The Quiet (Energy) Revolution:

Analyzing the Dissemination of Photovoltaic Power Systems in Kenya

Richard H. Acker* and Daniel M. Kammen†, [1]

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*School of Law, University of Chicago
1111 East 60th Street, Chicago, IL 60637

†Woodrow Wilson School of Public and International Affairs
Princeton University, Princeton NJ 08544

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[1] To whom correspondence should be addressed at: 444 Robertson Hall, Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton NJ 08544 USA.

Summary

The widespread introduction and adoption of renewable energy technologies remains high on virtually every national development policy agenda; renewable energies can assist national energy autonomy, decentralize resource management, promote environmental conservation, and serve as a means to reduce global warming. The track-record of efforts to turn this noble ideology into successful technology transfer and dissemination, however, remains very mixed. It is a story of a few successes amid many failures.

Here we document and examine the diffusion of small-scale photovoltaic (PV) systems in Kenya. At the same time that integrated energy plans and top-down models championing renewable energy futures are becoming increasingly common, a new power base, divorced from these grand schemes, has begun to emerge. Over the past decade, some 20,000 to 40,000 small PV systems, essentially all privately financed, have been installed in Kenya. Many valuable lessons for renewable energy research can be found here. The Kenyan case richly illustrates the dramatic role that actors on every scale, from grass-roots to international, can have in accelerating -- or when mismanaged, impeding -- technology transfer and the elevation of renewable energy systems from niche applications to a prominent role in household empowerment, and decentralized and sustainable development initiatives.

Introduction: Clear and Present Danger

Most of the increase in global energy consumption over the next generation is expected to take place in the developing world. The prospect of this future -- over four billion people pursuing an energy-guzzling path akin to that of the so-called developed nations -- is daunting. The potential damage to the global environment and the depletion of natural resources are so profound that environmentalists, resource economists, and many others are rushing to advocate schemes that maximize the use of renewable energy technologies in less developed countries (LDCs).

One area of LDC energy consumption that is certain to grow over the coming decades is that of electricity. Although there is a tremendous demand in the developing world for the benefits of electrification -- in the short-term notably lights, refrigeration, radios, and TVs -- nearly two billion people remain without electricity, with little immediate prospects for grid connection.[1] Not only does this pose a potential environmental danger of epic proportions, but there are major quality-of-life concerns as well. Lack of electricity is a hindrance to the provision of health services, community development, education, and industrial activity.[2]

In an effort to meet this enormous electrification demand in an environmentally-benign way, many have looked to photovoltaic (PV) energy as a solution. The history of PV electricity is long, at times tortured, and often exaggerated. The photoelectric effect was first discovered in 1839 by A. Edmond Becquerel, when he observed that certain materials produced a small current when exposed to light.[3] One hundred years later the technology had hardly advanced, and incident light-to-electricity conversion efficiencies were only 1%.[4] By the late 1950s, however, crystalline silicon technologies had advanced enough to be used in the American space program, and the first solar-powered satellite, Vanguard 1, was launched in 1958.[5] By the mid 1970s, prices for PV-generated power were just starting to approach the commercially-feasible range, and by the early 1980s a global PV market had been established. Nearly all PV modules in use today are made of silicon doped with phosphorus and boron, although advances involving a wide array of photoactive materials may rapidly change that in the future[6] Commercially-available PV modules now achieve over 14% efficiency, and cells in research laboratories are attaining efficiencies in excess of 25%.[7] Research is also underway to find more cost-effective materials than silicon, and promising results may be on the horizon for cadmium-telluride (CdTe) cells and copper-indium-diselenide (CIS) cells; commercial facilities are due to come on line for CdTe cells within the next few years.[8]

The potential for photovoltaic energy generation in developing countries is, in theory at least, vast. In its 1992 *World Development Report*, the World Bank noted that:

> in developing countries, solar insolation is roughly 6500 times the annual consumption of commercial energy. At current conversion efficiencies of 15%, less than 0.1% of these countries' land area would be required to meet, in theory, the whole of their primary energy requirements.[9]

A comparison to the energy/area ratio for hydropower is particularly instructive. Even if every developing nation had the hydro-resources to meet electricity demands, they would need to devote 10 to 100 times the total land area required for PV generation to achieve the same energy output[10].

The solar energy supply is certainly plentiful enough, and the applications for PV are also numerous: uses include refrigeration for vaccines, lighting projects for schools and other institutions, water pumping facilities, village electrification, electric fencing for ranches and national parks, and, of course, the full range of domestic services. PV is also used in communications for powering remote radio and telecommunications towers.

The reason PV is used for such a wide range of applications is that it is easily adaptable to any scale of power requirements. A large-scale PV system is not fundamentally different from a small-scale one; it primarily has more photocells and additional "balance-of-system" components (batteries, wiring, circuitry, and so on). Larger systems certainly can be far more complex than scaled-up versions of smaller ones, but even in these cases the gulf is chiefly one of magnitude, not of technology. Consequently, national policies to encourage the installation of PV arrays can find application and synergy in 100W household systems, 10 kW village arrays, even GW-scale regional generating facilities.

This contrasts with other fuels, like oil and gas, that do not "scale" from small to large facilities. Energy generation for a single household, community, or entire region generally depends on very different fuel handling and combustion technologies. As a result, large-scale PV projects may in many cases fit national development strategies for poor countries better than oil or gas plants. Although it may be sorely needed, a well maintained 100 MW coal or diesel fired power plant does very little, if anything, to spur a local energy industry appropriate to the needs of the majority of the populace of a developing nation. In most LDCs, such a facility will be managed by either a local or an imported technical elite, and the expertise is unlikely to disseminate outside of the plant to any significant degree. This can turn a development investment into a 'technical fix'. A PV project, on the other hand, can naturally lead to technology transfer and cross-fertilization between separate industries. The availability of PV modules is therefore a natural inducement to further local innovation, know-how, and technology borrowing between users of very different means.

Because many developing countries lie near the equator, photovoltaics offer an attractive alternative to traditional energy sources. PV has multiple advantages for electrifying rural households: it is decentralized, uses a locally-generated and abundant energy source (sunlight), frees the user from price fluctuations common to traditional fuels, is easily transportable and thus can penetrate remote areas, and is safer for the environment in many ways than traditional fuels.

The most important attribute of any energy source in the current environment, including PV, is that of price. In many applications PV is simply the least expensive alternative when considered on a life-cycle cost basis. As a result, individuals in developing nations have bought tens of thousands of installations for their homes. Countries such as Zimbabwe, Sri Lanka, Honduras, and the Dominican Republic have all seen markets develop for the private purchase, installation, and maintenance of PV systems.[11] Perhaps the most dramatic example, however, is Kenya, where an estimated 20,000 to 40,000 systems have been bought and installed in private homes and small businesses around the country.[12]

The emergence of this private market for photovoltaic systems has naturally attracted the interest of utility managers, environmentalists and policy makers. How did the market develop? What kind of consumers are buying the systems? How well are the installations actually working, and what can be done at the commercial and public policy level to improve PV performance, availability, and adoption in the future? What lessons can be learned about the more general question of the dissemination of energy and environmental technologies in developing countries?

In this paper we examine the technical, economic, and political factors that shaped the Kenyan PV market. Against a backdrop of initial economic growth and then price and policy fluctuation, we examine the evolution of the Kenyan PV market, its development, and what forces have helped or hindered the dissemination of PV technology. That sets the stage for the third section of this paper, which details the results of a survey of home systems undertaken in July and August, 1994; some of these results confirm notions about the PV market laid out in the second part, while others provide unexpected contradictions. Finally, the fourth part evaluates the mechanisms and methods of technology transfer, suggests several courses of action that can benefit current and potential PV users in Kenya, and examines the impact that PV has had in Kenya.

Taken in sum, this work explores an empirical example of technology diffusion that has been shaped by the interaction of technological change, energy demand, and political and economic forces. While the bulk of the Kenyan PV installations are private, this hardly implies a secondary role for national or international renewable energy policy. Far from it; the Kenyan example is full of technical and resource bottlenecks, economic roadblocks, and counterproductive policies. This suggests that intelligently directed research and development, multinational assistance, and wise economic policy could replicate or surpass the Kenya results elsewhere.

I. Profile of the Study Area

A. Kenya's Geographic Profile

Kenya straddles the equator, which bisects it into two nearly equal parts lying between 4.5° N and 4.5° S. This, of course, provides an ample solar resource, with many areas reaching peak solar radiation levels of over 1000 W/m^2. Approximately 25 million people inhabit the country, which is 560,186 km^2 in area. This population is growing at an annual rate of about 3% which, though very high, was 3.5% only a few years ago[13].

Figure 1: Map of Kenya

B. Kenya's Economic Profile

Given that most of the data collected for this report were from 1994, dollar equivalents are calculated at the average 1994 KSh/$ exchange rate; at the time of the survey, this was about 61 KSh/$. When data are from previous years, this is indicated and the relevant exchange rate is used.

1 • *The General Kenyan Economy*

After gaining independence in 1963, Kenya enjoyed ten years of steady and strong economic growth, possible because of the country's rich endowment of natural resources and political stability.[14] This early period of growth was generally steady and remarkably free of fluctuations (Figure 2).

Figure 2: Kenyan GDP

The initial post-colonial period of robust growth was interrupted by the first oil shock of 1973-1974. Since Kenya imports all its oil (though exploration efforts continue in the north and east of the country), it has proven economically vulnerable to fluctuations in petroleum prices. Nevertheless, Kenya rebounded from the oil shock and by the end of the 1970s was registering its strongest growth rates ever. With the second oil shock in 1979, though, the Kenyan economy took another nose-dive that persisted through the global recession of the early 1980s.

Figure 3: Kenyan Annual GDP Growth

The period of greatest interest for this study starts in 1985, when the Kenyan photovoltaics market began to develop. As can be seen in Figure 3, the Kenyan economy made a marked recovery for the second half of the 1980s. During this time, many Kenyan consumers were able to accumulate sufficient savings to purchase PV systems for their homes, farms, and small businesses. During the late 1980s, PV thin-film cell efficiencies rose from 10% to about 15%;[15] and prices correspondingly fell dramatically, from several dollars to $0.15 - $0.20/kWh. The combination of a strong economy and a rapidly improving PV industry not only made such systems attractive at the time, but promised additional efficiency gains and cost savings in the future Kenyan PV market.

2 • *Focus: The Kenyan Rural Sector*

We also have a special interest in Kenya's agricultural sector, because the vast majority of photovoltaic systems sold to private consumers, or are installed in rural areas unconnected to the electric grid. Perhaps the best indicators of the rural economy are the exports (Figure 4) and foreign exchange earnings (Figure 5) from coffee and tea, Kenya's principal export commodities.

Figure 4: Kenyan Coffee and Tea Exports: Quantity

Figure 5: Kenyan Coffee and Tea Exports: Value

During the first half of the 1980s, Kenya exported increasing quantities of both coffee and tea. Coffee prices have trended downwards since 1987, however, while tea prices have remained comparatively stable. In fact, the data show a concurrent shift in Kenyan exports away from coffee and into the production of tea. Nevertheless, coffee growers enjoyed high earnings during the 1980s -- especially in 1986, a year when high prices on the international market coincided with above-average exports. Tea growers, on the other hand, have profited from less spectacular but more consistent earnings throughout the period. The coffee and tea profits have, of course, gone principally to the rural elites and absentee landlords, with far more modest amounts accruing to the small-holders and wage laborers. Nevertheless, both crops have been critical to Kenya's economy, and the rural economy in particular. This has boosted Kenya's rural PV market, which has continued to expand even during times when the rest of the nation's economy has suffered. Indeed, several authors directly attribute some of the growth of Kenya's photovoltaic market to the steady performance of the rural economy.[16]

Figure 6: International Coffee and Tea Prices

C. Kenya's Energy Profile

1 • *Household Energy Consumption*

Kenya's energy consumption is typical of developing countries, except that it has no coal reserves and thus depends even more heavily on biomass (primarily wood, charcoal derived from rural wood resources, and crop residues such as maize cobs and cotton stalks). Household energy use, which constitutes 70% to 75% of total Kenyan energy consumption, is dominated by the use of these biomass fuels. In fact, wood is far and away the most widely-used fuel in Kenya, accounting for, based on 1989 data, nearly 68% of the country's total energy supply. The importance of biomass in the Kenyan economy is further illustrated by the rising demand, estimated to have increased from 27.8 million tons of oil equivalent (TOE) in 1988 to 35.3 million TOE in 1993.[17] This wood is used primarily for cooking, and also serves limited lighting purposes. Unfortunately, this energy source is not being used efficiently: pyrolytic conversion of wood to charcoal is only 15 - 25% efficient (typically transported to and then used in urban areas), and the three-stone fires used in rural areas also suffer from very low efficiencies of 5 - 20%.[18]

Table 1: Energy Consumption Patterns

2 • *Commercial Energy Consumption*

(a) • *Oil*

Commercial energy sources provide 25% to 30% of Kenya's total energy needs, and this sector is heavily dominated by oil imports. This, of course, is common for developing countries. Approximately 75% of developing nations import petroleum, and 29 of the world's 38 poorest countries depend on oil imports for over 70% of their commercial energy needs.[19] In Kenya, petroleum accounts for 80% of commercial energy consumption.[20] All the oil comes from the Gulf region, is refined at a Kenyan facility in Mombasa (the only oil refinery in East Africa), and then is either used to meet domestic demand or is re-exported to neighboring countries. Figure 7 illustrates the disposition of Kenyan refined oil during the last few years; while domestic demand has remained steady, oil exports have increased steadily in the 1990s.

