REPP RESEARCH REPORT

Renewable Energy Policy Project

January 2000 • No. 9

RURAL ELECTRIFICATION WITH SOLAR ENERGY AS A CLIMATE PROTECTION STRATEGY

by Steven Kaufman with contributions by Richard Duke, Richard Hansen, John Rogers, Richard Schwartz, and Mark Trexler[1]

As the world struggles to control energy-related greenhouse gases, electricity-starved rural families in the developing world toil to build decent lives. Photovoltaic systems provide a unified solution, bringing power to those that need it, while making a moderate but important contribution to climate protection.

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A Message from the Staff of the Renewable Energy Policy Project

Installing a solar home system (SHS) in a developing country is not the cheapest way to reduce carbon emissions today. And yet people frequently mention SHS as an important tool in the global effort to combat climate change. Should people think of solar as a prime climate change mitigation strategy?

You would say "no" if you are solely concerned about keeping the cost per ton of greenhouse gas (GHG) emissions as low as possible. But only for the short-term. Simpler, cheaper efficiency measures are much more tempting—like plugging up leaky gas pipes, making industrial boilers efficient, reducing transmission and distribution losses, and other relatively easy measures that developed nations have implemented.

You should say "yes" if you are concerned with pollution control as well as alleviating the inordinate amount of poverty in rural regions. The "co-benefits" to climate change mitigation, as some climate policy experts would say, are too great. Electrifying villages with grid extension to far-flung towns is often expensive—SHSs could cost-effectively fill rural lighting, leisure, and business needs. Plus, SHSs are amenable to distribution, servicing and financial networks that can employ people in many communities, and with different skills and educational levels. This feature can make SHSs an integral part of the solution to stem the desperate flow of rural people into cities—not only by fueling the trappings of modern life, but also by sparking job creation.

Yet SHSs' attractive features—small and located close to the user—can also disrupt the traditional electricity utility business, which typically relies on a big power plant connected to customers through extensive wires. Because of the institutional and associated financial challenges of adopting a "disruptive technology," many interests surrounding climate change policy are tempted to tout technologies—such as nuclear power, "clean coal," and even sequestration of carbon in ocean floors—that allow utilities to perform business as usual. These approaches essentially keep the current way of doing the electricity business intact. Yet anybody familiar with regulatory enforcement in many developing nations should shudder at the thought of nuclear plants. While coal is plentiful, "clean coal" does little to avoid carbon emissions, while coal mining often saddles regions with economic stagnation. And those knowledgeable about ocean habitats recoil at the thought of massive industrial operations at the bottom of our seas.

So it is imperative that climate change policy does not shy away from supporting disruptive technologies that promise enormous social benefits and long-term climate change benefits. As Clayton Christiansen (author of The Innovator's Dilemma and creator of the "disruptive technologies" concept) points out, disruptive technologies need the involvement of small firms who carry a big stake in their success. SHSs are poised well—while large multinationals manufacture SHSs, smaller organizations distribute and maintain them. Climate change policymakers have much to build upon.

It is unlikely that climate change policy alone unleash all of SHSs' benefits. But it can certainly contribute needed incentives for SHS adoption—especially if policymakers incorporate "sustainable development" considerations into their decisions, and do not rely on shortcuts that fail to seed an energy infrastructure equipped for long-term GHQ cuts.

SHSs can play a role in promoting economic and social development in the developing world while protecting the environment. It is an opportunity that is not easy seize, but it is worth it.

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November 15, 1999

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EXECUTIVE SUMMARY

Among the many technologies proposed to address climate change, one stands out for its ability to generate emission-free power while improving rural lives: small solar electric systems can cost-effectively supply energy to rural parts of the developing world while substituting for energy sources that emit carbon dioxide (CO_2). These systems enable people in the countryside to fashion more comfortable lives amidst isolation and frequent poverty.

Roughly 2 billion people still lack grid electricity. Most are in rural areas of developing countries. The World Bank estimates that in 1990, electric grids served only 33% of rural developing-country homes. Achieving the vast increases in electrification needed to satisfy basic demand without significantly increasing global greenhouse gas (GHG) emissions will be a substantial challenge.

Photovoltaic (PV) solar home systems (SHSs) are often the least expensive electrification option in sparsely populated areas with low electric loads. Typically consisting of a 10- to 50-watt peak (Wp) PV module, a rechargeable lead-acid battery, and sometimes a charge controller, the systems generate modest amounts of electricity for lights, radio, television, and other small appliances. Early experience with the technology included operational failures caused by poor maintenance and unsustainable donation programs. However, market-oriented activities in a number of countries increasingly demonstrate the technology's technical and commercial viability. Based on consumers' ability to pay and experience with various system delivery and finance models, the SHS market could reach as many as 170 million off-grid rural homes.

SHSs can make a small but important contribution to climate change mitigation. Typical SHSs of 10–50 Wp will directly displace roughly 0.15–0.30 tons of CO_2 per year through fuel substitution (mostly of kerosene). While modest on a per-household basis, if SHSs served 10% of currently unelectrified rural homes, they would directly offset the equivalent of Zimbabwe's 1995 fossil fuel CO_2 emissions; at 50% market penetration, they would offset the equivalent of Switzerland's emissions in 1995. There are also significant indirect carbon benefits. Widespread SHS use could help developing countries onto a low-carbon path for rural electrification while providing an important market niche to help make PVs more competitive for a range of applications worldwide.

Solar home systems have social, economic, and non-GHG environmental benefits. Vastly superior to kerosene lamps, electric lights enable families to extend their days after sunset productively and enjoyably, by studying, working, or simply cooking and eating dinner in a well lit home. Reducing the need to store and burn kerosene improves air quality and safety. The systems also ease access to information and entertainment via radio and television, and help families carry on income-generating activities.

While markets are starting to develop in many countries, SHS dissemination still faces substantial constraints. Barriers include lack of information about SHSs and grid extension plans, lack of capital for SHS businesses and consumer financing programs, and lack of trained technicians, managers, and other human infrastructure needed for system delivery and maintenance. Market distortions stemming from import duties on SHS equipment and subsidies for kerosene also constrain SHS dissemination in many countries. International initiatives and host-country policies can help to remove these constraints, accelerate SHS markets, and ensure that the potential GHG mitigation and development benefits are realized.

The Clean Development Mechanism (CDM), established under the Kyoto Protocol to the United Nations Framework Convention on Climate Change, could become important for accelerating SHS dissemination. The CDM will allow industrial coun-

[2] The author wishes to thank Don Aitken, Phil Covell, Moy Eng, Cathleen Kelly, Ken Locklin, Alan Miller, Michael Philips, Roby Roberts, Adam Serchuk, Virinder Singh, and Andre Verani for reviewing earlier drafts, Christiana Figueres, Kurt Johnson, Ted Kennedy, Peter Lilienthal, and many others for providing valuable input, and Mary Kathryn Campbell and Linda Starke for editing the document. Research for this paper was supported by the Joyce Mertz-Gilmore Foundation. The final draft is the responsibility of the authors and does not necessarily reflect the opinions of the funding organization, REPP, the REPP Board of Directors, or the reviewers.

tries to meet part of their Kyoto emission commitments through GHG mitigation projects in developing countries that also contribute to sustainable development. If CO_2 trades for about $20 per ton, CDM funding will generate about $3–6 per typical SHS per year, or about 10% of initial wholesale equipment costs when discounted at 10% over 20 years. If CDM transaction costs are kept sufficiently low, this funding could prove quite valuable in improving marginal project economics and making the systems more widely affordable. To encourage early action, categorical eligibility—or at least the rules by which SHS projects can participate in the CDM—should be declared as early as possible, even if work is still being done to determine how to treat other activities that are less obviously consistent with the CDM's goals.

Developing-country government agencies should take advantage of the incremental funding available for climate protection to help them promote sustainable SHS markets. In addition to the CDM, other international funds may be available to countries though various climate-motivated market development initiatives supported by multilateral and bilateral aid institutions.

To create an environment that will best enable growth in private SHS markets and maximize system use and the associated GHG benefits, developing-country governments should:

- clarify and publicize grid extension plans;
- require imported equipment to meet international quality standards;
- lower import taxes on SHS components;
- eliminate kerosene and/or rural electrification subsidies, or provide equal treatment for SHSs; and
- if providing subsidies for private SHS markets, embed them in the most stable framework possible and, where feasible, use a competitive mechanism to keep subsidy levels as low as possible.

To help initiate and foster SHS markets, bilateral and multilateral agencies and philanthropies should:

- fund SHS technician and business training, technical assistance, feasibility studies, and public education;
- support government capacity-building in the areas of renewable energy and the environment;
- provide seed capital and credit enhancement (such as loan guarantees) for SHS businesses and end-user credit programs, ideally as cofinancing that leverages larger private investments; and
- avoid system donations, as these can undermine commercial markets and are unsustainable.

Finally, businesses, private institutions, and citizens concerned about climate change should consider investing in SHS activities. To date, opportunities to invest in SHS businesses and consumer financing programs have been limited, but numerous private investments have been made and additional investment opportunities are emerging. The level of risk, rate of return, and amount of CO_2 displaced per dollar invested will vary, but all such investments can simultaneously help to elevate rural living conditions and mitigate climate change.

