations were eligible for rebates, while additional loan and financing structures have augmented even more private sector sales. When the market volume reached critical mass, government policies began to readjust to cater towards commercialization schemes. This paradigm shift allowed manufacturers to invest more readily with dealer and distributor networks, service centers, and credit schemes (Liming 2009). Moreover, to sustain the market growth, public agencies provided local service centers for technology maintenance. This proved to be a key element in the energy infrastructure because it provided functionality for the size, complexity, and sophistication of the systems and matched local capabilities.

Currently, entrepreneurs have entered the market with the emphasis on after sales service (Chaurey 2001, Chaurey and Kandpal 2010). Similarly, most of China's PV market has advanced in recent years on commercial grounds, primarily in the northwestern provinces and autonomous regions of Qinghai, Xinjiang, Tibet, Inner Mongolia, and Gansu (Peidong et al. 2009). A number of small donor programs developed by NGOs have helped with the initial build-up of these markets (Zhang and Wen 2008, Li 2001). Presently, solar PV commerce and infrastructure now exist for most needs such as installation, distribution, and maintenance, with almost all sales completed in cash in these well-developed commercial markets.

Financing schemes. Rapidly increasing capital investment requirements, especially with renewable energy technologies, necessitate a larger role for private financing schemes. Recognizing this, many national governments of developing countries are opening up their power sectors to private investment, originally through IPPs, although in some cases through sector privatization (Dunkerley 1995).

The implementation of IPPs has proven to be highly efficient. After the negotiation process is completed (though this can take several years) IPPs can dramatically improve energy access and alleviate shortages. For instance, the 1993 Power Crisis Act in the Philippines coordinated, negotiated, and implemented projects with 27 IPPs in less than two years total (Woodhouse 2005). Additionally, IPPs increase energy availability and reliability without further burden to the public sector, which is generally at capacity. If governmental resources are not sufficient to expand the power sector due to budgetary constraints, then private investment through IPPs can finance the electrification of homes that would not have been developed otherwise. Often, governments are asked to conduct market research to mitigate financing risks and guarantee a customer base for the electricity produced. However, government guarantees are considered by the International Monetary Fund (IMF) as liabilities – restated, governments that do not follow through with financial assurance risk damaging their credit rating, which increases interest rates on foreign debts. These guarantee-related issues have been addressed in some way through escrow accounts and direct billing of customers, which lessens the need for government guarantees while simultaneously giving private investors financial risk protection (Dunkerley 1995). Additionally, the flawed nature of capital market behavior may favor technologies with low initial investment over technologies with lower life-cycle costs due to the perception of greater technical and financial risk. It is clear that increased collaboration between governments, NGOs, and private investors can relax some of the constraints inhibiting renewable energy technology adoption.

Two basic private-sector models have been established: dealer sales and energy service companies. As stated in Martinot et al., a dealer sales model means that a dealer purchases systems or components from manufacturers and sells them directly to households, usually as an installed system (as in Indonesia, India, Sri Lanka, Vietnam, Bangladesh and China). An energy service company (ESCO) model means that the ESCO owns the system, charges a monthly fee to the household, and assumes responsibility for its service. As mentioned previously, the ESCO model can take different forms: it can be a monopoly concession regulated by the government to serve specific geographic regions (as in Argentina, Benin, and Togo), or it may operate competitively with other players in the electricity sector (as in the Dominican Republic) (Martinot et al. 2002). It is worth noting that the latter requires more regulatory involvement. For example, an ESCO concession model was considered unfeasible in China and was disallowed partly because there was no suitable authority in the electric power sector to regulate concessions (Martinot, Cabraal, and Mathur 2001).

In addition to these well-understood business models, other models that are demonstrating promise are building community grids based upon micro-enterprise and integrating renewable energy technologies into water purification and distribution, agriculture, education, and telecommunications systems. These emerging models promote long-term economic and social benefits, and local entrepreneurs and larger firms are pioneering new trails and should be encouraged to take new risks and form new renewable energy enterprises.