Figure 7: Kenyan Petroleum Imports & Domestic Demand

Despite the fact that oil does not dominate the total energy sector in Kenya, it plays a vital role in industrial activity, and is a major drain on the balance of trade. Sub-Saharan countries currently spend about one-third of their hard currency resources on oil imports, which impedes efforts at building up reserves of foreign exchange or fostering a secure national industrial base.[21] At the peak of the second oil shock (1981), Kenya saw 63% of its net export earnings consumed by oil imports, though that level dropped to 32% a few years later.[22] Figure 3 clearly illustrates the adverse effects the two oil shocks had on Kenya's petroleum-sensitive commercial sector.

(b) • *Electricity*

Practically all the remainder of Kenya's commercial energy needs are met through the electricity generated by the national utility, Kenya Power & Lighting Company (KPLC). This constitutes about 20% of Kenyan commercial energy, or 5% to 6% of total national energy usage (Figure 8).

Figure 8: Kenyan Electricity Generation

As we see in Figure 9, electric generation in Kenya comes mostly from hydropower, which in 1993 accounted for over 88% of the national electricity supply.[23] This supply is generated from numerous dams across the nation's rivers flowing into inland lakes or to the Indian Ocean. A small amount (8%) is also imported from Owen Falls in Uganda under a 50-year agreement scheduled to run through 2010.[24] This heavy dependence on hydropower has been problematic for Kenya; low rainfall caused KPLC to impose power rationing for four months in 1992.[25] The rest of Kenya's electricity comes from geothermal sources and thermal oil plants.

Figure 9: Sources for Kenyan Electric Supply

Although KPLC has steadily increased its electrical output, only a fraction of Kenya's population ever receives this power. This is because Kenya's electric grid hardly extends beyond its urban areas, a problem discussed more in section II B 3, "Slow Pace of Rural Electrification."

(c) • *Coal*

Finally, a small fraction of Kenyan commercial energy consumption is supplied through the import of coal, which is used as a substitute fuel for firing the kilns at the cement factory in Mombasa.[26] In 1993, less than 90,000 TOE of coal was used in Kenya.[27] Nevertheless, coal is starting to be used in the household energy sector, especially in areas along the southern frontier with Tanzania which are seeing more coal use in small household stoves. This could easily lead to alarming environmental and health effects, particularly as increasing population and logging pressure depletes forest resources.

3 • *Kenya's Energy Sector in Perspective*

Taken in sum, the energy resource mix described above for Kenya is highly representative of developing nations, particularly in sub-Saharan Africa. The overwhelming dependence on biomass energy combined with a problematic and expensive fossil fuel sector all point to a need for new alternatives. Also typical is the lack of any significant electricity grid outside the main urban centers.

But Kenya's status as one of the more stable African economies with a strong agricultural base, oriented to both domestic and export markets, opens up a number of technology development opportunities. An important and, in places, affluent rural sector provides a ready market for autonomous energy generation, particularly if it is on a single-family scale. The combination of these factors helped prime Kenya for the growth of a PV market. The diffusion of the new PV technology depended on numerous factors, including local technical knowledge, system and component availability and maturity, economic barriers and incentives, and national energy policy. We turn to an examination of these factors in the following section.

II. The Private PV Market in Kenya

A. History of the Market's Development

As noted above, the robust economic growth Kenya enjoyed in the ten years following independence was slowed considerably by the oil shock of 1973-4. This, however, helped to open the market for PV in the country as people looked for alternative, reliable, and fiscally predictable energy sources.

It was a meager beginning, though, primarily because PV's price, though falling, was still quite high: the installed price remained between $30 and $40 per peak watt. "Peak watt," abbreviated "Wp," is a measure of a solar panel's output power, and represents the power generated at 1000 w/m^2 of sunlight at 25°C. PV panels usually operate at levels below their Wp output, because the insolation may be less than 1000 w/m^2 or the temperature may be hotter than 25°C. A 40 Wp panel, therefore, typically will be generating 25 to 40 watts. At the prevailing mid-1970s prices, this 40 Wp panel would cost well over $1200, pricing it far out of reach for most Kenyan families. Moreover, most of the technology had to be imported.[28]

But the early 1980s saw PV prices continue to decline, encouraging donor agencies to use the technology more and more frequently in projects requiring electricity, such as water pumping, school lighting, and vaccine refrigeration. The late 1970's and early 1980's were also a period of high investment in renewable energy research. This combination of a declining PV price and international research activity benefited Kenya in particular because its climactic conditions are especially favorable for solar technologies. Several large international companies, notably Siemens and BP, opened regional offices in Nairobi; concurrently, a few Kenyan businesses also entered the solar sector.[29] Because donor agencies were the driving force behind the market, these companies tended to specialize in large-scale projects and did not interest themselves much in targeting private Kenyan households.

In fact, the "donor market" -- mostly large-scale photovoltaic projects funded by donor agencies -- was for a number of years the only PV market in Kenya. Although this study focuses exclusively on the "private market" -- small-scale systems bought by private homes -- the authors do not wish to understate the importance of donor agencies. Not only did their funding create a demand for PV that allowed the private market to subsequently develop, but the donor agencies supported workshops, training, and demonstration projects as well. These efforts in the early 1980s played a vital role in educating the first Kenyan solar technicians, sparking an initial interest among Kenyan consumers, and proving the viability of the technology in Kenya's conditions.

The donor market continues to drive the PV market in Kenya, with projects for school lighting, water pumping, and vaccine refrigeration comprising just some of the applications. Furthermore, environmental organizations continue to coordinate education efforts in cooperation with international agencies. Nevertheless, the authors have not focused on the donor market because the characteristics of donor-driven technologies are widely studied and well documented elsewhere. The evolution of a private market for environmental technologies, however, is less studied; hence, this survey.

The private market's genesis may be roughly dated as 1984. That year, an American engineer, Harold Burris, founded a small company called Solar Shamba[30] that focused on meeting the energy needs of rural Kenyan customers for homes and schools, as opposed to the large, infrastructure oriented, international aid programs.[31] Burris moved Solar Shamba from Nairobi to Embu, a town serving the rich agricultural area south of Mount Kenya; there, he and Mark Hankins initiated a training program for young graduates of polytechnic schools who could not find jobs. The training initially included the installation of four demonstration systems in local secondary schools.[32]

These systems sparked considerable interest among people in nearby communities; after the initial training program Solar Shamba then served the local market that quickly developed as homeowners turned to PV to power their TVs, radios, and lights. Solar Shamba shut down when Burris moved out of the country in 1988, but in those four years it installed at least 150 photovoltaic systems, mostly in the Embu and Meru area.[33] The importance of Solar Shamba was great: not only did the company create local awareness of PV, but it also left behind a skilled group of electricians qualified to make solar installations and it caught the attention of Nairobi-based companies which had earlier dismissed the rural market as not worth pursuing.[34] Combined with internationally funded PV demonstration and education programs, both a technical resource pool and an interested public began to form in Kenya. Many of the electricians Burris trained are still very active in PV, having either started their own businesses or gone to work for the Nairobi-based companies.[35] Burris's associate, Mark Hankins, has gone on to write extensively on solar energy in Africa, advise development projects, and is currently training electricians in Tanzania in much the same way he and Burris did ten years ago. Similar experiences can be found in other developing countries such as the Dominican Republic, where the training of a small group of local people has provided the spark for rapid growth of a PV market.

Figure 10: Kenyan PV Sales

Burris' work coincided with a boom in global PV production and a further drop in price. In response to the declining price and increasing local expertise in system installation and management, local demand continued to grow, and the Kenyan market for PV took off. Annual and cumulative sales of photovoltaics in Kenya can be seen in Figures 10 and 11. The period since the mid-1980s has been marked by phenomenal expansion in the Kenyan PV market. In addition to the energetic efforts of solar entrepreneurs, what have been the main reasons for this growth, and what has been the economic and political environment in which this expansion took place?

Figure 11: Cumulative and Annual Kenyan PV Sales (kW peak)

B. Factors Encouraging PV Dissemination in Kenya

1 • *Increasing Supply of Domestic Components for Solar Systems*

In the early stages of the growth of the Kenyan PV market, nearly all the components for the systems were imported, including the wiring accessories and solar batteries.[36] During the mid- and late 1980s, however, locally-produced components increasingly became available. For example, Associated Battery Manufacturers (ABM), which is Kenya's only battery producer, made a new "solar" model 100 Ah ("amp-hours", a measure of a battery's capacity) battery available in 1985; it had somewhat better deep-cycling characteristics than the standard car battery because its plates were shortened, thickened, and had a 1.7% antimony alloy added.[37] These technical modifications, known and utilized in the manufacture of batteries for other applications for years, improved PV system performance. The degree of this improvement is remarkable not in terms of actual performance, as will be discussed below, but mainly in the simple interaction of one local industry with another address the growing indigenous PV market. The adaptations and innovation of the ABM and other similar designs is a typical development of an "experience curve" as discussed in the following section.

The rising use of Kenyan-produced and -assembled components helped reduce the price of PV systems. By avoiding transportation costs and import duties, domestic batteries and light fixtures often cost only one-third or one-half as much as their foreign counterparts.[38] Yet initially the boon of lowered cost was accompanied by problems of poorer performance during the learning phase of the local industry. For example, ABM's quality control has not been consistently rigorous, and faulty batteries are not uncommon; for one school lighting project in Meru (1985), three of the fourteen new batteries bought from ABM had bad cells.[39] And ABM's "solar" battery is little more than a modified truck battery which, according to some dealers, offers only marginally better performance even though it costs significantly more.[40] Similarly, several solar companies reported to the authors that there are higher failure rates for domestic light fixtures than for foreign ones.[41] This was confirmed by the on-site observations conducted as part of a household PV survey conducted from July to August 1994. This survey is the subject of Section III of this paper.

Figure 12: Growth of the Global PV Market

2 • *Falling World Prices*

Worldwide, the production of photovoltaic modules continued to expand at a reasonable pace (Figure 12). The annual rate of increase in installed modules is now rising far more slowly than in the early 1980's, currently at about 16% to 18% per year compared to 70% per year from 1976 - 1983, but growth continues[42]. This growth has been accompanied by greater purchases by an increasingly diverse web of consumers as the price falls further and further. In fact, until 1983 the global PV production increased by about 70% per year, accompanied by a price decrease of roughly 20% for every doubling of cumulative production. This "experience curve" for the PV industry, has been documented by Williams and Terzian.[43] The PV trend is typical for emerging technologies, and saw the price per peak watt decline steadily as production increased, from about $40 in 1970 to under $30 in 1978 and less than $5 in 1993 (Figure 13).