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Growing scientific consensus indicates that human activity, particularly the intensive use of carbon-based energy sources, is altering Earth's atmosphere in a way that could profoundly affect the global climatic system. In response, the nations that are party to the U.N. Climate Convention drafted the Kyoto Protocol in 1997. The protocol commits industrial countries to limit their greenhouse gas (GHG) emissions, assigning country-specific goals that will reduce overall industrial-country emissions to 5.2% below 1990 levels over five years beginning in 2008. Developing countries, where per capita GHG emissions have historically been far lower, are not subject to binding limits under the protocol. They can, however, benefit from investments in climate change mitigation projects by participating in the Clean Development Mechanism (CDM).

Studies suggest that renewable energy may figure prominently in our energy future and play a critical role in strategies for greenhouse gas control.[3] Large grid-tied renewable energy projects have the capacity to displace vast quantities of current GHG emissions. Off-grid applications of renewable energy in developing countries can also displace GHG emissions while providing a valuable near-term market niche for emerging technologies and significantly elevating living conditions; in the long term, rural applications could also potentially have substantial GHG avoidance benefits, given that an estimated 2 billion people in these areas still do not have access to grid electricity.[4]

Due to cost reductions in photovoltaic (PV) technology and the high cost of grid extension, stand-alone PV systems now represent the least-cost option for electrifying homes in many rural areas.[5] These "solar home systems" (SHSs) are proving to be practical for providing small amounts of electricity to households beyond distribution networks. The systems typically consist of a 10- to 50-watts peak (Wp) PV module (which can easily be expanded by adding additional modules), a rechargeable battery sometimes coupled with a charge controller, wiring, lights, and connections to small appliances (such as a radio, television, or fan). Many household systems also electrify small businesses, and similar systems have agricultural and community applications (such as in schools and health clinics).

Experience from countries such as Honduras, India, and Zimbabwe has shown that SHSs can contribute to the energy supply mix of rural communities while directly displacing GHG emissions.[6] Since the carbon dioxide (CO_2) reductions that result from replacing kerosene with electric lighting can be readily documented, the CDM potentially offers a great opportunity for developing-country businesses and consumers to receive cash compensation for their contribution to addressing the global problem of climate change.

This report examines how solar-based rural electrification can contribute to climate change mitigation and improve living conditions in developing countries, and suggests ways to maximize these benefits. Part I examines how SHSs can contribute to climate change mitigation and calculates the potential PV commercialization benefits that could result if SHSs become more widespread. Part II summarizes the non-GHG environmental benefits and the social and economic benefits of SHS dissemination. Part III explores potential SHS project participation in the CDM. And Part IV presents conclusions and recommends policies to facilitate SHS dissemination within rural energy development and GHG control strategies.

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[3] Shell now predicts that renewable energy could supply up to 50% of the world's electricity by 2050; John Mills, Director of Corporate Affairs, Shell U.K. Limited, "Seizing Renewable Energy Opportunities," presented at Renewable Energy Conference, UK Government Office of the East Region, Cambridge, 26 February 1998, at <www.shell.co.uk/news/speech/spe_renewable.htm>, August 1999.

[4] World Bank, *Rural Energy and Development, Improving Energy Supplies for Two Billion People* (Washington, DC: World Bank, 1996).

[5] See, for example, Anil Cabraal, Mac Cosgrove-Davies, and Loretta Schaeffer, *Best Practices for Photovoltaic Household Electrification Programs*, World Bank Technical Paper No. 234 (Washington, DC: World Bank, 1996); available at <www.worldbank.org/astae/reports.htm>.

[6] Solar home system projects in these and several other countries are participating in international climate protection initiatives through the Global Environment Facility and the pilot program of Activities Implemented Jointly under the U.N. Climate Convention.

Box 1: Other Renewable Energy Technologies for Rural Electrification and Climate Change Mitigation

While this report focuses mainly on PV for stand-alone household and small business electrification, many other renewable energy technologies also help to supply electricity in rural areas of developing countries while reducing GHG emissions.

In addition to household and small business applications, PV technology can supply energy for a range of other needs in rural areas of developing countries, all of which could contribute to climate protection. Water pumping for domestic and agricultural use and health clinic refrigeration systems are two examples. Other approaches to rural electrification using renewable energy can also contribute to climate protection:

Grid-connected systems: Wind, biomass, hydropower, and geothermal energy all have tremendous potential to generate electricity for grid and mini-grid systems. Many developing countries are abundantly endowed with these energy sources. Where population and load density are sufficiently high, grid extension can be less expensive than SHSs. In addition, PVs and wind may be cost-effective in distributed grid-connected applications. For example, in areas with daytime demand peaks (from air conditioning, for instance), it may be possible to defer local transformer upgrades indefinitely by installing successive rooftop PV systems that keep pace with load growth.

Hybrid mini-grid systems: Wind, PVs, and hydroelectric generators can provide supplementary energy to, and even replace, the diesel generators commonly used in mini-grid applications in rural areas of many developing countries. This renewable energy application directly displaces diesel combustion and yields GHG benefits that are easy to quantify and monitor. Where sufficient resources exist, hybrid renewables systems can capture cost efficiencies by, for example, using PV and wind to take advantage of the fact that it is often windy during cloudy periods.

Individual household electrification: Where sufficient wind, micro-hydro, and biofuel resources are available, these technologies can sometimes electrify individual homes for less than PVs. Moreover, at its present cost, PV technology cannot realistically address thermal loads such as cooking, whereas other renewable technologies sometimes can, yielding additional GHG benefits.

Battery charging stations: PVs, wind, hydropower, or perhaps some combination of these can and have been used to charge lead-acid batteries that often supply electricity in off-grid rural homes.

PART I. ROLE OF SOLAR HOME SYSTEMS IN CLIMATE CHANGE MITIGATION

Each solar home system directly displaces a modest amount of greenhouse gas emissions by substituting for other energy sources in rural homes. Because of the very large number of homes still unelectrified and because SHSs are often the least-cost electrification option, they potentially can play a significant role in GHG control. In addition to directly displacing fossil fuel consumption, the SHS market can help build the international PV industry, leading to lower production costs and increased PV sales for a range of applications with substantial climate change mitigation benefits.

Potential Size of the Solar Home System Market

The magnitude of GHG benefits from SHSs will depend largely on how widely the systems are used. Although it is impossible to predict future penetration levels accurately, a sense of the potential size of the market can be gained by examining the number of unelectrified developing-country homes and the market niche and affordability of SHSs.

Estimates of the world's unelectrified population during the 1990s fell generally in the range of 1.8–2.0 billion people occupying 300–400 million homes, mostly in rural areas. While many industrial countries are nearly 100% electrified, the World Bank estimates that in 1990 only 33% of rural developing-country homes were connected to electricity.[7] By region, estimated rural electricity connection rates for 1990 were 45% for East Asia and the Pacific; 40% for Latin America and the Caribbean; 35% for North Africa and the Middle East; 25% for South Asia; and just 8% for sub-Saharan Africa.[8] Table 1 presents an estimate of the unelectrified rural population in 1990 by region.

SHSs are often the least-cost electrification option where population and load density are low.[9] On a life-cycle basis, the systems frequently cost about what rural households would otherwise spend on lighting fuels, dry cells, and car batteries. Yet the convenience and quality of service provided by an SHS generally far exceeds that of traditional alternatives. For example, one 15-watt fluorescent lamp or one 60-watt incandescent lamp provides the luminosity of 18 kerosene wick lamps or 60 candles.[10] Also, many households spend time, cash, and considerable effort transporting and charging car batteries so they can have access to television. Given their cost and convenience advantages, it is not surprising that SHSs are increasingly popular in many areas.

While the price of an SHS can be made comparable with current household energy expenditures if systems are paid for over time, the high up-front cost is a substantial barrier to broader dissemination. At current prices (ranging roughly from $125 to $1,300 for systems of 10 to 50 Wp), a small percentage of rural households can and will pay cash to purchase SHSs, but many more will only acquire systems if given access to some form of financing. Consumer loans and "fee-for-service" arrangements (where households make periodic payments for the use of an SHS) can greatly increase affordability and market penetration.

Estimates of the potential SHS market in developing countries vary widely, depending on assumptions about the cost and availability of financing. The potential cash market is estimated as roughly 5–10% of the rural households currently without an electricity connection.[11] With access to loans and fee-for-service arrangements, however, the estimates suggest that the SHS market could reach up to 50% or more of unelectrified rural homes.[12]

Table 1: Estimated Unelectrified Rural Population by Region, 1990

Region	Estimated Unelectrified Rural Population (million)
North Africa and the Middle East	73
Latin America and the Caribbean	75
Sub-Saharan Africa	314
South Asia	632
East Asia and the Pacific	642

Source: derived from World Bank electrification coefficients and population data.

Energy expenditures for displaceable items such as kerosene, candles, dry cells, and lead-acid battery charging provide an excellent indication of rural consumers' ability to pay for the energy services of an SHS. These expenditures differ greatly even within specific rural areas. One source estimates that as many as 80% of unelectrified rural households spend an average of at least $8 per month on such energy sources.[13] Current SHS fee-for-service businesses, including Soluz Inc.'s operations in the Dominican Republic and Honduras as well as Shell-Eskom's in South Africa, are providing services starting at about $8–10 per month.[14]

Based on rural consumers' ability-to-pay and the present cost for PV service, a 50% average penetration rate may be a reasonable upper-end estimate of the potential SHS market. Although a number of rural areas would probably not have this level of activity, others appear to have the potential for even higher levels of penetration on a commercial basis.