5. Implementation

In developing countries, the confluence of potential implementation constraints, such as liability of price subsidies, low service quality, low collection rates, and low availability, have caused many governments to lose interest in and thus support of rural electrification projects (Newbery 2004, Joskow 1998). It is evident that electricity sector reforms must take place to facilitate the implementation and maintenance process.

Service quality. A common cause for the failure of rural energy projects include low-quality products, inadequate training for installation and maintenance, and exaggerated marketing claims of the product which inflate user expectations. Well-defined codes, standards and certification have been identified as key elements in addressing these issues (Martinot and Reiche 2000). For instance, a government program in the Philippines for bio-gas powered water pumping initiated in the 1980s observed only 1% of the systems in use after a few years, 16% were unused, and 80% needed repair. The reasons cited included a lack of adherence to technical standards and guidelines, and inadequate training and maintenance practices, which resulted in engine failures (Bernardo and Kilayko 1990).

Consumer awareness. Lessons gathered from early pilot projects recommend that marketing and consumer awareness campaigns can be overly costly and time consuming in rural areas, frequently demanding door-to-door and direct contact. Consumer awareness is usually insufficient by itself, though it serves as an underlying catalyst for many necessary ingredients such as technology demand and initial market volume, as well as local expertise. Dealers benefit from consumer awareness and marketing programs in the nascent stages of new market development until a large enough customer base develops that facilitates marketing efforts (Martinot, Cabraal, and Mathur 2001).

6. Policy Recommendations

Many case studies of both public programs and private sector initiatives for rural electrification in a number of developing countries have been documented. In 1993, the World Bank set reform as a condition for lending to the power sector, and suggested five areas of support for renewable energy moving forward: renewable energy financing, electric power policy frameworks, rural energy enterprises, regulated rural energy concessions, and domestic technology manufacturing (Martinot 2001). Additionally, interviews conducted by the World Bank with the private sector suggest bolstering additional forms of support, such as assistance with business plans, funding of feasibility assessments, sustainment of market volume and stability, and pilot and experimentation of new business models (World Bank 1993). Achieving such a careful balance of policymaking requires an analytical approach on how to best carry out the confluence of programs simultaneously, and the exact weight that should given to each factor depends on political, economic, and social conditions. This section draws from lessons learned in reform models implemented in various developing countries.

Another way to promote renewable energy is through market facilitation organizations. As defined by Martinot et al., market facilitation organizations (MFOs) are hybrid public-private organizations "that support the growth of particular markets through a variety of means." MFOs operate in a unique role by espousing a business interest in the emerging industry, while simultaneously investing in the public interest of achieving an assortment of public benefits. For example, MFOs provide a multitude of services, such as partner matching, market analysis, identification of private sector opportunities, user education, technical assistance, and policy development. Historically, MFOs have been industry associations, NGOs, and government agencies. In India, the achievements of the rural biogas and wood stove programs has been attributed to the market facilitation efforts championed by the All India Women's Conference (Sastry 1997). Another example is the Council on Renewable Energy in the Mekong region (CORE), a partnership between government agencies, NGOs, research institutions, and private sector companies that conduct market research, enact appropriate changes in policy, and implement pilot projects cooperatively. Recently, private power developers have also served as MFOs, utilizing both private and public funds. Bridging the gap between public and private entities has been widely cited as a necessary ingredient to realizing the benefits of scaling projects. Stemming from the insight gained from demonstrated projects, Martinot et al. suggest that: a) MFOs can be powerful market stimulants yet very few exist; b) public-private MFOs most likely need full public funding to begin but eventually can become partly self-supporting through private contracts; c) very few people are thinking about the potential of MFOs to stimulate renewable energy market development (Martinot et al. 2002).