Figure 13: Experience Curve for Photovoltaics

3 • *Slow Pace of Rural Electrification*

While 75% of Kenya's population lives in rural areas, only 3.4% of the power supplied by KPLC is consumed by rural customers.[44] This problem is not isolated to Kenya. For example, in Ethiopia and Botswana, only 1% and 3%, respectively, of rural customers have access to electricity.[45] In fact, approximately 75% of the population in the developing world -- two to three billion people -- has no access to electricity whatsoever.[46]

For the Kenyan government, rural electrification is of secondary importance when compared to urban electrification. The ruling KANU (Kenyan African National Union) party already enjoys and manipulates strong rural support, and has frequently demonstrated more interest in the status quo than in equitable development. Furthermore, the lower population density of rural areas makes grid connection difficult and uneconomical.[47] Rural households in Kenya generally consume low amounts of energy even when connected to the grid -- rarely exceeding 30 kWh per month -- thus making rural electrification even less profitable.[48]

For most rural consumers, prospects of electrification are dim. First, the cost is prohibitive. Every kilometer of grid extension costs approximately 500,000 KSh ($8200) to construct.[49] In addition to that must be counted the costs for a step-down transformer (282,000 KSh ($4625), although one transformer can serve up to 50 customers) and the wiring for the home (20,000 KSh ($325), is typical for a two-bedroom home).[50] Normally, these costs would be borne by the customers themselves.

The costs of grid connection naturally vary widely for any given home. Key parameters include: the distance that the house is from the grid; how many neighbors the customer or community can organize to share the transformer; and how much wiring is needed for the home. Nevertheless, a very rough estimate can be made that grid connection often costs a rural home 100,000 KSh ($1640) or more. Considering that the average annual wages per employee are less than 48,000 KSh ($690)[51], such outlays are clearly beyond the means of most households.

Second, even if the customer has the financial resources to afford connection, multiple organizational barriers exist to thwart the formation of a group of like-minded neighbors who can also afford connection and can be counted on to pay the needed funds. When community groups do organize to acquire electrical connections, neighborhoods often fail to reach agreement over cost-sharing arrangements as lower-income residents resent having to share costs "equally" with wealthier residents who will get more benefit from the electricity.[52] Also, in many locations political considerations dominate the electrification equation. Electrification is frequently used as reward for constituent support; and thus often proceeds in a haphazard and inefficient pattern that bears no relationship to local needs or ability to profit from grid connection.[53]

Finally, even if the first two hurdles can be overcome, bureaucracy and politics make approvals slow to come from KPLC and actual connections even slower. It is worth noting that a large number of the homes surveyed in this study were located so close to the electric grid that grid expansion might actually have been the least costly alternative for them; yet, these homes chose PV instead.[54] This fact underlines the importance of the last two factors; the financial and political capital needed for electrification. For all these reasons, rural customers find electrification to be too distant in both a financial and a temporal sense.

There is a program to help rural customers get connected, however: the Rural Electrification Programme (REP), initiated in 1973.[55] Under this initiative, the customer has only to pay for the home wiring costs, a "token" connection fee (2500 KSh ($40)), and a meter charge (300 KSh ($5)).[56] While this largely surmounts the financial difficulties for rural customers, it does not address the organizational or bureaucratic problems, or those of patronage and corruption in the selection and support services provided to potential users. The REP has a reputation as a highly politicized program; many customers may face tall odds if they are not in politically favored areas.[57]

Figure 14: REP Connections, 1987-1992

The REP has received only minimal financial support, and thus has been very slow to bring electricity to Kenya's rural customers. For the first 13 years of its existence the program made fewer than 700 connections per year. Although the pace of rural electrification has since increased considerably, with about 5000 connections per year in the 1990s. It is sobering to note that 5000 connections/year is less than 1% of current birth rate; even at this faster rate it will evidently take hundreds of years for all of Kenya's rural population to receive electricity. The number of REP connections made in recent years is shown in Figure 14.

Consequently, an enormous demand for electricity in rural areas has gone unsatisfied by KPLC. Because they cannot count on grid connection, rural households have increasingly turned to photovoltaics to meet their electrification needs.

C. Factors Hindering PV Dissemination in Kenya

A critical ingredient in the diffusion of any technology is the availability of technological expertise and experience in system design, management, adaptation, and innovation. This need was largely targeted in the work of Burris, Hankins, and others. From that technological seed the capacity for further expansion can, of course, grow or wither. In this respect, even a variety of projects that individually may fail can serve the important role of preparing the soil for future programs to grow. The next stage, then, is the political and economic environment for technology diffusion. We now turn to that critical aspect of the Kenya PV story.

1 • *Changing Political Climate*

With the end of the Cold War, the United States and other Western nations began to re-evaluate the strategic importance of Kenya in their foreign policies. They soon began pressuring Kenya to address accusations of human rights abuses and to convert to a multi-party state. When President Moi showed reluctance to meet such demands, the Western countries increased the pressure by halting virtually all aid to Kenya in early 1992.

This international pressure affected photovoltaic sales adversely in two major ways. First, and most directly, the donor market for PV systems rapidly disappeared as donor agencies and governments withheld the aid dollars used to fund programs and buy PV systems. Second, the suspension of financial assistance helped push the Kenyan economy into a two-year tailspin from which it is only now recovering.[58] The faltering economy severely dampened the private market for PV systems because Kenyan customers were forced to cut back on expenditures, and big-ticket and more unknown purchases, like photovoltaic systems, were often the first to suffer.

2 • *Rising Prices in the Kenyan PV Market*

We noted above that the world price of photovoltaics had fallen steadily over the past decades. One of the commonest complaints from Kenyan customers and PV dealers, however, is that the costs of modules are rising so rapidly that they are no longer affordable. Since this runs contrary to the trend observed in the global markets, the claim is worth examining in greater detail.

Total Solar Kenya, one of the larger renewable energy companies in Kenya provided in-depth case-study information through a series of interviews between June and September, 1994. Total Solar specializes in solar water heating as well as PV, and has sold over 40 kWp of photovoltaic panels during the 1990s alone. Prices for key system components sold by Total Solar are shown in Figure 15. Component prices provided by other PV design and installation companies followed a similar year-to-year pattern.[59]

The most important, and costly, system components are the solar panel, the battery, and the charge controller (though many Kenyans choose not to buy a charge controller in order to save money). The remaining system components, primarily electronics, are typically termed "balance of system". Figure 15 clearly shows why many Kenyans feel that photovoltaic systems are now priced beyond their means: over the past three years, the price of a battery has risen by over 25%, a charge controller costs nearly 75% more, and the photovoltaic modules themselves have jumped in price by over 250%. What accounts for these dramatic increases when the global market is seeing stable or gradually falling prices?

Figure 15: Total Solar Price Schedule

Three factors are chiefly responsible for the rising PV prices in Kenya: the foreign exchange market; inflation; and government tariffs. Each will be considered briefly.

3 • *The Shilling's Fall*

From Kenya's independence up through the early 1990s, the Kenyan shilling was one of East Africa's most stable currencies. Because of this stability, Kenyan consumers were able to enjoy the benefit of falling photovoltaic prices through about 1990. The virtual halting of aid from Western governments described above, however, resulted in a financial crisis as inflows of hard currency to Kenya dried up. The Central Bank, which had begun imposing controls on the currency market in October 1991, devised a scheme to regulate the export of dollars called Forex-C (short for "Foreign Exchange Certificates"); a bearer could exchange shillings for dollars if he held a Forex-C note for the correct amount.

Speculators, aware of the dearth of dollars in Central Bank vaults, attempted to unload their shillings and hold on to hard currencies. Trading of the Forex-C notes soon began, with public auctions starting in May of 1992. From that point on, the market exchange rate for the shilling began to diverge significantly from the official rate; by July, it had fallen to over 45 KSh/$, a large drop from the 30 KSh/$ of only six months earlier[60].

Figure 16: The Kenyan Shilling, 1992-1993

Despite brief periods of recovery, the shilling continued to tumble through the summer of 1993, fueled by inflation (see next section) and successive devaluations in the spring of 1993. This hit imported goods especially hard, of course, so consumers found the KSh price of photovoltaic panels skyrocketing even when the dollar price was stable. In fact, some companies (including Total Solar) began pricing their modules in dollars instead of in shillings. The shilling stabilized and recovered much of its value in 1994, reaching a high of 38 KSh/$.[61] This has begun to translate into lower prices for customers, but the economy still has much ground to recover.

4 • *Rising Inflation*

The pressure put on Moi by the Western governments resulted in the country's first "free" multi-party elections in December 1992. They were not without cost, however. KANU was keenly aware that the opposition was very popular and stood to make a strong showing, if not a chance of winning the elections. The Central Bank, therefore, released 9 billion KSh of cash into the economy, completely unsupported by hard currency or gold, largely for the purpose of buying votes[62].

President Moi did indeed win the election (helped by the splintering of the opposition into several factions and allegations of widespread corruption), and the economy dived soon afterwards. Inflation, as seen in Figure 17, ran rampant because of the influx of currency, and the falling shilling helped spur inflation even further.

Figure 17: Kenyan Inflation, 1992-1993

Consequently, the prices of many domestically-produced items essential to a photovoltaic system, such as the battery, wiring, and lights, rose under the inflationary pressure. The prices of imported items were also increasing, of course, because of the declining shilling. It is hard to pinpoint how much of the increase in panel prices was due to the exchange rate and how much to inflation, but both certainly played a role.

5 • *Import Duties and VAT*

The third factor contributing to the rising nominal price of photovoltaics was the imposition of tariffs and value-added taxes (VATs) in 1992. Such taxes had been in place in the early 1980s, but the government removed them in June 1986 after lobbying efforts by the private sector; that act helped the government fulfill commitments made at the 1981 United Nations Conference on New and Renewable Energy in Nairobi.[63]

But these duties were reintroduced in the fiscal year 1992 budget, published in June 1991, in an effort to increase government revenues. The rate on modules was originally pegged at 30%, then lowered to 25% two years later, only to climb to 31% in September 1993.[64] It should be noted, however, that the tariff rate for PV modules is unclear because it is listed twice -- once under heading 8541.40.90, and again under heading 8502 (the headings represent listings in the Kenyan Customs Bureau's listing of import duties). The actual rate charged at the border may well depend on an arbitrary choice by the customs official.

Table 2: Duties and Taxes for Photovoltaic Equipment -- 1993

The real effect of the removal and subsequent reinstatement of tariffs and VATs on PV sales is subject to debate. Hankins states that the removal of tariffs in 1986 resulted directly in lower prices for the consumer, while Karekezi found that in fact no savings were passed on to the customer.[65] PV dealers interviewed as part of this research generally claimed that the removal of tariffs had little or no effect on sales or prices.[66] Furthermore, almost all the dealers interviewed were unaware that the tariff had been reimposed in 1992. It would seem, therefore, that the effects of the tariffs and VATs are not very large, or are overshadowed by the inflation and currency depreciation discussed above. Nevertheless, the imposition of duties and taxes can only have a damping effect. In either case policy communication to the PV industry was lacking. Minimal steps, such as public announcement of changing energy technology tariffs -- for example, in the three primary national newspapers -- would be nominal first step in reducing the uncertainty and arbitrary treatment by government officials that is consistently cited as a hindrance to the expansion of new industries in Kenya.

Figure 18: Total Solar Price Schedule, Adjusted for Inflation

6 • *Kenyan PV Prices in Real Terms*

Because the inflation Kenya experienced during the 1990s has been so severe, it is worth looking at the price of photovoltaic equipment in constant shillings (Figure 18). When we do this, a dramatically different story emerges: the price of locally manufactured parts (i.e. the battery) has, in fact, fallen while the costs of imported components (i.e. the panels and controllers) has vacillated somewhat and currently stands below 1991 levels. This is more in keeping with the global trend noted earlier of steadily falling PV prices. The relevance of the price fall on the international market is limited, however, because Kenyan wages have not kept pace with inflation. In fact, the real purchasing power of the average Kenyan employee fell 36% from 1990 to 1993.[67] For the typical prospective PV buyer in Kenya, therefore, the price of photovoltaics relative to his or her annual income has still increased.

D. Kenya's PV Market Today

For the largely economic reasons outlined in the previous sections, the price of photovoltaics is putting the technology out of the reach of more and more customers. This has had a clear impact on sales. Returning to the case of Total

Solar, we find that sales were robust in 1991, before the inflation and depreciation really struck, but then dropped off sharply beginning in 1992.

Figure 19: Total Solar PV Sales, 1990-1994 (kW peak)

Though one must be careful not to attach too much meaning to the sales trend of a single dealer, Total Solar's example is highly instructive. Most photovoltaic businesses in Kenya were understandably reluctant to reveal their specific sales figures for this study, but the majority did report that sales fell by around 50% beginning in 1992 or 1993. One small dealer even reported a decrease in sales of over 90%, forcing him to rely more heavily on his other businesses for income. According to Michael Wanjagi of Total Solar, the recent downturn in sales is due both to decreased donor purchases (for the political reasons described above) and to decreased private purchases (for the economic reasons). Although the Kenyan economy is just beginning to recover and the shilling is steadily appreciating, PV sales have been slow to respond. This is not surprising since consumers often resume purchases of lower-cost essentials first, such as food and clothing, rather than spending on high-cost durable goods like PV systems.