Table 2 estimates the market potential for SHS dissemination based on 1990 unelectrified population figures, assuming an average of 5 people per household and an average system size of 40 Wp. Obviously, growth in the unelectrified population would increase the potential SHS market.

[7] World Bank, op. cit. note 4, p. 42.
[8] *Ibid*.
[9] Cabraal, Cosgrove-Davies, and Schaeffer, op. cit. note 5.
[10] R. Van der Plas and A.B. de Graaff, *A Comparison of Lamps for Domestic Lighting in Developing Countries*, Industry and Energy Department Working Paper, Energy Series Paper No. 6 (Washington, DC: World Bank, 1988).
[11] For example, a report by the German development agency GTZ, evaluating its experience with SHS projects in 19 countries, estimated that "in most developing countries at least 10% of the rural households would be willing and able to pay cash for an SHS"; GTZ, *Basic Electrification for Rural Households* (Eschborn, Germany: 1996), p. 120.
[12] Enersol Associates, Inc.'s experience in the Dominican Republic and Honduras indicates that consumer loans with up to three-year terms can make systems affordable for 15–25% of the unelectrified rural population. Soluz, Inc.'s market studies and commercial operations suggest fee-for-service arrangements could enable market penetrations of 50% or more in certain communities. Enersol Associates and Soluz Inc. are direct affiliates of Global Transition Consulting, two of the principals of which contributed to this report.
[13] GTZ, op. cit. note 11, p. 106.
[14] "Shell and Eskom Bring Power to the People," downloaded from <www.shell.com/b/eskom>.

Table 2: Estimated Potential Solar Home System Market

Scenario	Number of People	Number of Homes	Installed PV Capacity	System Value in Dollars[b]
Lower-End Rural Market Potential (10% penetration)	170 million	34 million	1,360 megawatts	$17 billion
Upper-End Rural Market Potential (50% penetration)	850 million	170 million	6,800 megawatts	$85 billion

[[a]Assumes an average system size of 40 Wp. [b]Assumes an average system cost of $500 installed.]

Although Table 2 indicates that the developing-country SHS market could become quite large, to date only a tiny fraction of this potential has been realized. Even in countries where SHS markets are most active, such as Kenya, Morocco, and the Dominican Republic, only about 1–2% of the potential SHS customer base has been reached.[15] Still, the developing-country SHS market accounted for an estimated 13–15 megawatts of PV module sales in 1998, about 10% of the world's PV shipments.[16] One prominent industry analyst predicts that the SHS market will experience sustained growth of 20–22% annually.[17]

Several factors constrain SHS market growth. In addition to the high up-front system costs mentioned earlier, the principal barriers to sustainable growth in SHS markets include:

- high import taxes on SHS components and kerosene subsidies in some markets;
- lack of clarity regarding electricity grid extension plans, which makes consumers and businesses uncertain about whether to invest in SHSs;
- lack of SHS businesses with trained staff operating in rural areas;
- lack of reliable knowledge about the technology;
- capital constraints for SHS businesses; and
- inadequate system design and maintenance, including the inability of some end-users to pay for parts replacement.

Governments, multilateral and bilateral development assistance agencies, private foundations, nongovernmental groups, and businesses can do a great deal to facilitate SHS markets. The World Bank and other organizations have published detailed reports examining institutional and financing modalities for SHS dissemination that provide valuable insights regarding good practices for those seeking to structure sustainable SHS dissemination activities.[18]

Experience suggests that actions targeted at enabling and supporting private SHS markets will be most effective and sustainable. Governments can facilitate SHS markets by reducing import tariffs on SHS components, reducing subsidies for kerosene and grid extension (or providing commensurate ones for SHSs), clearly identifying grid expansion plans, and setting regulations conducive to private participation in off-grid markets. Government, multilateral, and foundation support for training and public education as well as the provision of seed capital for SHS businesses and financing programs for SHS buyers also clearly help catalyze SHS markets. SHS businesses should be trained to properly design and maintain systems. Ideally, homeowners should also be educated about proper maintenance.

Substantial direct subsidies and system donations often have proved counterproductive because they enable people to ob-

[15] Kenya figures based on Robert Van der Plas and Mark Hankins, "Solar Electricity in Africa A Reality," Energy Policy, vol. 26, no. 4 (1998). Dominican Republic and Morocco figures are from the Global Environment Facility (GEF) Project Brief for the Solar Development Corporation, 8 September 1998.

[16] PV Energy Systems, *World Photovoltaic Markets 1975 to 1998* (Warrenton, VA: August 1998), available at <www.pvenergy.com>, indicates that SHSs accounted for about 15 MW out of 153 MW in estimated world PV shipments for 1998. Information in the GEF Project Brief, op. cit. note 16, coupled with information in E.A. DeMeo, R. Johnson, and G. Schramm, *The Present and Future Prospects of PV-Based Network Generation: Can An Assured Large Market Bring PV-System Costs Down To $3,000 Per Installed Kilowatt?* Prepared by Renewable Energy Consulting Services, Inc. for Environmental Projects Unit, International Finance Corporation (draft), 1 March 1999, indicates that SHSs accounted for about 13.5 MW out of 136 MW in estimated world PV shipments in 1998.

[17] Personal communication with Paul Maycock, PV Energy Systems, Warrenton, VA, 8 October 1999.

[18] See, for example, Cabraal, Cosgrove-Davies, and Schaeffer, op. cit. note 5, and Anil Cabraal, Mac Cosgrove-Davies, and Loretta Schaeffer, Accelerating Sustainable PV Market Development; both are available from <www.worldbank.org/astae/reports.htm>.

tain systems without making a substantial personal investment. Some of these individuals may lack the commitment or financial resources to maintain their systems adequately. Furthermore, unless subsidies are channeled through the private sector and embedded in a reliable long-term framework, they can undermine sustainable commercial markets.

A cluster of Global Environment Facility (GEF) projects could substantially accelerate SHS markets. The GEF provides financial support for development projects that also address one of four global environmental priorities, including climate change. Removing barriers to renewable energy dissemination is part of the GEF's climate change strategy, under which it is now committed to supporting 20 SHS and rural energy service projects that could help to catalyze over 1 million new SHS installations.[19] Included among these projects are the multi-country Photovoltaic Market Transformation Initiative (PVMTI) and the Solar Development Corporation, as well as numerous initiatives in individual countries. A recent document reviewing the GEF's energy efficiency and renewable energy projects includes a section summarizing GEF participation in SHS market development.[20]

Direct Carbon Displacement

Nearly all SHSs substitute electric lights for kerosene lamps and other hydrocarbon-based lighting sources. Often, SHSs also directly displace CO_2 emissions from the charging of lead-acid batteries with a grid connection or a diesel or gasoline generator.

Since fossil fuel energy is generally used to produce and transport PV modules and other SHS system components, these activities generate some "upstream" GHG emissions. Yet a study prepared for the World Bank found that for solar lanterns (which are smaller than typical SHSs and provide just a single light but otherwise are substantially similar), the upstream emissions are offset by comparable upstream emissions savings associated with displaced kerosene refining and transportation.[21] Based on another recent study that examined embedded energy in SHSs, it appears that upstream emissions for the kerosene displaced by SHSs will generally exceed those associated with the SHS components themselves (PV modules and lead-acid batteries) for a range of system sizes.[22]

Table 3: Baseline Kerosene Lighting Figures for Different SHS Projects

Project Location and and Type	Kerosene for Lighting (liters/month)
Argentina GEF	15.2–21.3
Benin GEF	3.0–11.7
Bolivia AIJ[a]	5.0
Burkina Faso AIJ	12.0
Honduras AIJ	7.6
Indonesia AIJ	16.4
Indonesia GEF	15.0
Peru GEF	7.5
Sri Lanka AIJ	10.0–13.4
Zimbabwe GEF	2.8
Togo GEF	3.0–11.7

[a] Figure is for diesel fuel.

Source: derived from project documents and personal communications.

Kerosene Displacement

Since displacing kerosene usually represents the biggest direct carbon benefit, SHS projects that quantify their GHG benefits—including ones receiving GEF support or participating in the Activities Implemented Jointly (AIJ) pilot program of the Climate Convention—almost always use kerosene consumption figures to calculate the baseline emissions expected without the project. Table 3 shows kerosene use figures reported in the baseline for a geographically diverse sampling of GEF and AIJ projects.

Higher-income rural families tend to burn more kerosene for lighting than lower-income families. The calculations presented here attempt to account for this variability and the likelihood that comparatively higher income homes will be the first to adopt SHSs.

[19] Eric Martinot and Omar McDoom, Promoting Energy Efficiency and Renewable Energy: GEF Climate-Change Projects and Impacts (Washington, DC: GEF, October 1999) (pre-publication draft).

[20] *Ibid*.

[21] Alternative Energy Development, Inc., India Non-Conventional Energy Projects for Global Environment Facility Funding, Vol. I: Main Report, prepared for the World Bank (Washington, DC: December 1991).