7. Conclusion

Access to clean, reliable energy is vital to achieving basic social needs, driving economic growth and fulfilling human development. Energy services influence productivity, health, education, availability of safe water, and communication services. Renewable energy sources such as solar and wind are proven technologies that work uniquely well in rural and remote areas where access to the grid is unattainable. Rural electrification projects in many developing countries have demonstrated common keys to achieving a commercially viable market, as well as unique characteristics for specific nations that require both public and private sector reform. There are a significant number of rural electrification projects underway which employ various technologies, delivery mechanics, and financing arrangements. If properly evaluated and their lessons incorporated in future projects and programs, these pilot projects can pioneer the way to creating a robust environment for cost-effective, easily accessible renewable energy systems.

References

Akella, AK, RP Saini, and MP Sharma. 2009. "Social, economical and environmental impacts of renewable energy systems." *Renewable Energy* no. 34 (2):390-396.

Anderson, Dennis, and Kulsum Ahmed. 1994. *Renewable energy technologies: a review of the status and costs of selected technologies*. Vol. 240: World Bank Publications.

Banks, Douglas, and Jason Schäffler. 2006. "The potential contribution of renewable energy in South Africa." *Draft Update Report*.

Barnes, Douglas F, and Willem M Floor. 1996. "Rural energy in developing countries: A challenge for economic development 1." *Annual Review of Energy and the Environment* no. 21 (1):497-530.

Barnes, Douglas F, and Michael A Toman. 2003. "Energy, Equity and Economic Development."

Bernardo, Francisco P, and Gregorio U Kilayko. 1990. "Promoting rural energy technology: the case of gasifiers in the Philippines." *World development* no. 18 (4):565-574.

Besant-Jones, John E. 2006. *Reforming power markets in developing countries: what have we learned?*: World Bank Washington, DC.

Bhattacharya, SC, and Chinmoy Jana. 2009. "Renewable energy in India: historical developments and prospects." *Energy* no. 34 (8):981-991.

Bose, Sarmila. 1993. *Money, energy and welfare: The state and the household in India's rural electrification policy*: Oxford University Press New Delhi.

Bugaje, IM. 2006. "Renewable energy for sustainable development in Africa: a review." *Renewable and Sustainable Energy Reviews* no. 10 (6):603-612.

Byrne, John, Bo Shen, and William Wallace. 1998. "The economics of sustainable energy for rural development: a study of renewable energy in rural China." *Energy policy* no. 26 (1):45-54.

Chaurey, Akanksha. 2001. "The growing photovoltaic market in India." *Progress in Photovoltaics: research and applications* no. 9 (3):235-244.

Chaurey, Akanksha, and Tara Chandra Kandpal. 2010. "Assessment and evaluation of PV based decentralized rural electrification: An overview." *Renewable and Sustainable Energy Reviews* no. 14 (8):2266-2278.

Duke, Richard D, Arne Jacobson, and Daniel M Kammen. 2002. "Photovoltaic module quality in the Kenyan solar home systems market." *Energy Policy* no. 30 (6):477-499.

Dunkerley, Joy. 1995. "Financing the energy sector in developing countries: context and overview." *Energy Policy* no. 23 (11):929-939.

Flowers, Lawrence T, Ian Baring-Gould, Jerry Bianchi, David Corbus, Steve Drouilhet, Dennis Elliot, Vahan Gevorgian, Anthony Jimenez, Peter Lilienthal, and Charles Newcomb. 1997. *Renewables for sustainable village power*: National Renewable Energy Laboratory.

Foley, Gerald. 1992. "Rural electrification in the developing world." *Energy Policy* no. 20 (2):145-152.

Givler, T, and P Lilienthal. 2005. "Using HOMER® software, NREL's micropower optimization model, to explore the role of gen-sets in small solar power systems." *Case Study: Sri Lanka, National Renewable Energy Laboratory, Golden, Colorado*.

Gmünder, Simon Michael, Rainer Zah, Somnath Bhatacharjee, Mischa Classen, Prodyut Mukherjee, and Rolf Widmer. 2010. "Life cycle assessment of village electrification based on straight jatropha oil in Chhattisgarh, India." *biomass and bioenergy* no. 34 (3):347-355.