III. Results of Home PV Surveys

Now that we have examined the playing field for the dissemination of photovoltaics in Kenyan market, it is instructive to examine the market more carefully from the consumer's perspective. This section discusses the results of a series of interviews, conducted from July to August of 1994, of Kenyan homes which have installed small PV systems. The results represent some forty systems, ranging in size from 10 Wp to over 100 Wp, clustered in three areas near Nakuru, Meru, and Bungoma. These systems were located by research and word of mouth.

Figure 20: Areas Surveyed

This survey did not try to gather a representative sample of all Kenyan systems; indeed, given the number of systems, only a major survey could achieve any statistically significant results. Moreover, the survey was biased, for reasons of convenience and accessibility, towards sites near urban centers.

Nevertheless, the survey contains a wealth of information about the private PV market in Kenya. The owners surveyed have spent over 1 million KSh on these systems, which range in age from only one month old to about ten years old. The PV systems surveyed total about 1.5 kWp and provide electricity for an estimated daily demand between 7 kWh and 10 kWh -- a small amount by western standards, but significant to the Kenyan families and businesses otherwise dependent on kerosene, diesel, or other fuels.

A. Who Is Buying PV Systems, and Why?

1 • *The Affluent*

The apparent contradiction between the rural poverty of developing nations, including Kenya, and the impressive spread of PV systems comes as a surprise to a great many researchers and public officials. It is precisely this lack of awareness, however, that is largely to blame for the lack of national energy policy actions designed to nurture or accelerate the spread of PV systems. The explanation of the process of dissemination is not only economically straightforward, but also illustrates the commonly cited "affluent seeding" effect.

The answer to the contradiction of system cost and rural poverty, of course, is that the typical Kenyan cannot afford PV at all. Per capita GNP in Kenya remains far below that enjoyed in developed countries, and has in fact been steadily declining (in real terms) for the past five years (Figure 21). A small home PV system, which typically costs between $600 and $1000, is clearly beyond the reach of most Kenyans.

Figure 21: Kenyan GNP per Capita (1985 Dollars)

Nevertheless, wealthier Kenyan families often do have the resources to invest in PV systems for their homes. We have already noted the prosperity enjoyed by many tea and coffee farmers in the last decade. Other professions -- notably those of doctors, nurses, university professors, and teachers in primary and secondary schools -- also can bring in enough money to enable the purchase of a PV system, especially when both the husband and wife are employed. Many government posts, particularly those higher up in the governing hierarchy, also pay well enough to make a solar installation possible.

The average Kenyan wage in 1993 was about $686.[68] Though figures on annual household incomes were not available, we may estimate that with one to two wage earners per home (i.e. husband and wife, although two such incomes per household is uncommon), the typical Kenyan home has an income between $686 and $1372. For this section, the income range of $686 to $1372, with a midpoint of $1029, will be used as a ballpark estimate for the "average" Kenyan household.

Figure 22: Income Distribution of Surveyed Homes (<$3000)

As expected, the average surveyed home proved to be considerably wealthier than the average Kenyan household. The average annual income for surveyed households was about $2800, almost three times the $1029 mean household value estimated above. This average, however, was skewed to the upper end by a handful of exceptionally wealthy households reporting annual incomes in excess of $5000, including one of nearly $19,000. If we look instead at the *median* income for the surveyed homes, we find it to be around $1380; at the upper end of our hypothesized values for typical Kenyan households. Since half the reported incomes for surveyed PV owners fall under the $1380 mark, it seems that PV technology may actually be within reach for a reasonable fraction of Kenyan households that have two or more wage earners. The obvious complication, however, is that a great many Kenyan families have very complex income patterns that include several persons working on an irregular basis for a combination of wage and non-wage (material) incomes. Even steady work does not translate directly into disposable income for the great majority of rural households. We do note, however, that a few of the homes surveyed have annual incomes between $300 and $500, on the lower end of the mid-range even by Kenyan standards, and yet managed to acquire systems.

2 • *Relative and Absolute Expenditures on the Systems*

Although PV systems make sense from a cost-benefit analysis, it is often a difficult matter for these less wealthy households to purchase their systems. The average system in the survey costs its owner almost $800, suggesting that the homes at the lower end of the income scale are making, relative to their incomes, a very substantial investment. The risk and uncertainty (both in terms of anticipated benefits, and the potential problem of finding reliable and honest technical help) in installation and maintenance make such investments even riskier. It is here that national and NGO-based support networks, ensuring quality and reliability, could have a dramatic impact on consumer confidence. Minimizing the end-user's risk, as simple as it sounds for a commercial enterprise, is often totally overlooked in energy policies that focus simply on access to technology. In this respect, development planners have much to learn from the simplest of private sector businesses.

Figure 23: Relative Expenditure on System vs. Annual Income

Indeed, Figure 23 bears out the problematic system cost/income ratio. Many of the households whose annual incomes are less than the survey average of $2800 are spending over 75% of their income for their systems, with some homes spending almost 200%. This highlights the tremendous demand for electricity in rural homes, and is a testament to the ability of many Kenyan homeowners to economize and arrange the requisite credit for important investments.

It is equally remarkable that while the less wealthy homes are putting a great deal (in a relative sense) of money into PV, the richer households which can afford it much more are spending very little. Figure 23 suggests that absolute expenditures on home PV systems in Kenya are nearly equal across income levels; Figure 24 confirms this.

Figure 24: Expenditure on PV System vs. Annual Income

Figure 24 further demonstrates that there is, as expected, some relationship between the homeowner's annual income and how much he or she spends on the PV system, but it is not particularly strong -- especially if the outlier that spent over $2600 on his system is excluded.

Figure 24 highlights the niche that PV primarily fills at present in the Kenyan market. Even though the wealthier households could afford to purchase much more powerful systems, they appear not to be overly interested. This confirms what has been observed about PV elsewhere -- namely, that it is an attractive alternative for small-scale applications, but for larger energy needs, other options currently prove to be more economical or appear to be more reliable. An obvious role for development organizations interested in the further dissemination of PV technology is to concentrate more systematically on this small-scale, decentralized market.

3 • *Close to the Grid*

As we discussed earlier in Section II.B.3, one of the factors contributing to PV's success in Kenya has been the limited reach of the country's electric grid due to the high costs of grid extension, estimated to be roughly 500,000 KSh ($8200) for every kilometer of new lines.[69] We might expect, therefore, to find that households close to the grid have been less likely to invest in solar panels.

A simple cost comparison between grid connection and photovoltaic system acquisition can be made. Balancing these costs yields a "break-even" distance beyond which PV would be cheaper, and within which grid connection would be cheaper. This analysis, of course, disregards many of the most interesting and central issues in the evaluation of the actual diffusion process: the politics of grid connection, the reliability of PV power vs. grid electricity, the technical skills necessary to manage one method vs. the other, the household's specific electricity demands, the up-front vs. amortized costs, and so on. But for the sake of estimating a break-even distance, we make the comparison nonetheless.

We can approximate the distance from a 1992 report by the US Office of Technology Assessment (OTA) on energy supplies in developing nations. The OTA found that, assuming a grid extension cost of $4500 per km and a PV cost of $0.50 per kWh, the break-even distance is 13.9 km; for a cost of $10,000 per km, the break-even point is 6.3 km.[70] Since the cost of grid extension in Kenya is approximately $8200 per km, we can estimate by interpolation a break-even point of 8.8 km. While only an approximation, this value is unlikely to be off by more than a factor or two.

In the selection of surveyed households, however, we find that nearly 85% are 5 km or closer to the grid, half lie within 2 km, and one-quarter are less than 1000 meters away (Figure 25). This seeming disregard for the cost/distance analysis made above is hardly surprising in light of the uncertainty and of state-provided electricity in most developing nations.

Figure 25: Distance of Surveyed Systems from the Grid

This is not meant to suggest that such a large percentage of all Kenyan home PV systems lies so close to the electric grid. The survey we conducted was heavily biased towards systems near urban centers (as indicated in Figure 20) -- and thus near the grid. This was done for reasons of convenience and accessibility, so systems close to the grid are sure to be over represented in the results. What it does point out, however, is that a good number of photovoltaic systems are still bought by households even when they are close to the grid. This would appear to support the estimate that up to 40% of Kenyan home PV systems are installed close (within 15 km) to the electric grid.[71] This emphasizes the difficulty of getting connected even when the grid is close; a step-down transformer is still quite costly, and bureaucratic delays can be considerable. Some of the surveyed homes with photovoltaic systems actually had power lines running through their backyards. Even after connection, many Kenyans are still likely to find PV to be attractive: one of the homes surveyed was indeed connected to the grid but still uses solar energy to reduce its monthly electric bill. This reality stands in contrast to the argument that PV is still only viable in niche markets: unless one is content to count most of the developing world as only a 'niche.'

4 • *How They Learned about PV*

One important issue in technology dissemination is the diffusion of knowledge about the technology in question: how did the system owners learn about photovoltaics?

Figure 26: How System Owners First Learned about PV

Our survey confirmed what might well have been suspected -- namely, that word of mouth plays a central role in educating the Kenyan public about PV technology. The vast majority of respondents -- nearly 75% of homes surveyed -- reported that they first found out about photovoltaics from friends, neighbors, or relatives. In most cases, the friend or relative in question already owned a system and the respondent had seen it. The simplest and most sensible explanation is risk. The rural poor, cautious in general of new technologies that are not necessarily tailored to their needs, and the more affluent are both unwilling to assume the risk of expensive investments with unproven benefits. Therefore, the prospective buyer wants to see a system first-hand, or hear an evaluation from a trusted friend, before she or he buys one. Ownership of a PV system can earn the household a local reputation, because neighbors can see the lights at nighttime and friends and relatives are often invited over to watch the television. In fact, one household reported that an advantage of owning a solar energy system is that PV is a highly visible status symbol.

To explore this point further, a half-dozen families neighboring PV owners were interviewed; those respondents were aware of the nearby solar installations and had reasonably good knowledge of what applications photovoltaics can be used for -- lighting and small electrical appliances. This provides a direct, albeit anecdotal, test of the "IMNBY" hypothesis: 'I want it if it is In My Neighbors Backyard.'

It seems, therefore, that the photovoltaics market in Kenya is sufficiently mature to have generated its own technical and social momentum. Representatives of at least three major PV retailers in Nairobi reported that they no longer need to advertise as much as they did six or seven years ago, because knowledge of photovoltaics has become so widespread. Though they continue to invest in some advertisements and attend agricultural shows to demonstrate their products, these companies receive so many inquiries where the customer comes in on his or her own initiative, there is not as much need for advertising.

B. What Kind of Systems Are They Buying?

1 • *System Power*

A histogram of the power of the surveyed systems is shown in Figure 27. The bimodal distribution reflects the nature of the Kenyan photovoltaics market which, though it offers panels in a variety of sizes, tends to concentrate on small (25 Wp or less) and medium-sized (between 40 Wp and 60 Wp) systems. The vast majority of systems surveyed fell into one of these two categories, with a couple of larger systems also observed. The average system size was 38 Wp.

Figure 27: Power of Surveyed Systems (Wp)

The small systems usually use amorphous-silicon panels which, though relatively inefficient, are also cheaper to manufacture. The low price of these systems is their singular advantage, making them affordable to Kenyans who cannot afford large systems, and also attractive to Kenyans who are hesitant to invest a great deal of money in a new technology. In this regard, amorphous-silicon panels have been instrumental in keeping the Kenyan PV market moving forward. While their low prices have certainly contributed to the growth of the Kenyan PV market, however, their low efficiencies have simultaneously detracted from it. More often than not, a Kenyan household with an amorphous-silicon panel will tend to have its battery in a perpetually low state of charge, thus degrading the performance of the whole system. This is a result of the fact that the amorphous-silicon panels provide comparatively low power levels. Users thus tend to draw on the battery very frequently. In fact, the small systems observed in this survey were significantly more prone to problems than were the systems using more powerful panels; a more detailed comparison will be laid out in Section D, "How Well Are the Systems Really Working?"