[22] The author's calculations found that emissions embedded in SHS components were less than the upstream emissions associated with refining and delivering the kerosene they typically displace. These calculations are based on emissions figures in A.E. Alsema, *Energy Requirements and CO2 Mitigation Potential of PV Systems*, presented at BNL/NREL Workshop "PV and the Environment 1998." That paper itself, however, reached a different conclusion by assuming SHSs would displace diesel generators rather than kerosene.

Most SHS projects structured for climate change mitigation anticipate that electric lights will displace nearly all kerosene lighting in homes, but the extent of actual kerosene displacement may vary. Where enough lights are installed and systems function properly, anecdotal reports suggest and at least one study confirms that kerosene displacement is nearly complete.[23] Studies of some SHS activities, however, report continued kerosene use in the 20–45% range.[24] In some cases, continued kerosene use has been attributed to system design and operational problems and to market distortions related to kerosene subsidies as well as for outdoor and supplemental lighting.[25] Projects participating in formal GHG control programs such as the Clean Development Mechanism will generally need to confirm that projected emission reductions are actually achieved. The calculations in this section assume 90% kerosene lighting displacement.

Battery Charging Displacement

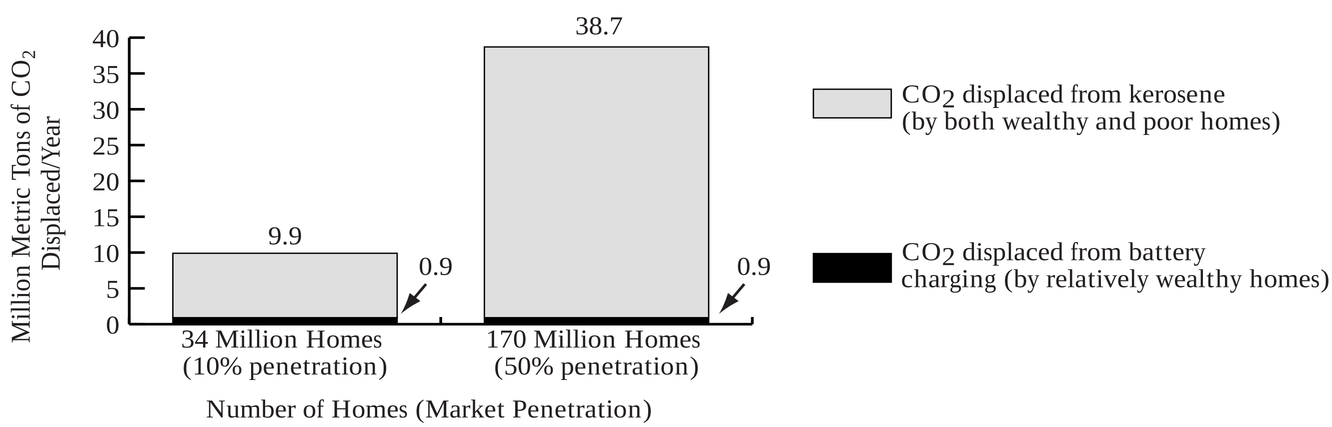
In many developing countries, car batteries are commonly used to provide household electricity. Limited data suggest that perhaps 10% of all unelectrified households regularly charge lead-acid car batteries. In Kenya, for example, about 5% of the unelectrified homes charge lead-acid batteries (in addition to homes using SHSs), while in Morocco 14% of rural homes use car batteries.[26] Figures reported for a few other countries also fall within this general range.

Households that use car batteries usually recharge them two to four times a month. Recharging 50- to 100-amp-hour 12-volt batteries produces CO_2 emissions of roughly 15–30 kilograms a year for grid-based battery charging, and considerably more where small diesel and gasoline generators are used.[27]

Overall Direct Displacement Potential

The first 10% of SHS adopters are expected to be higher-income rural households who are motivated to gain better access to electricity. For this group, SHSs are assumed to substitute for both kerosene lighting and battery charging, and baseline kerosene consumption is assumed to be relatively high, at 10 liters per month. Each SHS in this group directly displaces about 0.3 metric

Figure 1: Direct Carbon Dioxide Displacement from SHS Dissemination



[23] For example, the National Rural Electric Cooperatives Association's experience in Bolivia was cited in the USIJI application for an SHS project in that country to support the assumption of 100% kerosene displacement. In Honduras, household surveys conducted and documented in an unpublished 1999 study by Brown University student Maria Reff indicate 94% kerosene displacement for SHSs bought with cash and suggest higher levels of displacement for SHS rentals.

[24] Continued kerosene use of 20% after SHS installations in Nepal from Regina Betz, *The Activities Implemented Jointly (AIJ) Project of the E7 Initiative: Renewable Energy Supply Systems in Indonesia: A Case Study*, ISI Working Paper (Karlsruhe, Germany: February 1999); continued kerosene use of 45% after an SHS project in India from Tata Energy Research Institute (TERI), *Evaluation of SPV Systems Installed Under INDO-US Collaboration Programme, Sundarbans, West Bengal* (draft) (Arlington, VA: 1998).

[25] Personal communications with Douglas Barnes on 19 July 1999 and with Hasna Khan on 20 July 1999.

[26] M. Hankins, F. Ochieng, and J. Scherpenzeel, *PV Electrification in Rural Kenya: A Survey of 410 Solar Home Systems in 12 Districts*, Final Report, Prepared by Energy Alternatives Africa for the World Bank, ESMAP (November 1997); Michel Rodot and Abdelhanine Benallou, eds, *Electricite Solaire au Service du Developpement Rural* (Rabat: Reseau International d'Energie Solaire, 1993), p. 30.

[27] Assumes 500 to 1,000 watt-hours per charge and a grid emissions rate of 0.8 kg/kWh, which is roughly the developing-country average for 1995. The 0.8 kg/kWh figure is based on data in U.S. Dept. of Energy, Energy Information Administration, *1997 International Energy Annual* (Washington, DC), Table 24, and emissions factors from U.S. Dept of Energy, *Sector Specific Issues and Reporting Methodologies Supporting the General Guidelines for the Voluntary Reporting of Greenhouse Gases under Section 1605(b) of the Energy Policy Act of 1992*, October 1994, Vol. 2, Table B1.

tons of CO_2 per year or about 6 tons over 20 years.[28] SHS use for the next incremental 40% of potential adopters is assumed to displace kerosene alone, using 8 liters per month as the baseline. Each SHS for this group would displace about 0.2 tons of CO_2 per year on average or about 4 tons over 20 years.

As illustrated in Figure 1, at a market penetration level of 10%, SHSs would directly displace roughly 10 million metric tons of CO_2 per year, while at 50% penetration the figure would be nearly 40 million tons. At the lower-end penetration level, the annual CO_2 emissions directly displaced would approximately equal CO_2 emissions from fossil fuel use in Zimbabwe during 1995, while at the upper-end level they would equal those of Switzerland for that year. Compared with the world's 23 billion tons of CO_2 emissions from fossil fuel use in 1995, however, the amount of direct CO_2 displacement is still quite small.[29]

Although the total direct CO_2 displacement per SHS is small, the rate, defined as CO_2 displacement per kilowatt hour (kWh), is extremely high. Reports on AIJ and World Bank/GEF projects in Indonesia indicate that the rate of CO_2 displacement per kilowatt-hour (kWh) from SHS was 10 times greater than for renewable energy applications displacing fossil-fuel-based power generation.[30] Other studies have reached similar conclusions. The high rate of displacement is due to the tremendous inefficiency of kerosene lighting. Consider, for example, that a 40 Wp PV module connected to an electric grid in the United States would displace roughly 40 kilograms of CO_2 per year, but the same module supplying electricity to a rural home in Kenya would displace about 350 kilograms of CO_2 emissions a year by replacing inefficient kerosene lighting alone.[31]

In addition to displacing kerosene lamps and battery charging, SHSs also typically substitute for candles, dry cell batteries, and occasionally small generators, all of which have associated GHG emissions.[32] While not quantified here, avoiding the GHG emissions associated with these energy sources will clearly add to the direct GHG benefits from SHSs.

Well-designed SHS market development programs can help ensure that SHS installations result in sustained carbon benefits. For example, SHS marketing programs should target areas not likely to obtain grid electrification for some time. If the grid comes to an area where SHSs are installed, the direct GHG displacement benefits will be largely lost if households connect to the grid but keep their systems as backup. Secondary markets for used equipment would, however, encourage the recovery of systems investments and allow the direct GHG benefits to continue. Fee-for-service arrangements would also protect against such a loss of GHG benefits, since SHS rental companies would remove and reinstall any equipment made superfluous by the arrival of grid electricity.

The periodic battery replacements essential for proper system functioning are also needed to ensure durable GHG benefits. Adequate technician training, end-user orientation, and dissemination based on the market as opposed to donations would encourage this and other essential maintenance steps.

Avoided Grid Emissions

While displacing kerosene lamps and battery charging will probably be the most direct carbon abatement mechanism, SHS use can also help to avoid emissions from new connections to electric grids. This is particularly applicable in countries like Argentina and South Africa, where the governments have decided to use SHS as an alternative to the grid in their aggressive rural electrification efforts.[33] In the past, some analysts have considered SHS a form of pre-electrification due to the comparatively small amount of electricity typically provided. Given their comparative economic advantages for dispersed populations and the ease of deployment, however, governments, businesses, and consumers could increasingly favor SHS over grid extension to electrify rural homes, especially if PV prices continue their downward trend.