Goldemberg, José, Amulya KN Reddy, Kirk R Smith, and Robert H Williams. 2000. "Rural energy in developing countries." *World energy assessment: energy and the challenge of sustainability* no. 10:368-389.

Graham, James. 2001. "Ripening RE markets: capacity building for the rapid commercialisation of RE in China." *Refocus* no. 2 (3):18-23.

Huacuz, JM, and AM Martinez. 1995. Renewable energy rural electrification. Paper read at Natural resources forum.

Huacuz, Jorge M, Jaime Agredano, Gonzalo Munguia, and Roberto Flores. 1994. Los Sabinos PV Rural Electrification Project: results after 30 months of operation. Paper read at Photovoltaic Energy Conversion, 1994., Conference Record of the Twenty Fourth. IEEE Photovoltaic Specialists Conference-1994, 1994 IEEE First World Conference on.

Jacobson, Arne. 2007. "Connective power: solar electrification and social change in Kenya." *World Development* no. 35 (1):144-162.

Jadresic, Alejandro. 2000. "A case study on subsidizing rural electrification in Chile."

Joskow, Paul L. 1998. "Electricity sectors in transition." *The energy journal*:25-52.

Lew, Debra J. 2000. "Alternatives to coal and candles: wind power in China." *Energy Policy* no. 28 (4):271-286.

Li, Junfeng. 2001. Commercialization of solar PV systems in China. Beijing: China Environ. Sci. Press.

Liebenthal, Andres, Subodh Mathur, and Herbert Wade. 1994. "Solar energy: Lessons from the Pacific Island experience." *NASA STI/Recon Technical Report N* no. 95:17298.

Liming, Huang. 2009. "Financing rural renewable energy: a comparison between China and India." *Renewable and Sustainable Energy Reviews* no. 13 (5):1096-1103.

Margolis, Robert M, and Daniel M Kammen. 1999. "Underinvestment: the energy technology and R&D policy challenge." *Science* no. 285 (5428):690-692.

Martinot, Eric. 2001. "Renewable energy investment by the World Bank." *Energy Policy* no. 29 (9):689-699.

Martinot, Eric, Anil Cabraal, and Subodh Mathur. 2001. "World Bank/GEF solar home system projects: experiences and lessons learned 1993–2000." *Renewable and Sustainable Energy Reviews* no. 5 (1):39-57.

Martinot, Eric, Akanksha Chaurey, Debra Lew, José Roberto Moreira, and Njeri Wamukonya. 2002. "Renewable energy markets in developing countries*." *Annual Review of Energy and the Environment* no. 27 (1):309-348.

Martinot, Eric, and Kilian Reiche. 2000. "Regulatory approaches to rural electrification and renewable energy: case studies from six developing countries." *World Bank, Washington, DC, Working Paper*.

MNES, Ministry of Non-Conventional Energy Sources. 1994. "Annual Report: 1993–94." *Government of India, CGO Complex, Lodhi Road, New Delhi (India)*.

Narayan, Deepa, Robert Chambers, Meera K Shah, and Patti Petesch. 2000. *Voices of the Poor: Crying out for Change*: New York: Oxford University Press for the World Bank.

Newbery, David. 2004. "Issues and options for restructuring electricity supply industries."

Nieuwenhout, FDJ, A Van Dijk, PE Lasschuit, G Van Roekel, VAP Van Dijk, D Hirsch, H Arriaza, M Hankins, BD Sharma, and H Wade. 2001. "Experience with solar home systems in developing countries: a review." *Progress in Photovoltaics: Research and Applications* no. 9 (6):455-474.

Nieuwenhout, FDJ, A Van Dijk, VAP Van Dijk, D Hirsch, PE Lasschuit, G Van Roekel, H Arriaza, M Hankins, BD Sharma, and H Wade. 2000. Monitoring and evaluation of Solar Home Systems. Experiences with applications of solar PV for households in developing countries. Netherlands Energy Research Foundation ECN, Petten (Netherlands).