Most of the systems in the middle range -- 40 Wp to 60 Wp -- use polycrystalline or monocrystalline panels. Because of their higher power, they are better able to meet the electricity demands of Kenyan households, and are less likely to suffer from the problems of battery draw-down that plague small systems. At the same time, the higher cost of these more powerful systems can put them out of the reach of many prospective buyers, forcing them to settle for a small system.

Has Kenya's recent recession forced customers to turn to amorphous-silicon panels in larger numbers? The intuitive answer would be 'yes', and several of the PV dealers interviewed stated that, even as sales of polycrystalline and monocrystalline panels slumped with the economy, amorphous panels have continued to sell reasonably well because of their low price. The data from the survey, however, do not bear this out. An examination of Figure 28 shows little relation between system size (measured in Wp) and system age, meaning that there is no strong trend to buy smaller-wattage panels in the past couple of years.

Figure 28: System Size vs. System Age

2 • *Cost Breakout for a PV System*

When a consumer buys a system, how much is paid for the various system components? Several authors have offered breakouts showing the initial costs associated with buying a typical PV system; one is shown in Figure 29. The first observation to be made is that the solar panel accounts for 40% of the total, with the battery, electronics and wiring, and other components -- the so-called 'balance of system' -- coming to more than half the cost. This cost breakout is typical for small-scale PV systems, and explains an important aspect of PV diffusion. It is normally true that an industry based on an imported technology would be a recipe for trouble. While the PV modules are imported, they do not even account for half the total costs, and the balance of system can be, and generally is, designed and constructed locally (as in the case of some of the PV companies in Kenya that we have already discussed). Foreign exchange problems, tariffs, and other vagaries of the international commercial network can and do strongly impact the Kenyan PV market, but at least the preponderant role of balance-of-system components serves to foster an active domestic industry instead of technological dependence.

Figure 29: Cost Breakout for Small PV Lighting System

Most estimates such as this one are based on prices quoted by solar companies, and give a good idea of what the consumer can expect to pay initially for a medium-sized solar "package". In this survey, we were interested in also finding out what consumers actually have paid for their systems, and what their subsequent costs have been since the time of purchase. This breakout is shown in Figure 30.[72]

Figure 30: Average Expenditures for Systems Surveyed

Two important observations emerge from the expenditure breakout of Figure 30. One is that the amount spent on charge controllers is insignificant because very few customers purchase them. Of the systems surveyed, less than 15% had charge controllers. The other point is that battery replacement and repair make up a small but non-negligible share of overall costs. Not only had many of the surveyed systems already spent money on battery expenses, but the current batteries were also often in need of repair or replacement. It may well be that the money saved by not buying a charge controller is actually paid later with the need to replace short-lived batteries.

C. What Are the Consumers Using the PV For?

First and foremost, the Kenyans surveyed use their photovoltaic systems for lighting needs. The prospect of improved lighting is often a main factor in the decision to buy a solar panel, and PV helps lighting in two main ways. One is that the quality of light is a significant improvement over lantern light; the other is that, with lights in several rooms, the family now has multiple sources of light allowing different people to do various activities in several rooms instead of having to crowd around the family's one or two lanterns. Because electric light can improve a household's quality of life so much, it is not surprising to find that the average home in this survey uses more than half its available solar electricity for lights, especially fluorescent lights.

TVs and radios account for nearly all the remaining energy usage (Figure 31). These items are very important to Kenyans, serving both as a major source for news information and also as a source of entertainment. The World Cup was being televised during the time of this survey, and it is difficult to overstate how much it meant to the respondents to be able to watch the games in their own homes -- usually accompanied by a sizable contingent of neighbors and friends.

Figure 31: Usage of PV Electricity, Sunny Season

During the rainy season, the respondents reported cutting back their usage by about 30% on average. This reduction did not happen uniformly, however, but showed a slight shift towards more lighting and less TV. (See Figure 32) This is hardly surprising during a time of year that is typically darker and where the need to conserve energy compels families to turn off the high-wattage items such as TVs first.

Figure 32: Usage of PV Electricity, Rainy Season

D. *How Well Are the Systems Really Working?*

Although an estimated 20,000 to 40,000 photovoltaic systems have been sold to Kenyan households, that does not necessarily mean that all of them are working as they are supposed to. The central question to consider before declaring Kenya a success story for PV is whether the systems are actually performing well.

If the results of this survey are representative of the systems throughout the country, then the results are mixed. At the time of visit, 40% of the systems had problems sufficient enough to impair the system's operation to a significant extent -- e.g. blackened bulbs, repeated light malfunctions, and weak batteries -- and a quarter of those were completely inoperational (Figure 33). These problems were almost always with either the battery or the lights, and descriptions of the most common types of problems, and how they are caused, can be found in Section F, "Typical Problems with PV."

Figure 33: Performance of All Photovoltaic Systems in Survey

As alluded to earlier, not all systems were equally likely to suffer from problems. Specifically, the small systems relying on amorphous-silicon panels were much more prone to partial or total failure, with less than half functioning fully. This is doubtless due to the small size of the systems, which often cannot produce enough electricity to satisfy the demand of the household. When the family tries to use more energy than the panel can supply, it leaves the battery in a continuously low state of charge, resulting in a damaged battery with a shorter life. The larger systems, on the other hand, fared better, with two-thirds functioning properly and less than 10% inoperational (Figures 34 and 35). An additional factor in system performance is undoubtedly the fact that those households able to purchase larger systems initially are also more likely to have more funds available for system maintenance and troubleshooting as problems do arise.

Figure 34: Performance of Small (< 25 Wp) Systems in Survey

Figure 35: Performance of Medium and Large (≥ 40 Wp) Systems in Survey

Still, many would consider a 60% to 90% success rate (comprising the full range of 'operational' plus 'partly operational' in Figure 33) to be, in fact, a dramatic success. These PV systems are generally operating far from steady maintenance, and extremely far from the international source of some of the components. There is no doubt that performance will increase as more and more Kenyans respond to the demonstrated demand, but having 60% to 90% of systems at least partly operational in rural Kenya is impressive compared to many technologies in such use -- in either rural or urban, or developed or developing country settings. Room for improvement clearly exists, however, particularly given that the PV industry in Kenya is now more than a decade old.

But that does not mean there is no room for improvement. Increased use of charge controllers, more willingness from the owners to restrict their electricity usage, and decreased panel prices to facilitate the purchase of larger panels, can all contribute to even better system performance in Kenya.

E. Many Benefits from PV

Even though many PV systems in Kenya are not working perfectly, solar energy is still bringing a large number of benefits to system owners. The vast majority of respondents, even those whose installations had problems at the time of the site visit, said that they were glad to have bought their systems and that photovoltaics is a good energy source. Many owners expressed frustration with either the battery or with the fluorescent lights, but drew a distinction in their minds between PV technology and balance-of-system problems: a common response was that the batteries and lights were no good, but solar power itself (i.e. the panel) was fine. They still felt that PV is the best choice and will become even better if the problems can be ironed out and the prices can come down.

When asked what the principal benefits of photovoltaics are, and why PV was chosen, the most popular response was that it is the least costly alternative when compared to grid extension (generally out of their control) or diesel generators (for which they could have opted). This underscores what was noted before, namely that economic motivation is the chief factor encouraging the dissemination of PV in Kenya. This remains the acid-test of technology choice, and PV in Kenya appears to be a legitimate success, particularly because the selection of these systems was made largely without any form of subsidy or other market manipulation.

Other authors have conducted detailed life-cycle cost analyses of PV versus grid electricity, diesel generators, dry cell batteries, and kerosene. Rather than repeat their efforts, this study will highlight some of their findings and refer interested readers back to the original sources.[73] In a study looking only at the most common end-use (lighting), Karekezi found that PV is cheaper than kerosene lanterns on a daily-expenditure basis when a family has four or more lights. Compared to a diesel generator, however, PV is about twice as expensive. This is not so much a reflection on the technology as on the policy; most of the price difference stems from the tax and import duties imposed on photovoltaic equipment. An analysis from neighboring Tanzania finds PV to be less expensive than diesel generators by a large margin, and also concludes that PV costs less than extension of the electric grid; all figures are based on costs per kWh. A study from Zimbabwe, though less relevant because of that country's different market conditions, is one of the more detailed ones and allows for varying real discount rates and multiple end-uses. It finds that a 15 Wp system is often cheaper for the low-income home than current energy expenditures (on batteries, candles, and kerosene), and a 50 Wp system can be similarly cheaper for a middle-income household. PV is more expensive than either candles or a kerosene lamp when only a couple lights are used; but when more lights are added, or when a radio is added, PV becomes the most economical choice.

Cost was not the only benefit reported by the surveyed families, however. The improved quality of light was the second most frequently given answer (Figure 36), along with the convenience of PV -- for example, having no generator to maintain, the simple maintenance of a solar panel, and the ease of turning lights on and off with a simple switch instead of having to light a lantern or start up a generator.

Figure 36: Advantages of PV in Owners' Opinions

Customers also relished the idea that, once the panel had been bought, their electricity was free. Many were glad not just for economic reasons, but for resource security ones as well. Grid customers know that blackouts are not uncommon, and there are also periodic kerosene shortages, so many customers found photovoltaics to be the most reliable energy source. PV spares the consumer from fluctuations in the prices of various fuels and energy sources. Since KPLC had doubled its rates shortly before the survey, this was fresh in the minds of many respondents, and tales about the ever-increasing price of kerosene were common. PV owners were also grateful for the journeys saved by their PV system -- trips to buy fuel and to recharge lead-acid batteries were no longer necessary, or at most only infrequently, once the solar installation had been purchased. And respondents appreciated the flexibility of electricity, noting that it can be used not just for lights, TVs, and radios, but also for many other applications such as security lights, fans, VCRs, and so on. This contrasted to their opinion of kerosene and wood as fuels, which are only good for lighting, heating, and cooking. Several families also talked about how PV is safer than kerosene lamps and diesel generators, both of which can cause fires and emit fumes that irritate the eyes, especially of children. One woman described an all too common problem in rural Africa: injury. She reported that her two young sons had been badly burned from an accident when fueling the family's generator; after burying the ruined machine deep in the ground and far from home, she recounted, the family immediately switched to photovoltaics.

Although it is hardly surprising, it is important to highlight the fact that the environmentally beneficial aspects of photovoltaics were last among the advantages noted by PV owners. Only one person -- or less than 3% of respondents -- even mentioned the environmental benefits of solar technology, and even he was correct in only a very general and indirect sense, as he spoke of solar panels as saving trees. The clear lesson here is that the widespread dissemination of solar electricity has not occurred because of any great environmental conscience among the people. Rather, it is the more immediate and economic alternative for these homes, and any environmental benefits are incidental and practically unknown to the users.

F. Typical Problems with PV

Although photovoltaic systems have brought many benefits to the families that buy them, certain chronic problems seem to recur frequently. Nearly all of them affect the battery or the lights, or both.

1 • *Battery*

The battery is normally the weakest link in any domestic PV system, and is the most common cause of failure for photovoltaic systems in East Africa.[74] Although both nicad (nickel-cadmium) and lead-acid batteries can be used in PV systems, nicads are practically unavailable in Kenya, so nearly all domestic photovoltaic systems use lead-acid batteries. The advantages of lead-acid batteries are that they are cheaper than nicads and can be made relatively easily with locally available materials.

Figure 37: Battery Life

Lead-acid batteries suffer from certain disadvantages as well. Their discharge voltage decreases as power is drawn out, which can damage fluorescent lights, a problem that will be covered in more detail in the next section. Also, lead-acid batteries do not tolerate deep charging and discharging very well. A "cycle" for a battery consists of charging it and then discharging it, so a typical PV battery goes through one cycle a day -- it is charged by sunlight during daytime, and then discharged at night when the family uses the lights, TV, and radio. Lead-acid batteries are most typically used for automotive needs, which require a "shallow cycle": the battery gives a large burst of energy for a short time. In contrast to this, most photovoltaic systems need "deep cycle" batteries that provide a low level of energy for an extended period of many hours.[75] Because lead-acid batteries are ill-suited for deep cycling, they often fail in PV systems; Figure 37 shows how excessive discharging of the battery, which is common in the rainy season, can shorten the battery's life considerably. Furthermore, lead-acid batteries have high self-discharge rates -- especially if they are old or damaged. Finally, lead-acid batteries are also problematic because their performance suffers substantially under high temperatures, which are common in many areas of Kenya (Figure 38).[76]

Figure 38: Effect of Temperature on Battery Calendar Life

Although it is recommended that batteries not be discharged more than 20% (for shallow-cycle batteries) or 60% (which can be tolerated by deep-cycle batteries)[77], a common cause of system failure is that PV users do in fact regularly exceed these limits. This explains the frequent problems found with the small systems that have only 10 Wp or 20 Wp panels. Because the panels do not generate very much electricity, the user is often drawing out more energy than the panel has put in during the day, and the battery's charge drops lower and lower. This is aggravated by the self-discharge problem. In fact, the output of a 10 Wp module may not even be enough to overcome the self-discharge rate of the battery.[78] Because most of the respondents do not use charge controllers to measure the battery's charge and prevent excessive discharge, they tend to keep using electricity until visible signs indicate there is little energy left -- e.g. the lights get dim or the TV picture gets smaller and smaller. By that point, of course, it is too late and they are already damaging their batteries.