To estimate the amount of grid electricity and GHG emissions avoided by an SHS, it is more instructive to use the level of

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[28] Calculations assume that three battery charges per month result in 0.025 tons CO_2 emissions per year. In all cases, SHSs are assumed to displace 90% of baseline kerosene usage and each liter of avoided kerosene displaces 2.45 kg of CO_2.

[29] Country and world CO_2 emissions figures from World Resources Institute, *World Resources 1998–99* (New York: Oxford University Press, 1998), Tables 16.1 and 16.3.

[30] *Renewable Energy Supply System in Indonesia, Progress Report No. 2, Activities Implemented Jointly under the United Nations Framework Convention on Climate Change*, Agreed to by the Republic of Indonesia and the E7 Initiative, October 1998; deLucia and Associates, Inc. *Indonesia Renewable Energy Development Project: A Note on the Global Environmental Calculus*, prepared for the World Bank East_Asia & Pacific, Country Department III, Industry & Energy Operations Division (Cambridge, MA: 14 October 1994).

[31] U.S. grid calculations are based on the 1992 average electricity CO_2 emissions rate of 0.586 kg/kWh and assume daily insolation of 4.5 kWh per square meter; Kenya figure is derived from Robert Van der Plas and Mark Hankins, "Solar Electricity in Africa: A Reality," *Energy Policy*, vol. 26, no. 4 (1998), p. 299.

[32] The carbon content of petroleum-derived candle wax, at about 85%, roughly equals that of kerosene.

[33] Nathanael Greene, Richard Duke, and Dale Bryk, "Regulating for Renewable Rural Electrification," Natural Resources Defense Council, forthcoming December 1999.

electricity consumption typical in grid-connected rural homes as a benchmark rather than the amount supplied by an SHS. SHSs in the range of 10–50 Wp generate much less electricity than that consumed by average grid-connected rural households. SHS owners nonetheless often derive many of the functions that they would from grid connections because they generally couple their SHSs with highly efficient fluorescent lights and direct current appliances. Direct current fluorescent lamps, for example, are three to four times as efficient as standard incandescent bulbs, and black and white televisions that use 15 watts when connected to a direct current power source require about 35 watts when connected to alternating current. While the limited amount of electricity from an SHS necessitates careful and efficient energy use, if households were connected to a grid rather than an SHS, they would probably consume electricity at the same rate as other grid-connected households.

Average electricity consumption for grid-connected rural households varies widely among and within developing countries, largely depending on income. World Bank reports showing a breakdown of household electricity consumption in developing countries indicate that lower-income households often consume on the order of 20 kWh per month, mostly for lighting.[34] Middle-income households use on the order of 50 kWh per month for lighting and other applications, many of which have fairly small loads that can be reasonably satisfied by a typical SHS. High-income households can use up to 100 kWh or more per month and generally have at least some appliances with load requirements that exceed the capacity of a small SHS. Household electricity consumption also tends to increase over time.[35]

Table 4 presents various scenarios of the potential for SHS dissemination to avoid grid-based GHG emissions. While less direct than displacing kerosene and battery charging, the potential GHG benefits from grid avoidance could be significantly greater under moderate or higher levels of avoided consumption. Since PV modules can be added to augment system capacity, SHSs can accommodate growth in electricity demand without increasing GHG emissions. For long-range estimates of grid avoidance, this is plausible since average system size will probably increase if module prices continue to fall and average rural incomes in developing countries rise. Over time, the benefits of avoided grid-based CO_2 emissions could grow substantially.

Table 4: Avoided Electric Grid Emissions from SHS Dissemination

Consumption Scenario	Low-End Rural Market Potential (34 million homes)	High-End Rural Market Potential (170 million homes)
	(million metric tons of CO_2 avoided per year)	
Low Average Consumption (20 kWh)	7	33
Moderate Average Consumption (50 kWh)	16	82
High Consumption & Growth (100 kWh)	33	163

Note: calculations assume a grid emissions rate of 0.8 kg CO_2 /kWh, the approximate average for all developing countries in 1995. Since India and China represent large potential SHS markets and have large coal reserves, the actual rate of avoided emissions might be higher. Consumption levels in the "moderate average" and "high consumption" scenarios likely include some end-uses not generally met by small SHSs; these scenarios would overstate avoided emissions somewhat if those end-uses are met with GHG-emitting energy sources (such as propane for cooking).

PV Market Transformation Benefits

Another indirect though possibly substantial GHG benefit comes from the ability of SHS purchases to help fuel growth in the PV industry. If the SHS market can substantially increase PV module sales, this could help increase PV production capacity, bring down cell and module costs, and contribute to tremendous GHG benefits as PVs become cost-effective for a broader range of applications.

The relationship between cumulative production of a manufactured product and total cost per unit produced can be characterized by an experience curve. Empirical studies reveal a consistent pattern, generally attributable to the efficiency gains from learning-by-doing and economies of scale, whereby costs fall by an approximately fixed percentage with every doubling of cumulative production.

[34] See, for example, World Bank, op. cit. note 4, p. 41, and Gerald Foley, *Photovoltaic Applications in Rural Areas of the Developing World,* World Bank Technical Paper No. 304 (Washington, DC: World Bank, 1995), p. 35.
[35] Foley, *ibid.* note 35, p. 35.

Figure 2 demonstrates the tight empirical relationship between cumulative industry-wide production and the unit price for photovoltaics. This series from 1976 to 1992 indicates that inflation-adjusted prices drop by 18% with every doubling of cumulative production. Other analyses using different data sets and periods have indicated price declines as high as 32%, but most studies indicate that prices have historically fallen by about 20% with every doubling of cumulative PV output.[36]

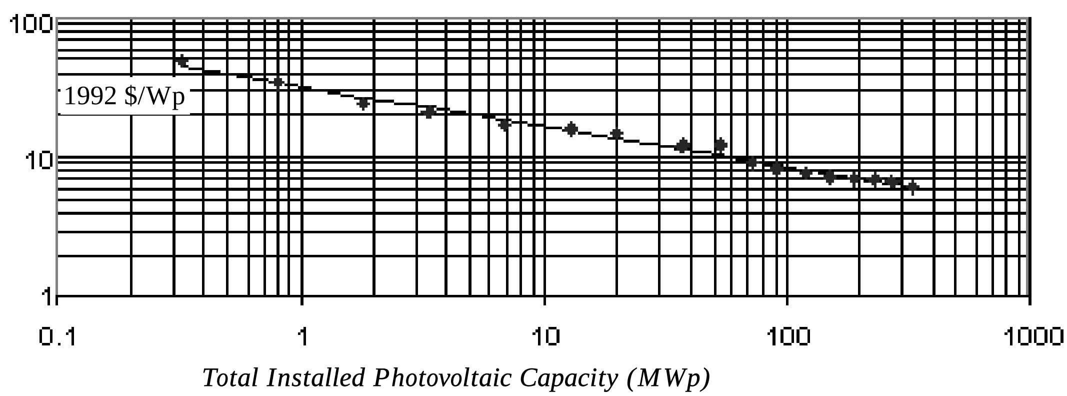
By extrapolating from the historical PV experience curve, it is possible to estimate future PV prices as a function of projected sales growth. If all current segments of the PV market grow by 20% annually and prices decline by 20% for every doubling of cumulative PV sales, module costs would fall from a 1998 wholesale price of $3.65 per Wp to about $1.20 by 2018.

If market transformation initiatives can successfully accelerate growth in the SHS market, experience curve theory suggests that the additional module sales would lead to more rapid PV cost reductions. Programs such as the GEF-supported PV Market Transformation Initiative and Solar Development Corporation have the potential to "jump-start" SHS sales early on and maximize the incremental price reduction associated with any given level of SHS sales. For example, adding 25 MWp of additional SHS sales in 2000 (that is, assuming year 2000 sales of 43 MWp rather than 18 MWp) and sustaining market support so future SHS sales match the 20% annual growth assumed for non-SHS sales yields an estimated 5% average annual PV price drop over a 20-year period attributable to SHSs alone. This is based on a static assessment that does not account for the positive effect of cost reductions on demand.

In practice, markets respond to cost reductions with increased demand; the extent to which this happens is characterized by the "price elasticity of demand." While this demand elasticity is uncertain, the implication is that anything that boosts demand for PV may induce a price reduction via the experience curve, which in turn would induce an increase in future demand. This "virtuous cycle" could continue indefinitely but it will likely dampen over time. It is impossible to quantify precisely the importance of these dynamic effects, but one analysis suggests that for PVMTI they will likely exceed the static-experience-curve benefits from the program.[37]

PV manufacturers are continuously making decisions about whether and when to invest in more efficient larger-scale production facilities. The technology exists today to bring production costs down substantially by moving to larger-scale production facilities; manufacturers have yet to take on this risky investment, however.[38] Recent PV market growth has been fueled in large part by highly subsidized grid-connected markets such as residential rooftop programs in Japan, Germany,

FIGURE 2: 1976-92 PV EXPERIENCE CURVE



Source: R. Williams and G. Terzian, *A Benefit/Cost Analysis of Accelerated Development of Photovoltaic Technology*, Report No. 281(Princeton, NJ: Princeton University Center for Energy and Environmental Studies, 1993).