Peidong, Zhang, Yang Yanli, Zheng Yonghong, Wang Lisheng, and Li Xinrong. 2009. "Opportunities and challenges for renewable energy policy in China." *Renewable and Sustainable Energy Reviews* no. 13 (2):439-449.

Pohekar, SD, Dinesh Kumar, and M Ramachandran. 2005. "Dissemination of cooking energy alternatives in India—a review." *Renewable and Sustainable Energy Reviews* no. 9 (4):379-393.

Posorski, R. 1996. "Photovoltaic water pumps, an attractive tool for rural drinking water supply." *Solar Energy* no. 58 (4):155-163.

Reiche, Kilian, Alvaro Covarrubias, and Eric Martinot. 2000. "Expanding electricity access to remote areas: off-grid rural electrification in developing countries." *Fuel* no. 1 (1.2):1.4.

Saghir, Jamal. 2005. "Energy and poverty: myths, links, and policy issues."

Sastry, EVR. 1997. "The photovoltaic programme in India: An overview." *Solar energy materials and solar cells* no. 47 (1):63-69.

Smith, Kirk R, Jamesine Rogers, Shannon C Cowlin, and World LPG Association. 2005. *Household Fuels and Ill-Health in Developing Countries: What Improvements Can Be Brought by LP Gas?*: World LP Gas Association.

Urmee, Tania, David Harries, and August Schlapfer. 2009. "Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific." *Renewable Energy* no. 34 (2):354-357.

Van Campen, Bart, Daniele Guidi, and Gustavo Best. 2000. Solar photovoltaics for sustainable agriculture and rural development. Paper read at RURAL DEVELOPMENT", FAO PUBLICATION.

Van der Plas, Robert, and AB de Graaff. 1988. *A comparison of lamps for domestic lighting in developing countries*: World Bank Industry and Energy Dept.

Wade, Herbert. 1991. "Photovoltaic Rural Electrification Projects in the Pacific Region and Lessons Learned." *South Pacific Institute for Renewable Energy, BP* no. 11530.

Wilkins, Gill. 2010. *Technology transfer for renewable energy*: Taylor & Francis.

Woodhouse, Erik J. 2005. "The IPP experience in the Philippines." *Center for Environment Science and Policy Working Paper* no. 37.

World Bank. 1993. The World Bank's Role in the Electric Power Sector. A World Bank Policy Paper.

Zhang, Kun-min, and Zong-guo Wen. 2008. "Review and challenges of policies of environmental protection and sustainable development in China." *Journal of Environmental Management* no. 88 (4):1249-1261.

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Louis Tse is a Ph.D. candidate in the Department of Mechanical and Aerospace Engineering at the University of California, Los Angeles. His specialization includes numerical modeling, heat transfer, and systems engineering. He was awarded the NSF Graduate Research Fellowship in 2012 for research in thermal energy storage concept using low-cost media, which was funded by the Advanced Research Projects Agency-Energy (ARPA-e) under the Department of Energy. He was a summer associate at the RAND Corporation in 2014, where he developed computational tools for analyzing the U.S. nuclear command, control, and communications network. Tse completed his B.S. in Mechanical Engineering from Arizona State University with Summa Cum Laude honors. He also serves as the president for the engineering graduate student body at UCLA, Project Leader for the UCLA Volunteer Center, and STEM mentor for high school and undergraduate students.

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Tobi Oluwatola is a Ph.D. candidate at the Pardee RAND Graduate School. His dissertation research, titled "Let there be light: Reducing energy poverty in the face of climate change" is looking at identifying new approaches for stimulating domestic renewable energy manufacturing in developing countries. In addition, he is part of RAND's team on the Solar Energy Research Institute for India and the United States. Prior to RAND, he worked in management and policy consulting with KPMG and the British Department for International Development. He has volunteered extensively for the World Energy Council, where he served on the studies committee and is a member of the Future Energy Leaders Advisory Board. His research interests include infrastructure, energy, robust decision-making, climate change, security and economic development.