2 • *Lights*

The advantages of life span and broadcast illumination of fluorescent over incandescent lights are well known, and fluorescent lights dominate small domestic systems in Kenya despite their higher cost.[79] They enjoy high efficacies of 30 to 75 lumens/watt; three to four times higher than incandescent bulbs, which usually only produce between nine and 16 lumens/watt, with the rest of the energy being lost as heat.[80] Furthermore, fluorescent tubes have a lifetime of 2000 to 5000 hours, which is four to five times longer than the life of most incandescent bulbs.[81]

Unfortunately, however, fluorescent tubes can only run on high AC voltage, and photovoltaic systems produce low DC voltage. To use fluorescent tubes, therefore, every light fixture must be fitted with a ballast inverter that switches the current to AC and steps up the voltage. This leads to three difficulties. The first is that the ballast uses some energy itself when converting the electricity. This can reduce the tube's efficacy by over 40%, particularly for low-wattage models (Table 3). These losses are partially offset, however, by the fact that DC inverters run at high frequencies (over 20,000 Hz) and fluorescent lamps operate more efficiently at higher frequencies.[82] Even with the inverter, however, fluorescent lamps are still several times more efficient than incandescent bulbs.

Table 3: Effects of a 12V Inverter on Fluorescent Efficacy

The second problem is that the inverter makes the cost of fluorescent light fixtures considerably higher. The capital cost of a fluorescent light fixture in Kenya is typically eight times as much as that of an incandescent fixture.[83] This high cost sometimes discourages Kenyan PV owners from replacing burnt-out bulbs or damaged fixtures.

The third problem is that low voltage can damage the ballast and tube. This results in blackening: the accumulation of black deposits of mercury compounds inside the tube.[84] Because lead-acid batteries give off lower and lower voltage as their energy is drawn out, blackening of fluorescent tubes is a common problem in Kenyan systems. In contrast, incandescent bulbs continue to operate at below-normal voltages, and this in fact increases their lifetime (although it decreases their brightness).[85] We have already seen that many of the PV systems surveyed had batteries in a habitually low state of charge. Therefore, many of the fluorescent light fixtures in these homes were being damaged by low voltages, and dim or blackened bulbs were indeed found in a great many homes. Again, however, this suggests a important opportunity more than a problem of system design. New "PV adapted" light bulbs and other appliances would make a natural local industry that relies more on adapting and innovating on known technologies than having to begin from scratch. This sector, too, would be a natural target for start-up development funds that would further add to the strength of an indigenous PV infrastructure.

3 • *Panel Mounting*

Most of the systems surveyed for this study were mounted directly on the roof. The obvious advantage to this is that it is a very inexpensive and easy way to mount a solar panel. Another less obvious advantage is that panels can be effectively "hidden" either by mounting them behind the chimney and thus out of sight from the ground (but making sure the chimney does not throw a shadow over the panel) or by placing them in the trough between two downward-sloping sections of roof. As the number of stolen panels continues to rise in Kenya, this may become a more important consideration.

There are two major drawbacks to these fixed roof mounts, however. One is that the roof, commonly metal, can get extremely hot in direct sunlight. A crystalline panel's output typically falls by 0.5% for every 1° C increase in temperature (this is less of a problem for amorphous panels).[86] Panels are rated at 25° C, but the temperature of these metal roofs may get as high as 60° C, meaning the panel's output is probably reduced by 15% or 20%. Raising the mount off the roof by half a meter can help cool the panel by allowing air to circulate underneath it.

The other drawback is that fixed mounts cannot track the sun for optimal energy production. As the sun travels from the Tropic of Capricorn to the Tropic of Cancer and then back again, a solar panel should ideally follow its path through the sky. Since Kenya straddles the equator, a graph is included showing the best angle for a solar panel located on the equator at noon on various days throughout the year. For example, a panel near Meru (which is practically on the equator) should ideally be tilted about 12° north on April 22, about 23.5° north on June 22, and about 20.5° south on November 22. This is summarized in Figure 39. Tracking is also useful not just from season to season, but within each day: a panel tilted about 30° due east in the morning and then about 30° west in the afternoon can improve its energy output by up to 20% to 30%.[87]

Figure 39: Optimal Angles for a PV Panel on the Equator

Although simple rotating mounts are easy to construct and inexpensive, they do not appear to be in widespread use; of the surveyed systems, only one had a tracking device. Getting the panels off the roofs and onto rotating mounts could, for the two reasons noted here, significantly raise the amount of energy produced by Kenyan home PV systems. Since this would keep the batteries in a higher state of charge, many of the problems with batteries and lights would also be alleviated.

4 • *Other*

Our observations that batteries and lights figure prominently in the complaints owners had about their systems is not confined to Kenya; similar concerns have been voiced about remote PV systems worldwide.[88] As seen in Figure 40, those are major, but not the only concerns. The principal other complaint is that solar panels do not provide as much energy as the owners would like, especially in the rainy season. To a large degree, of course, this is not a problem of the systems, but of the communication process that preceded sale and installation. The fact that the survey was conducted in July and August (two rather cloudy and rainy months in Kenya) certainly biased these results, but does not diminish their importance at all. This goes hand-in-hand with another common criticism from system owners: they wished PV could supply enough power for cooking or ironing. Again, however, these comments are of increased, not disappointed, expectations. A striking feature of all these system "problems", of added expectation and desired performance on the part of the system owners, is the role that education and training centers could play in bringing expectation in line with performance by educating system owners and potential new customers about the capabilities and limits of different sizes of PV systems. Further, evolution from a 'technical fix' approach where one or more specific technologies are expected to save the day is an important part of new models of sustainable development. Instead, suites of technologies, particularly involving renewables -- that always face the challenge of intermittent power sources -- promise the best approach. Rural energy programs that introduce PV in concert with wind, biomass, and solar thermal technologies, potentially backstopped by efficient biomass or fossil-fuel generators define an environmentally clean energy infrastructure for development.

Figure 40: Disadvantages of PV in Owners' Opinions

IV. Recommendations & Conclusions

A. Estimating the Benefits to Kenya's Environment from PV

Until the recent price reductions in PV technology, virtually all dissemination efforts were justified on broad environmental grounds. It can be viewed as a triumph of technological innovation that the Kenyan PV story is not fundamentally being driven by these environmental concerns, valid and important though they are. In fact, there is relatively little *direct and local* environmental benefit from the spreading of PV systems throughout Kenya. The most pressing energy problem, from an environmental perspective, is the overwhelming domination of fuelwood in Kenya's energy sector. This dependence results in extensive deforestation, causes soil degradation, endangers habitat, and releases vast quantities of greenhouse gases. Moreover, it is highly inefficient. Biomass burning to produce charcoal for urban use wastes 80% to 90% of the wood's initial energy content, with even more energy lost in the subsequent charcoal combustion.[89] To all this waste should be added the transportation costs incurred. To the extent that fuelwood is used for lighting in Kenyan homes, PV may cut into this market a little; but because it is not powerful enough for cooking or heating, its effect on Kenya's biomass consumption will remain minimal. Further quantitative investigations of this effect remain to be completed.

PV systems do not generally replace fuelwood directly; rather, they replace dry cell batteries and kerosene.[90] Some biomass lighting or space heating may be replaced by PV systems, but it is not the primary fuel substitution on the energy ladder. The environmental benefit of reducing dry cell battery usage is undeniable, but may be partly offset by the increased use of solar batteries. Perhaps the largest environmental benefit PV offers in Kenya comes from the decreased use of kerosene, which is a non-renewable petroleum product that requires drilling. If we examine Kenyan consumption of petroleum products over the five years from 1989 to 1993 (Figure 41), we see that Kenya uses 9.2% of its petroleum to make kerosene for illuminating purposes. Though this seems small, it represents nearly 176,000 metric tons of petroleum, and the resulting greenhouse gas emissions, every year.

Figure 41: Kenyan Demand for Petroleum Products

Still, even if PV were to replace all of Kenyan kerosene use, that would represent less than 3% of national energy use. Figure 41 shows that the disadvantages -- both economic and environmental -- of Kenyan dependence on imported oil will not be solved without addressing the demand for fuel and diesel by the industrial and transportation sectors. It would seem clear that the contribution PV utilization makes to reducing petroleum usage will, in the end, have comparatively little *direct* environmental benefit.[91]

But such an analysis, failing to look beyond the mere numbers, neglects the key role that solar energy can play in blazing a trail for sustainable energy use. The overall satisfaction that the system owners professed, and the evidence of 20,000 to 40,000 such systems in Kenya, provide tangible evidence of the utility of renewable energy systems generally. It is these concrete examples that encourage further research, diffusion, and community interest in what were once considered 'unreliable' technologies. It is probably no coincidence that several of the PV owners surveyed had also installed biogas systems for cooking, and others were interested in solar box cookers. These households had their interest piqued by photovoltaics, and now are excited about pursuing total energy independence for their homes. This provides an important technological snowball effect, characteristic of many innovations. The history of PV in Kenya therefore documents a counterpoint to Michael Grubb's famous comment that, "renewable energy is an enigma; everyone is in favor of it, but few take it seriously"[92] If the survey results are any indication, Kenyan households are just beginning to take renewable energy seriously -- very seriously -- and are simply waiting for the market to provide the desired technology at affordable prices.

B. PV's Contributions to Kenyan Standard of Living

A corollary to Grubb's point is that environmental benefits can only be realized, of course, if the systems are adopted. We recall Gerald Foley's wise statement that:

> ...The primary purpose of renewable energy projects in the developing world is not the promotion of renewable energy technology as such, but rather to meet the energy needs of the developing world in the most effective manner possible.[93]

There is no question that PV is indeed meeting energy needs effectively. Perhaps the greatest benefit of photovoltaic dissemination in Kenya is the improvement in the quality of life for those who can afford systems. Though this is more difficult to quantify than, say, decreased carbon dioxide emissions or reduced deforestation, certain tangible benefits can be enumerated.

1 • *Education*

The difference in brightness between a kerosene lantern and an electric light is dramatic. With the lantern, it is usually difficult for more than one or two family members at a time to use the light because it is so meager; fuel shortages may cause the family to run out of kerosene at times; price increases may force a rationing of available fuel and thus less study time; and many children's eyes are irritated by kerosene fumes. For all these reasons, using kerosene lamps can make studying difficult or even impossible. In contrast, the light from a 15-watt fluorescent bulb can easily illuminate an average-sized room so that all family members can read comfortably. Because sunlight is free and abundant, there is no worry of fuel shortages or price increases. Many of the families interviewed in the survey listed the improvement in light quality as a main advantage of their system, and reports of children's grades improving were not uncommon.

Furthermore, Kenyans receive much of their information about current events and the modern world from radio and television. Most homes surveyed reported that they now can use their TVs and radios much more than before purchasing their PV systems, especially during the sunny season.

2 • *Safety*

Kerosene lamps pose a real danger to homes because of the potential fire hazard they represent. Diesel generators are no better; one respondent decided to switch to PV after two of her sons were badly burned in an accident fueling the family's diesel generator. In contrast to the risks of these energy sources, photovoltaic modules are quite benign, involving no inflammable fuels and posing negligible risk of shock because of their low voltage.

Another way in which PV systems have contributed to the safety of their owners is through the provision of outdoor security lights that can allow the family to see outside without leaving the safety of their home. Several respondents in our survey reported that they and their family members feel "safer" now that they have electricity, and some also believe the bright lights inside the home are a deterrent to would-be burglars who find dimly-lit domiciles easier targets. The mounting incidence of crime that Kenyans are experiencing makes this benefit alone of considerable value.