[36] Richard Duke and Daniel M. Kammen, "The Economics of Energy Market Transformation Programs," The Energy Journal, vol. 20, no. 4 (1999), pp.15–64.
[37] *Ibid*.
[38] "Solar Energy: From Perennial Promise to Competitive Alternative," Project 2562, written by KPMG Bureau voor Economische Argumentatie/ Economic Research and Policy Consulting on the Commission of Greenpeace Nederland (Hoofddorp, Netherlands: August 1999). Available at <www.greenpeace.org/~nl/solaris1.html>

and other industrial countries.[39] These markets could evaporate quickly in the face of diminished government support. Manufacturers are understandably skittish about scaling up aggressively to meet such uncertain demand.

In contrast with programs that rely on large subsidies to make PVs economically attractive, efforts to promote SHS markets have the advantage of greater inherent stability because in most cases where they are adopted, SHSs are cost-competitive. Consequently, modest subsidies can build durable markets. The credibility of the SHS demand niche for PVs can be further enhanced if subsidies are embedded in stable frameworks like the CDM or the off-grid fee-for-service concessions emerging in countries like South Africa and Argentina. Consequently, crediting SHSs for their contributions to climate change mitigation represents an important strategy for achieving PV market transformation, even if the per-system credit is small.

Actions to transform PV markets for SHSs and other promising applications could have very important mid-term and long-term climate change mitigation benefits. Without encouraging the development of promising new technologies, the world may rely on mature but limited carbon mitigation strategies, such as displacing coal with natural gas. Investing in clean emerging technologies like PVs creates essential policy "option value" by ensuring that alternatives are ready if the international community decides it must take aggressive action to reduce carbon emissions at some point in the future.

PART II. OTHER BENEFITS OF SOLAR HOME SYSTEMS

Although this report focuses principally on the role for SHSs in climate change mitigation, other benefits of SHSs make them an attractive candidate for participation in the CDM (see Part III). Of course, they also are critical influences on consumer demand as well as host-country and international support for SHS markets.

NON-GHG ENVIRONMENTAL BENEFITS

In addition to CO_2 displacement, decentralized photovoltaic systems offer many environmental advantages relative to the energy sources they commonly replace in rural homes (such as kerosene lamps, dry cell batteries, and car batteries charged from a grid or generator).

Replacing kerosene lamps with solar-powered lights mitigates the risks and health problems associated with storing and using kerosene. In surveys conducted by India's Tata Energy Research Institute, people reported eye irritation, coughing, and nasal problems associated with the use of kerosene lamps.[40] In addition to emitting pollutants with known respiratory impacts (such as carbon monoxide, nitrogen oxide, and hydrocarbons), kerosene lamps are a fire hazard. Furthermore, a substantial number of children reportedly die of accidental kerosene poisoning every year.[41]

Solar electric systems often displace dry cell batteries that are used to power radios, cassette players, and flashlights. Since rural areas generally lack programs for solid waste management, the incineration or disposal of used dry cells in open dumps or as litter can contaminate soil and water sources with toxins, including mercury.

Not only are PVs environmentally superior to kerosene and dry cells, they also have advantages over other electricity supply options. PV modules generate electricity without emitting local air pollution or acid rain precursor gases, water pollution, or noise. The modules are typically roof-mounted or require very little ground space, so PV-based rural electrification also avoids the disruptive land use impacts associated with power lines and some methods of electricity generation (such as large-scale hydropower).

Since stand-alone PV systems provide electricity without power lines, their use in protected forest areas and buffer zones can be particularly valuable for ecosystem preservation. Power-line corridors can open access for the development of forested areas, change the diversity of species within ecosystems, and cause ecosystem fragmentation. Furthermore, power-line construction and maintenance activities themselves can be quite disruptive.

In many developing countries, migration from rural to urban areas is creating tremendous social and ecological problems. People move to the city for jobs and to gain access to electricity and other modern amenities. But urban infrastructure often has not

[39] These markets accounted for about 34% of total PV sales in 1997 and 29% in 1998 according to DeMeo, Johnson, and Schramm, op. cit. note 16.

[40] TERI, op. cit. note 24, Chapter 3, p. 7.

[41] K.R. Smith, Biofuels, Air Pollution and Health: A Global Review (New York: Plenum Press, 1987), pp. 318–21.

kept pace with population growth. While it is unlikely that electricity alone will stem the tide of rural to urban migration, it is possible that solar electrification in rural areas can help by improving the quality of life there.

A negative environmental impact from SHS dissemination can result from the improper disposal of lead-acid batteries. While careful recycling of lead-acid batteries is the best way to prevent this, current recycling practices vary substantially by country. As SHSs become widespread, it will be important to encourage well-managed battery recycling programs.

In the near term, however, SHS dissemination may actually result in a net reduction in the rate of battery disposal. Experience from several countries shows that rural households that regularly charge car batteries are among the first to obtain PV systems. When deeply discharged in between charges, car batteries may last only about 12 months. SHS applications give car batteries a more advantageous charge-and-discharge profile that can potentially extend their life by 50% or more. Furthermore, many SHS installations use deep-cycle batteries that can last several times longer than car batteries. Thus although SHS dissemination will likely increase the number of lead-acid batteries in use, it may decrease the rate of battery disposal until market penetration reaches a level beyond the estimated 10% of off-grid homes presently using car batteries as an electricity source. Even then, SHSs may reduce contamination from lead-acid batteries if dissemination methods such as fee-for-service incorporate aggressive recycling.

Economic and Social Benefits

By many accounts, SHS dissemination and use improves living conditions and can aid in economic development. Vastly superior lighting from electric lamps by comparison with kerosene and candles is often described as the most notable quality-of-life improvement—one that has important educational benefits.[42] In addition to lighting, solar electricity provides the entertainment and education benefits of television access.

Socio-economic impact studies have found that a significant percentage of small PV systems provide power and light for cottage industries, farm-related activities, and rural stores. In the Dominican Republic, for example, about 30% of systems were found to support business activities, often within homes.[43] A study of SHSs in India found that systems extended occupational or business activities into the nighttime in about 40% of the homes surveyed.[44] Examples of numerous "productive use" PV applications are documented in *Solar Photovoltaics for Development Applications*.[45]

Once a workforce of trained technicians gains employment installing small solar electric systems, the installation of more technically sophisticated PV systems for community and business applications becomes possible, with added confidence in the availability and adequacy of local maintenance. In the Dominican Republic, for example, numerous community and agricultural water pumping systems have been installed by PV technicians who got their start installing basic home systems.[46]

PART III. PROSPECTIVE SHS PARTICIPATION IN THE CLEAN DEVELOPMENT MECHANISM

International Climate Change Agreements

Under the United Nations Framework Convention on Climate Change (UNFCCC), which opened for signature at the Rio Earth Summit in 1992, 36 industrial countries (designated as "Annex I") made voluntary commitments to reduce their GHG emissions to 1990 levels by the year 2000. Developing countries, whose per capita emissions have historically been far below those of industrial countries, agreed to inventory though not limit their GHG emissions.

In 1995, at the first Conference of the Parties to the climate convention, the Activities Implemented Jointly pilot phase was created to encourage climate change mitigation projects between parties in different countries. As of June 1999, a total of about 130 AIJ projects of various types (energy, forestry, etc.) had been officially registered, five of which involve SHS dissemination. The number and scale of projects has thus far been modest largely because, at present, Annex I countries cannot use AIJ to help meet their domestic emissions reduction commitments.

At the third Conference of the Parties, held in Kyoto, Japan, in 1997, parties agreed to what has become known as the Kyoto Protocol, which established binding emissions limits for Annex

[42] TERI, op. cit. note 24, Chapter 3, p. 11.
[43] Richard D. Hansen and Jose Martin, *Photovoltaics for Rural Electrification in the Dominican Republic*, Prepared for University of Lowell, Massachusetts, for the U.S. Department of Energy (Lowell, MA: 1987), p. 69.
[44] TERI, op. cit. note 24, Chapter 3, p. 12.
[45] Elizabeth Richards and Lisa Sheppard, *Solar Photovoltaics for Development Applications*, SAND93-1642 Distribution Category 270 (Albuquerque, NM: U.S. Department of Energy, Sandia National Laboratories, August 1993).
[46] See, for example, Steven L. Kaufman, "Solar Electricity for Rural Development: Experience in the Dominican Republic," Energy for Sustainable Development, vol. I, no. 1. (May 1994).

I countries. Collectively, these amount to reductions of 5.2% below 1990 industrial-country levels over a five-year period beginning in 2008. Developing countries are not subject to binding limits under the protocol, but can host climate change mitigation projects within their borders by participating in the Clean Development Mechanism.

The CDM will provide Certified Emission Reduction (CER) credits to qualifying greenhouse gas reduction projects that also provide development benefits to their non-Annex 1 host country. The CERs will be transferable to industrial countries, where they can be applied toward emissions reduction targets. (The CDM is one of three so-called Kyoto mechanisms established by the protocol to help industrial countries meet their emission targets cost-effectively through international GHG trading.)

Since too few countries have ratified the Kyoto Protocol for it to enter into force, the CDM does not yet formally exist. At the same time, the protocol says that crediting of CDM projects can begin in the year 2000; thus the Parties are moving quickly to develop structures and criteria for the CDM in order to give companies and countries guidance on how to proceed with projects as early as possible.