3 • *Convenience*

Photovoltaics can also make life much easier for the homeowners. Many seemingly small conveniences improve their day-to-day existence -- such as the ease of lighting a room with the flick of a switch, instead of having to fumble in the dark outside trying to start a diesel generator, or struggling to refill a kerosene lantern. This has enabled family members to do things that were not practical before -- like wives getting up early to cook, and children staying up late to read or do homework.

Solar systems also save the family the hassle of having to make multiple trips each month. They no longer need to go to town to buy kerosene twice a month, or to lug their car battery to the nearest *jua kali* (small-scale repair facility) every week.

C. Policy Recommendations

This study shows that, not surprisingly, even decentralized, market-driven, technologies are susceptible to political and macro-economic factors. Many of the most important variables -- inflation, the value of the shilling, the re-imposition of tariffs -- resulted from national policy and, ultimately, from the ending of the Cold War. In general, these factors tended to raise PV prices and lower Kenyan incomes. But these effects can be offset by intelligent and focused policies initiated by the international community. With proper encouragement, photovoltaics may advance from its current niche market in Kenya to enjoying widespread and diverse use.

The following policy recommendations are aimed at encouraging such widespread and diverse use. Though they are written with the Kenyan PV context in mind, readers will note that their underlying goals -- to reduce risk, leverage funds, encourage domestic industry, and so on -- are applicable to environmental technologies in developing countries in general.

1 • *Small-Scale Approaches*

If PV has been as beneficial to Kenyans as our study indicates, then the obvious next question is: how can we make the technology available to more than just wealthy families? There are at least two small-scale approaches to extending the benefits of photovoltaics to Kenyans who currently cannot afford to buy home systems. One is the use of solar lanterns instead of entire systems. These devices are much less costly than a home system -- typically between $100 and $300 -- and have a capacity between 2 Wp and 10 Wp.[94] Since lighting requirements play the largest role in home PV systems, turning to solar lanterns would help a great many families address their most pressing electrification need. Nevertheless, solar lanterns have proven unpopular so far. For one thing, they must be left outside, making them quite vulnerable to theft unless someone stays to guard them. For another, most families prefer to wait and save the additional funds needed for a full home system that can power multiple lights and a TV or radio, rather than limiting themselves to a single light.

A second option is the idea of PV battery charging stations. For instance, one person could buy five 50 Wp panels for his or her home and then, for a small fee, offer to charge the lead-acid batteries that rural homes so often use for powering TVs and radios. The typical *jua kali* price for battery charging is about 25 KSh; the station owner could therefore make 125 KSh per day and recoup the cost of the panels in 3 to 4.5 years, depending on the original per panel cost (see Table 4).

Table 4: Payback Period for Battery Charging Station (25 KSh/Charge)

Since most panels are guaranteed for ten years (except amorphous panels) and usually have life spans of twenty years or more, the business could be economically feasible. In fact, the idea of battery charging stations using PV panels has already begun to spread. Of the homes surveyed, nearly 10% reported that they charged batteries for friends, relatives, or neighbors for free. It would not be a very big step, therefore, for entrepreneurs in rural Kenya to see PV battery charging stations as a profitable business venture.

2 • *Financing Schemes*

a • *Consumer*

Models of successful revolving credit funds (like the Grameen Bank) for rural development and PV system acquisition are already available. For example, a rural development association named ADESOL (Associación de Desarrollo de Energía Solar) was founded in 1984 in the Dominican Republic by Enersol, an international NGO promoting solar energy. ADESOL typically requires the customer to pay 25% of the cost of the system up front, with the remainder to be repaid in installments over the next two years at prevailing interest rates; the returned money then helps future consumers buy systems.[95]

Fortunately, it is becoming increasingly common for a national government to include photovoltaics in rural electrification programs. Mexico's ambitious PRONASOL (Programa Nacional de Solidaridad) scheme for aiding the rural poor has as one of its major components a rural electrification plan. Working in conjunction with the national utility, CFE (Comissión Federal de Electricidad), PRONASOL identifies areas that are unlikely to benefit from grid extension in the near future; it then encourages the use of renewable energies for these remote locations by offering attractive financing.[96] PV projects can fall into two categories for PRONASOL financing: "productive" (i.e. income-generating) and "general" (i.e. non-income-generating). To qualify for a "productive" PV project loan, the applicant must prove to PRONASOL that the scheme is economically viable; if so, then preferential loans are made available from Mexican development banks. As for "general" PV projects, the federal government usually pays for half of the project, the state government pays for thirty percent, and the remaining twenty percent is split between the local government and the end users, whose share is determined by their ability to pay.[97] For both categories of projects, the user is responsible for all future costs, so it might be appropriate to establish some sort of revolving credit fund like those described above for anticipated system expansion and maintenance.

A plan like this may also be feasible in Kenya. KPLC has a Rural Electrification Programme, so the funding mechanism is already in place. Although KPLC has expressed a great deal of skepticism about photovoltaics,[98] solar energy's cost efficiency -- and some direct policy pressure -- may prove persuasive. Because PV systems are often the least costly alternative for electrifying rural homes, KPLC may find it can bring power to more households for less money.

b • *Dealer*

In addition to programs that extend credit to potential PV customers, aid agencies and NGO's could make financing available to solar dealers. Our survey found this method of credit extension to be widespread and, apparently, effective. Daniel Kithokoi, a solar dealer in Meru, reports that he used to allow customers to pay for their systems in installments; Kithokoi would typically allow the customer to pay 50% up front, with the balance to be paid within three or six months at low interest rates. Many of his customers would not have been able to buy their systems if not for his credit scheme. Moreover, Kithokoi reported 100% repayment from the over 100 customers who purchased their systems under this arrangement. This is directly reminiscent of the Grameen Bank approach that was initially derided by the World Bank and other international donors, but has now gained policy prominence in this same community. Kithokoi's scheme was effective, no doubt, because he knew his customers and could judge who would make a good credit risk. He was able to give credit because his supplier in Nairobi first extended the credit to him. After a management change, however, the supplier withdrew its credit scheme from all dealers; Kithokoi, in turn, had to revert to demanding full payment from his customers. He reports that business has dropped off as a result.

Similarly, Peter Musumba, a solar dealer in Bungoma, extended credit to selected customers whom he thought would act as good "seeds" in an area with few PV installations. His terms, not as generous, usually called for 80% up front and the balance due two months later, with no interest charged. Like Kithokoi, his repayment rate was nearly 100%. Because he was not giving as much credit as Kithokoi, he was able to finance it just from profits on earlier sales, obviating the need to rely on any outside supplier for credit. Unfortunately, he too has had to suspend credit because the poor economy has dried up sales, and hence, profits.

If dealers like Kithokoi and Musumba were able to access a "PV Extension Fund," then they could resume their credit extensions to customers. This might ensure efficient use of limited funds in furthering solar energy in Kenya, because the money would strategically leverage funds from willing customers. Further, this scheme would build local industry capacity that itself would likely percolate through the local economy.

3 • *Capacity Building*

The further development of local PV expertise, the Kenyan "experience curve," requires dedication, patience, and support for fledgling training programs and commercial ventures. The support of such initiatives is a primary area where multinational, non-governmental, and national development agencies must become far more willing to get involved. This approach, while popular in program design statements and brochures, is largely ignored in practice due to the slow progress and labor-intensive nature inherent in the program management and training that it requires. The interest and investment in such demonstration and education workshops, including school PV electrification, by national and some international agencies during the early 1980's certainly helped to "prime the pump" for subsequent interest in PV systems. Again, such investments in the early 1980's would not at the time have appeared cost-effective, but are instrumental in long-term development planning.

The traditional role of non-governmental and small-scale development agencies working to foster alternative or 'appropriate' technologies for development has been to: (i) popularize a technology; (ii) demonstrate and train local 'facilitators'; and (iii) explore funding options to formalize what began with their technological advocacy. This process remains critical in the effort to demonstrate the viability of new technologies to communities that are generally excluded from the development process due to geographic isolation, poverty, lack of education, or other political or social reasons. This often expensive and difficult process must be expanded and taken far more seriously by the large national and international actors in the development process.

The experience with PV technology in Kenya, however, illustrates an additional role and opportunity that has so far been largely ignored by energy planners: reducing risk to the households. Because of the enormous investments solar installations represent relative to most households' annual incomes, prospective purchasers are often deterred from buying by the risks of PV -- battery failure, blackened lights, etc. In the case of many new technologies, including PV systems, this could be addressed through an infrastructure that can reduce this uncertainty and risk. Such a service often represents a remarkably inexpensive investment within the means of many development agencies or NGOs. In the PV story examined here, these needs and opportunities include:

a • *Renewable Energy Information and Advising Services.*

In many cases, knowledge of the range of available technologies, and the expertise needed to manage, or even select, these systems for particular applications is wholly lacking among the potential end-user population. This is commonly the case in 'technology driven' programs, some of which allocate over 90% of total project funds to R&D and technology demonstration. Solar dealers in Kenya have educated their customers to a limited extent, but many purchasers find the company suddenly stops caring once the transaction has been completed.

Most dealers, especially from Nairobi-based companies, do not leave written instructions for system maintenance, do not give the customers the informational pamphlet that accompanies the solar panel, and never return for a follow-up visit. Consequently, the customer often must fend for himself or herself. PV dealers in Kenya need to be held to higher standards for technical support and customer assistance. It also would be useful to have some sort of independent entity to give customers unbiased evaluations of how to meet their energy needs. Some sort of Renewable Energy Information and Advising Service that fulfilled these roles -- suggesting industry standards and educating the public -- could potentially be of great assistance to the future success of PV in Kenya.

b • *Technology Engineering and Management Training.*

Familiarity breeds adoption. There is a diverse range of approaches to technology diffusion: community self-help, cooperative or small-scale industry, centralized manufacture, and so on. These all have a role to play in different markets and social systems. The one constant through all these approaches is the necessity for technical training. If more funding were available for training programs like those led by Harold Burris and Mark Hankins, small cadres of expert technicians would be available to offer maintenance and follow-up -- currently two of the weakest areas in Kenya's PV industry. As shown by the Burris example, the positive effects of good training can reverberate for years to come. This could help move the process of energy planning from sound ideology to indigenous industry.

c • *Sectoral Cooperation: Mutual Benefits*

A tension exists between traditional suppliers of electricity, in this case the KPLC, and renewable energy systems. This tension is structurally similar to that in the U. S. between the large utilities and small-scale producers, where fights over the Public Utilities Regulatory Act (PURPA) have dragged on for well over a decade. Just as small-scale power producers generally augment, not detract from the large utilities, the KPLC's antagonism to non-grid PV is equally counterproductive. If anything, the KPLC should encourage rural PV, the result of which will be an increased demand for electricity and grid extension.

4 • *Domestic Production*

Returning to the global PV production figures cited at the beginning of this report (Figure 12), we see two trends, one of which is discouraging for Kenya while the other is encouraging. The disappointing trend is that PV production, which had been rising at a healthy 15% to 20% from 1988 to 1991, has slowed to annual increases of 7.3% for 1992 and just 3.5% for 1993. Because of the experience curve we saw earlier (Figure 13) associating cost with cumulative production, Kenyan customers like others worldwide may suffer if the slowed growth in the global PV market means prices are unlikely to drop as rapidly. The cost reductions associated with cumulative production increases (typically a 20% cost decrease for each doubling of cumulative production[99]) are critical for future dissemination of PV systems. The expectation that this trend should continue, and even improve, is justification enough for increasing photovoltaic R&D to steady and sufficient levels.

Fortunately, we can be encouraged by the trend of increasing participation by developing countries -- chiefly India and China -- in the manufacture of photovoltaic systems (Figure 42). Not only is their absolute output rising, but their relative contribution is also increasing, from less than 4% of global PV production in 1984 to nearly 10% in 1993.[100]

Figure 42: Annual Global Photovoltaic Production

The growth of PV production capacity in developing countries could potentially benefit Kenyan consumers, because it may result in lower-priced components, and perhaps open the door to eventual PV production in Kenya itself. The current reliance on foreign modules exposes the customer to high import tariffs and fluctuations in the exchange rate which have hurt the market in recent years, as seen in the section detailing factors hindering PV dissemination in Kenya (Section II C). If Kenya can learn from the experiences of other developing countries manufacturing photovoltaic modules and establish its own PV industry, consumers would be sure to benefit.