If the CDM develops as anticipated, it will most likely prove to be a primary funding source for climate change mitigation projects in developing countries as part of what could become a multibillion-dollar GHG mitigation market. One estimate suggests the flow of CERs could be on the order of 2 billion tons of CO_2 per year (that is, just under 10% of current global CO_2 emissions and about 50% of projected Kyoto-mandated reductions).[47]

Possibility and Value of CDM Participation

Since SHS dissemination activities simultaneously contribute to climate change mitigation and host-country development, they have the potential to be an excellent fit for the CDM. Based on the criteria being considered, most observers think that most SHS projects would be CDM-eligible, though activities directly supported by official development assistance (ODA) and the GEF would likely be excluded on the basis of additionality criterion (see discussion in next section).

The extent to which CERs can help to expand SHS markets will largely depend on future CER values, which are uncertain. A recent White House report estimated that CO_2 may trade for \$4–6 per ton in 2010, while a U.S. Department of Energy report predicted possible CO_2 prices of \$20–100 per ton by that time.[48] CER values not only will depend on CDM activities, they will be influenced by GHG values from the other Kyoto mechanisms. In addition, the transaction costs associated with CDM participation could have an important impact on the net value of CERs.

Given a range of CO_2 prices from \$4 to \$100 per ton, a 40 Wp SHS displacing 0.3 tons of CO_2 annually could generate CERs worth anywhere from \$1 to \$30 per year. This differential underscores the tremendous uncertainty about CER market value projections, but also shows that CDM participation could improve marginal SHS project economics. For example, if CO_2 trades at \$20 per ton, then each qualifying SHS would generate about \$6 in CERs per year. Assuming a 10% discount rate and 20-year life, the \$50 present value of the \$6 payment stream would equal about 10% of the system's initial wholesale equipment cost. Alternatively, a \$6 CER value could augment annual fee-for-service revenues by about 3–5% per system, potentially enabling an otherwise marginal business to attract sufficient investments to proceed. Since direct carbon displacement per Wp is often larger in smaller SHSs, CERs would tend to have a greater beneficial impact on the economics of the smaller systems generally used by poorer families.

Anticipating CDM Eligibility Requirements

While it is not yet possible to predict with certainty how the CDM will be structured, based on Article 12 of the Kyoto Protocol and on work to date, it appears likely that the eligibility criteria will be based in some way on host-country government approval, advancement of sustainable development in host country, and additionality. Projects would also need to quantify and monitor their GHG reduction benefits adequately.

Host-Country Approval

To be eligible for the CDM, the Kyoto Protocol says that projects must be "approved by each Party involved." Many developing countries do not yet have institutions or processes in place to evaluate CDM projects and will need to build their capacity for

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[47] Christiana Figueres, How Many Tons? Potential Flows through the Clean Development Mechanism (Center for Sustainable Development in the Americas, 1998); accessed from <www.csdanet.org> in August 1999.

[48] White House, *The Kyoto Protocol and the President's Policies to Address Climate Change: Administration Economic Analysis* (Washington, DC: July 1998); Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity* (Washington, DC: U.S. Department of Energy, October 1998). Available from <www.eia.doe.gov/oiaf/kyoto/kyotorpt.html>.

project review. Once procedures are in place, if host-country concerns are adequately addressed in the negotiations, approval seems likely.[49]

Advancing Sustainable Development

The Kyoto Protocol states that "[t]he purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development." It remains unclear how this sustainable development focus will affect project eligibility. Operationally, a sustainable development criterion would be implicit in the host-country approval process, which gives countries veto power over projects they deem unsuitable. Given the socio-economic development and environmental benefits from SHS dissemination and use (such as improved rural quality of life), SHS activities are likely to be highly compatible with the sustainable development goals of many developing countries. This view is bolstered by the substantial government efforts to encourage SHSs in a diverse range of countries, including Argentina, India, and South Africa.

SHS activities are most applicable where large segments of the population still have no electricity, which tends to be in poorer countries. Furthermore, SHS activities primarily benefit rural areas, which often have the greatest need for economic development. Consequently, a prominent role for SHSs within the CDM would help to ensure that local benefits from CDM projects accrue to segments of the developing world in greatest need.

Additionality

Article 12 of the Kyoto Protocol says that GHG benefits from CDM projects must be "additional to any that would occur in the absence of the certified project activity." While it is not yet clear how additionality will be defined, the parties involved have put forward various interpretations.

The concept of environmental additionality embedded in Article 12 would require that all CDM projects result in real, measurable, and long-term GHG emissions reductions. An essential prerequisite would require that projects be additional to what would occur under "business as usual," since CERs granted for standard practices in developing countries would enable Annex I emissions to increase without real corresponding emissions reductions.

The concept of financial additionality refers to whether a project's financing is in some way supplemental to "business as usual" financial flows. Many observers believe activities supported by the GEF and ODA should not generate CERs. This would help to ensure that the CDM generates new financial inflows for developing countries and avoids redirecting funds that are already targeting environmental and economic development activities. Under this criterion, while SHS installations directly receiving GEF or ODA funds would be excluded from the CDM, ones indirectly benefiting from GEF or ODA activities (via public education, for example, or feasibility assessments) arguably should not be excluded.

Some parties to the debate think a financial additionality criterion should limit the profitability of CER-generating activities to assure that they are not standard practices. Others believe this is unnecessary and that limiting profitability would be counterproductive, discouraging prospective climate protection activities that have the greatest potential to mobilize private capital and generate self-sustaining markets for carbon-reducing technologies and practices. In the case of SHSs, numerous assessments indicate that commercial activities are more sustainable than ones that rely principally on charity.[50]

Two primary approaches to assessing additionality are being considered: project-specific reviews and benchmarks.

Project-specific reviews, which prevailed under the AIJ pilot program, involve constructing "with" and "without" project scenarios on a case-by-case basis. The "without" project scenario, describing what is expected in the project's absence, is compared with a "with project" scenario. If a project demonstrates that it adheres to all the additionality criteria and results in emission reductions, it is deemed additional. Although this approach considers the specific circumstances of individual projects, analysts in good faith can reach different conclusions about the additionality of a given project. In the AIJ pilot phase, case-by-case additionality reviews lacked transparency, resulted in high transaction costs, and created substantial uncertainty for project developers.[51] The project-specific approach also creates a strong incentive for developers to manipulate their projections and overstate project benefits.

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[49] Several developing countries have expressed concern regarding CDM equity issues and measures to ensure that Annex I countries meaningfully reduce their domestic emissions rather than using the Kyoto mechanisms exclusively. Information about these issues and the climate treaty negotiations generally can be found at the Web site of the UNFCCC Secretariat at <www.unfccc.de> and at the International Institute for Sustainable Development's climate change site at <www.iisd.ca/linkages/climate>.

[50] See, for example, Cabraal, Cosgrove-Davies, and Schaeffer, op. cit. note 18.

[51] See, for example, R. Lile, M. Powell, and M. Toman, *Implementing the Clean Development Mechanism: Lessons from U.S. Private-Sector Participation in Activities Implemented Jointly*, RFF Discussion Paper 99-08, available at <www.rff.org/disc_papers/PDF_files/9908.pdf>, accessed August 1999.

The benchmark approach would set a uniform standard at the regional, national, or subnational level by which the "additionality" of a project could be determined without reliance on subjective assessments. Benchmarks can be performance standards (such as kilograms of CO_2 emitted per kilowatt-hour) or "normative" technology standards (that is, that certain technologies are additional while others are not). Performance standards would define a level of GHG emissions below which a given project could generate emissions reduction credits. Technology standards would determine eligibility, though a separate "baseline" (see below) may still be needed to determine the level of emissions additionality.

Performance standard benchmarks would generally be based on a country's or region's historical or projected carbon intensity for a given sector or activity. Alternatively, they could be based on a "standard to beat." As a zero emission renewable energy source, SHSs would probably qualify for crediting under most conceivable approaches to carbon intensity benchmarking.

Normative technology benchmarks rely on nonquantitative indicators of project additionality. For example, given the well-understood barriers to the dissemination of small-scale renewable energy technologies using solar, hydro, or wind energy—and the potential of such applications to help reduce the cost of these emerging technologies—a normative benchmark could attribute additionality to all such technologies. A normative benchmark may take into account qualitative features that the other benchmarking schemes would miss. It might, for example, exclude electricity generation technologies that could have GHG benefits but cause other environmental concerns, such as large hydro and nuclear facilities. Given clear social benefits and zero emissions energy for project areas, SHSs could receive a blanket endorsement under the CDM in a normative benchmarking arrangement.

The disadvantage of granting CDM eligibility to all activities in a given category such as SHSs is that it enables credit for some "free rider" projects that would happen even without CDM participation. In the case of SHSs, the potential environmental downside of granting CERs to some installations that would happen anyway is very small and will probably be offset by the market development benefits of the truly additional SHS installations induced by the CDM.

Some parties have suggested using a technology matrix approach that would allow crediting for a project only until its technology reaches a certain level of penetration in a given country. This would be one way to assure that activities are no longer CDM-eligible once they become commercially mainstream.

Baseline Setting

Once a project is deemed CDM-eligible, the applicable CERs will be calculated by subtracting the project's anticipated emissions from "baseline" emissions expected in the project's absence. If a performance benchmark is used to determine additionality, it would also probably define the baseline. In other cases, a baseline must either be constructed or selected. For SHS projects, setting a baseline to estimate the quantity of CO_2 offset by each SHS could be fairly straightforward, with the principal option being whether to base calculations on historic energy use or the more speculative concept of grid avoidance. Standardized approaches to baseline setting could help to keep CDM transaction costs low while achieving reasonable accuracy. Streamlined approaches to monitoring the GHG benefits of SHS activities could do likewise, for example by random sampling or the selected use of remote data acquisition technology, though more experience is needed before specific standard monitoring approaches can be recommended.

Nearly all SHS projects in the AIJ and GEF programs use a historic energy baseline, in most cases consisting of kerosene lighting and sometimes lead-acid battery charging.[52] Based on this experience, targeted analyses could be used to set standard historical energy baselines by country or possibly by region, expressed in kilograms of CO_2 per household per year. These baselines could be set as averages for a broad range of system sizes (for example, 10 to 75 Wp = 240kg/yr) or by narrower ranges of system sizes (12 to 20 Wp = 180 kg/yr; 21 to 35 Wp = 240 kg/yr; 36 to 50 Wp = 300 kg/yr; and so on). Alternatively, historic energy use baselines could be established project-by-project, trading greater possible accuracy for greater cost. In such cases, there could still be advantages to standardizing the methodology for calculations.

A forward-looking baseline for SHS could consider avoided grid or mini-grid electrification. While historic energy use patterns in rural areas of many countries may continue for some time, a few developing countries such as South Africa have significant rural electrification programs. If grid or mini-grid electrification serves as the baseline, the impact of SHSs could be calculated in

[52] AIJ and GEF project experience with baseline setting and other issues related to quantifying, monitoring, and evaluating GHG benefits from SHS projects are reviewed in a draft paper prepared as a part of REPP's Joyce Mertz-Gilmore Foundation–sponsored SHS assessment project. See Steven L. Kaufman, *Calculating, Monitoring, and Evaluating Greenhouse Gas Benefits from Solar Home Systems in Developing Countries (1999)* working draft at <www.repp.org>.

two ways. One approach would base emissions avoidance calculations on the amount of electricity generated by each SHS. Given the small amount of electricity typically generated by each SHS and the inefficiency of kerosene lighting, this approach would often indicate that the GHG benefits from grid avoidance are less than those from direct fuel substitution. The other approach would base calculations on the level of electricity consumption expected if homes were actually connected to a grid (as done in Table 4), which could be based on national or regional averages. This method is appropriate to the extent that SHSs actually are expected to avoid the grid. In any case, the rate of CO_2 avoidance per kWh for CER calculations must be selected and would also have an important impact on the amount of CERs attributable to each SHS.

PART IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

SHSs can a make a small but important contribution to climate change mitigation. Typical SHSs of 10 to 50 Wp will directly displace roughly 0.15 to 0.3 tons of CO_2 per year through fuel substitution. While modest on a per household basis, reaching the first 10% of the potential SHS market would directly offset an estimated 10 million tons of CO_2—the equivalent of Zimbabwe's 1995 fossil fuel CO_2 emissions—and extend new electric service to 35 million homes. At a 50% market penetration level, SHSs would directly offset the equivalent of Switzerland's 1995 CO_2 emissions from fossil fuel.

There are also significant indirect GHG benefits from SHS dissemination including support for PV market transformation and the potential to avoid substantial grid-based emissions. Widespread use of SHS has the potential to put developing countries on a low-carbon path for rural electrification while providing an important market niche to help make PV more competitive for a range of applications worldwide.

SHSs have a high rate of CO2 displacement per installed Wp. Due to the tremendous inefficiency of kerosene lighting, rural household electrification in developing countries is among the highest impact PV applications for climate change mitigation per installed Wp. Displacing kerosene lamps typically reduces far more CO_2 per installed Wp than grid-connected PV applications, in some cases by a factor of ten.

SHSs have significant social, economic, and non-GHG environmental benefits. SHSs dramatically improve rural life by providing high quality light. By reducing the need to store and burn kerosene for lighting, SHSs improve household health and safety. The systems also ease access to information and entertainment via radio and television. Furthermore, socio-economic impact studies have found that many of the systems contribute to income generation.

Numerous barriers still constrain potential SHS markets. While markets are starting develop in many countries, SHS dissemination still faces substantial constraints. Barriers include: lack of information about SHSs and grid extension plans; lack of capital for SHS businesses and consumer financing programs; and lack of trained technicians, managers and other human infrastructure needed for system delivery and maintenance. Market distortions stemming from import duties on SHS equipment and subsidies for kerosene also constrain SHS dissemination in many countries. International initiatives and host country policies can help to remove these barriers, accelerate SHS markets, and ensure that potential GHG mitigation and development benefits are realized.

The Clean Development Mechanism could accelerate SHS dissemination. Since SHS dissemination advances the CDM's climate change mitigation and sustainable development goals, with the exception of installations directly supported by ODA or the GEF, most SHS activities would probably be CDM eligible. Furthermore, SHS activities tend to benefit rural areas in poorer countries and would thus promote the distribution of CDM benefits to areas and countries that might otherwise be left out. Unless CO_2 values exceed \$20 per ton, however, CDM funding alone is unlikely to generate more than about \$3 to \$6 per typical SHS each year or about 10% of initial wholesale equipment costs when discounted at 10% over twenty years. Still, if CDM transaction costs are kept low, this funding could prove quite valuable in improving marginal project economics and making the systems more widely affordable. For example, the additional

CER income could increase the profitability of an SHS fee-for-service business sufficiently to make the difference in attracting the capital needed to reach critical scale economies.

Recommendations

The following actions can help ensure that the potential climate protection and development benefits outlined in this paper are achieved and maintained.

National delegates and nongovernmental participants in the climate change negotiations should advance CDM policies conducive to SHS participation. Most important, monitoring and certification processes should be streamlined to minimize transaction costs. For example, standardized approaches to baseline setting could easily be developed for SHS activities, offering consistency and simplicity without sacrificing accuracy. In addition, managers might prequalify all SHSs installed after a certain date (such as 2001) for the CDM, provided that they do not directly receive GEF or ODA support. While this would allow credit for some installations that would occur even without the CDM, the environmental consequences would be small and would be offset by the market catalytic affect of the truly additional SHS sales induced by the CDM. Categorical CDM eligibility for emerging technologies such as SHS would be particularly justified if it were to remain effective only until a predetermined national, regional, or global utilization rate is reached.

To encourage early action, CDM eligibility for SHSs, or at least the rules by which SHS projects could participate, should be declared as early as possible, even if work is still being done to determine how to treat other activities that are less obviously consistent with the CDM's goals. Projects indirectly benefiting from GEF or ODA assistance—for example, through public education or simply because they are in countries where GEF or ODA support helps to catalyze SHS markets—should not be excluded from the CDM, as this would be counterproductive and unfair.

Government agencies in developing counties should take advantage of the incremental funding available for climate protection to help them promote sustainable SHS markets. In addition to CDM participation, other international monies may be available to countries though various climate-motivated market development initiatives supported by the GEF and other multilateral and bilateral institutions. While SHS projects receiving direct GEF and ODA support may not be CDM-eligible, a blend of complementary activities could be implemented simultaneously. For example, GEF and ODA funds could be used to cover the cost of developing and enforcing product quality standards, while CDM monies helped system rental companies maintain profitability while lowering their fees to reach a broader customer base.

To maximize potential penetration levels, countries should make every effort to encourage sustainable private markets for SHSs. Governments should clarify and publicize grid extension plans in order to minimize consumer and business uncertainty about whether to invest in SHSs in a given area. They should require imported equipment to meet international quality standards. And finally, governments should ensure that pricing is efficient by lowering import taxes on SHS components and, where kerosene and/or rural electrification subsidies exist, eliminating them or providing equal treatment for SHSs. To the extent that governments subsidize private SHS markets, they should embed the support in the most stable framework possible and, where feasible, use a competitive mechanism to keep subsidy levels as low as possible.

Bilateral and multilateral agencies and foundations should support SHS market development.

These groups should expand support for SHS technician and business training, technical assistance, feasibility studies, public education, and government capacity building in the areas of renewable energy and the environment. These activities can catalyze renewable energy markets and yield environmental, social, and economic dividends.

International public and foundation support can also play a useful role by providing seed capital and credit enhancement (such as loan guarantees) for SHS businesses and end-user credit programs. Ideally these investments should be offered as co-financing that leverages larger private investments in order to promote sustainable commercial markets. Large subsidies and system donations should generally be avoided, as these can undermine commercial markets and are unsustainable.

Socially and environmentally oriented investors concerned about climate change should consider investing in SHS activities. To date, opportunities to invest in SHS businesses and consumer financing programs have been limited, but numerous private investments have been made and additional investment opportunities are emerging. The level of risk, rate of return, and amount of CO_2 displaced per dollar invested will vary, but all such investments can simultaneously help to elevate rural living conditions and mitigate climate change.

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REPP receives generous support from the U.S. Department of Energy, The Energy Foundation, the Joyce Mertz-Gilmore Foundation, the U.S Environmental Protection Agency, The State of New Mexico, National Renewable Energy Laboratory (NREL), and the Bancker-Williams Foundation.

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