The initial steps of PV module production -- making high-grade silicon and then slicing it into wafers, or cells -- may require equipment currently beyond the means of Kenyan industry. At the same time, however, a joint proposal from the University of Nairobi and a private manufacturer has recently been submitted to the World Bank to fund a pilot PV foundry.[101] This would be an exciting development that is a clear candidate for multinational funding. In any case, the final step of panel production -- assembling solar cells into modules -- holds particularly promise for developing countries.[102] The process is not especially complicated, essentially involving the wiring of cells in series, the soldering of cells into circuits, and the encapsulation and framing of the module; the skills are easily learned, and do not require complicated tools.[103]

A Kenyan PV industry would certainly not be a panacea, however. There are risks involved; Singh warns about the dangers of investing a great deal of capital in PV technology when the market is still evolving because the particular technology chosen for the plant could quickly become obsolete.[104] Nevertheless, even if having a domestic industry would involve a certain amount of risk for producers, the current dependence on imported panels already involves a great deal of risk for consumers, as described above. Compared to other industries, however, the growing rural and urban market, plus the degree to which PV can become an indigenous industry make it a winner with diverse benefits.

Figure 43: PV Production Capacity in Developing Countries

Examples of efforts to establish a domestic PV industry can be found in certain developing countries. In one recent effort, Richard Hansen succeeded in having PV modules assembled locally in the Dominican Republic, but did not pursue the efforts further because he found the enterprise to be uneconomical on a small scale. He felt that it would be too difficult for local workshops to compete against the automated PV assembly facilities in the US, Japan, and Europe.[105]

Nevertheless, prospective Kenyan entrepreneurs might look to the example of Zimbabwe. There, the commercial company Solarcomm had been installing solar systems using imported panels since the early 1980s.[106] Faced with growing demand for small-scale (less than 50 Wp) home systems, however, the company saw an opportunity and purchased the necessary laminating equipment in 1988. After importing polycrystalline cells from Kyocera in Japan, Solarcomm assembled and encapsulated the cells into modules ranging from 2 Wp to 50 Wp (though they now focus on the larger modules). Its output climbed steadily from the start: 32 kWp in 1989, 68 kWp in 1990, and 78 kWp in 1991. Although shortages of foreign exchange have prevented Solarcomm from reaching its rated capacity of 180 kWp, the PV market in Zimbabwe continues to expand and at least 3000 home systems have been installed around the country. Since a much larger market already exists in Kenya, it is certainly possible that some sort of manufacturing facility could be established that would be large enough to enjoy economies of scale, thus overcoming the problems experienced by Hansen.

Other difficulties may remain. The quality of the Solarcomm panels has not been consistently good. Also, their inability to keep costs down is threatening their future because their panels are priced at levels much higher than the competitive world market.[107] Even the major PV producers, China and India, have suffered production problems. The entry of poor quality PV modules into the Kenyan market could potentially do more to harm the market through damaged reputation than to help it. This has caused some observers such as Hankins to call for a "basics first" approach: help Kenya improve the quality of its solar batteries, lights, and other balance-of-system components before venturing into PV production.[108]

Nonetheless, domestic production could well lie in Kenya's future. The advantages of avoiding tariffs and the allure of the large internal market indicate that Kenya may soon be ready to support a PV industry. Quality and cost issues could conceivably be addressed under some of the solutions mentioned above, which might allay the worries of skeptics.

Conclusion

The history of alternative energy research, development, and dissemination reads as a litany of models of the dissemination of new technologies, with diverse and excited claims about the substitution of renewables for fossil fuels. Models of every kind abound, with goals ranging from "induced innovation" to "rapid fossil fuel replacement" to "green future" to "CO_2 neutral." The great majority of these efforts, however, have yielded very little insight into how to foster a truly different energy future.

As we argued previously, an obvious role for development organizations, public or private, interested in the further dissemination of PV and other 'green' technologies is to concentrate more systematically on the small-scale rural market. Training to foster local technical expertise coupled with credit or other financing schemes, coupled yet again with demonstration sites and informational meetings could integrate and solidify the critical components of this market. Just as Grameen Banks targeted each of the important areas of rural poverty: access to funds; economic development opportunities; and social structures to encourage sensible loan utilization and repayment -- so too could integrated rural PV efforts. Programs of this type require extensive local networks to implement, and are, by definition, not well managed on a top-down basis. With the economic, environmental, and social benefits of increased rural affluence and prosperity so striking, the lesson should be clear: national and international aid and development agencies must adapt *their* operations to the emerging local energy requirements. Successful examples include the Small Grants Program of the UNDP/World Bank Global Environment Facility, but this does not go nearly far enough. Support for small-scale development requires local partnerships to be supported with training resources and funds on a long-term basis. Further, individual projects managed through multinational institutions do not foster local energy infrastructures. A basic investment in technical training, from workshops for unemployed electricians, to research leading to advanced degrees, to the inclusion of local NGO's, must all be seen as central to the process.

But the Kenya case provides tangible evidence for a practical route to the adoption of renewable energy technologies. This approach is based on matching the product to meet a pre-existing demand, training enough locals to install and service the product, and making it the least expensive alternative available. This technology transfer has succeeded because concerned individuals and organizations worked with Kenyans for years to lay the foundation, and then economic factors propelled it forward. Above all, it should be noted that environmental considerations alone were not enough. The environmental technology only diffused when it became economically advantageous and served pressing development needs. Any efforts to advance energy or environmental technologies outside of this development and economics context are bound to suffer setbacks. But those that work within a development and economic framework may well succeed and -- like PV in Kenya -- make a concrete step towards sustainable development.

Acknowledgments

Without the kind assistance and support of a great number of researchers and community groups this study would have been impossible. First and foremost, Mark Hankins was tremendously generous with his time and material on the photovoltaics industry in East Africa, while Stephen Karekezi provided leads to important material, much needed feedback, and logistical support in tracking field locations and in evaluating the dissemination of new technologies in Africa generally. We would like to thank Clint Andrews and Dennis Anderson for comments. Professor R. O. Genga, Dr. B. O. Kola, and Dr. R. Raturi of the Physics Department at the University of Nairobi provided invaluable logistical support and encouragement, while the physics students Joseph Muliaro Wafula, Lona Ndjeli, and Moses Akubia each contributed to the identification of important field sites.

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[1] Gregory and McNelis.
[2] Hankins (1993), p. 1.
[3] Shepperd and Richards, p. 5.
[4] Gregory and McNelis.
[5] Gregory and McNelis.
[6] Zweibel, K. and Barnett, A. M. (1993).
[7] Barlow *et al.* and Gregory and McNelis.
[8] Gregory and McNelis and Barlow *et al.*
[9] World Bank (1992), p. 123, as cited in Barozzi and Guidi, p. 7. In fact the 0.1% is conservative by almost a factor of 10 over most large PV-grid efficiencies.
[10] Anderson, D. and Ahmed, K. (1994) The case for a solar initiative (World Bank: Washington, DC), p. 2.
[11] Shepperd and Richards, p. 2.
[12] Mark Hankins, interview July, 1994. Note that this number reflects only small-scale,privately-bought PV systems. Kenya has an equally large (in terms of power) market for large-scale, donor-funded PV systems. This "donor market" is not the focus of this study.
[13] Kelley, A. C. and Nobbe, C. E. (1992).
[14] Karekezi (1994), p. 1.
[15] Williams, R. H. (1994) reference for polycrystalline figure.
[16] Hankins (1994), p. 5; Karekezi (1994).
[17] Hall, D. O. and Mao, Y. S. (1994).
[18] Karekezi (1994), p. 5.
[19] Barozzi and Guidi, p. 6.
[20] Central Bureau of Statistics, p. 143
[21] Barozzi and Guidi, p. 6.
[22] Othieno, p. 407.
[23] Central Bureau of Statistics, p. 148.
[24] Karekezi (1994), p. 6 and Central Bureau of Statistics, p. 149.
[25] Karekezi (1994), p. 6.
[26] Karekezi (1994), pp. 6-7.
[27] Central Bureau of Statistics, p. 150.
[28] Masakhwe, p. 66.
[29] Masakhwe, pp. 66-7.
[30] "Shamba" being the Swahili term for small, rural, farm.
[31] Hankins (1990), p. 71.
[32] Hankins (1992), p. 91.
[33] Hankins (1990), p. 72.
[34] Hankins (1993), p. 33.
[35] Hankins (1993), p. 33.
[36] Masakhwe, p. 68.
[37] Hankins (1990), p. 74.
[38] Author's interviews with solar companies, July-August 1994.

39 Hankins (1992), p. 94.
40 Hankins (1993), pp. 34-35.
41 Hankins (1993, p. 35) also notes that the performance of foreign light fixtures is hardly uniform; American and British lights tended to perform better than the less expensive imports from China.
42 Curry, R. (1992).
43 Williams, R. H. and Terzian, G. (1994).
44 World Bank (1994), and Central Bureau of Statistics, p. 149.
45 Karekezi and Turyareeba, 1994.
46 Shepperd and Richards, p. 1.
47 Singh, p. 69.
48 Hankins (1994), p. 25.
49 Interview with Swaleh Imu, 27th June 1994.
50 Hankins (1994), p. 25.
51 Central Bureau of Statistics, p. 58. Wage figure is for 1993 and dollar equivalent is calculated using the average 1993 exchange rate of about 69 KSh per dollar.
52 Hankins (1993), p. 6.
53 Walubengo and Onyango, p. 43.
54 In a 1992 report, the US Office of Technology Assessment found that, assuming a grid extension cost of $4500 per km and a PV cost of $0.50 per kWh, the break-even distance is 13.9 km; for a cost of $10,000 per km, the break-even point is 6.3 km. (Barozzi and Guidi, p. 7) Since the cost of grid extension in Kenya is approximately $8200 per km, we can estimate a break-even point of 8.8 km by interpolation. Over 80% of the households surveyed lay closer than 8.8 km from the grid, with several being less than 500 meters away.
55 Ranganathan, V., editor (1992).
56 Hankins (1994), p. 25.
57 Walubengo, "The Socio-Economic Impact of Electricity," p. 73.
58 Not only did the Kenyan Shilling drop in value on international markets from roughly 30 Ksh/$ to 80 Ksh/$, but inflation more than doubled during that period as well.
59 Acker, R. and Kammen, D. M. (1994) Unpublished data on X companies.
60 The Forex-C market, in fact, was subject to tremendous abuse that, in all likleihood, further hastened the devaluation of the Shilling. Forex-C certificates were intended to reward Kenyan business ventures that brought hard currency into the country. In practice, however, the Forex-C market could, at times, net the 30% of the value of the imported currency in ther form of traded certificates. Currency exchange thus became the best business in town, and elaborate schemes were devised by non-Kenyans to trade in the market. The resulting transactions often netted large profits to those with access to foreign currency with little new currency actually entering the Kenyan economy.
61 Hankins, personal communication, November 18, 1994.
62 Newspapers even carried photographs of eligible voters lining up to receive their 500 KSh bills.
63 Hankins (1994), p. 7.
64 Karekezi (1994), pp. 87-88.
65 Hankins (1994), p. 7 and Karekezi (1994), p. 88.
66 It should be noted, however, that Hankins (1993) describes PV module prices as falling "significantly" and system sales as increasing "markedly" after the 1986 tariff removal. (Hankins (1993), p. 33)
67 Central Bureau of Statistics, pp. 58 and 60.
68 Using the average 1993 market exchange rate of 69.1 KSh/$. Central Bureau of Statistics, p. 58.
69 Interview with Swaleh Imu, 27th June 1994.
70 Barozzi and Guidi, p. 7
71 Hankins (1994), p. 5.
72 Systems paid for as "package deals" are not included in this breakout. Wiring and installation are grouped together here because most consumers paid for them together. Also, percentages do not quite add to 100% because of the exclusion of "package deals" data.
73 See Karekezi (1994), pp. 90-6; Zimbabwe Ministry of Energy and Water Resources and Development, pp. 54-62; Tanzania Industrial Studies and Consulting Organisation, pp. 27-31.

74 Hankins (1991), p. 29.
75 Hankins (1991), p. 27.
76 Hankins (1990), pp. 27-29.
77 Hankins (1991), p. 29.
78 Hankins, personal correspondance, November 18, 1994.
79 A fluorescent tube typically costs 10 or 20 times an incandescent bulb. (Hankins (1991), p. 43)
80 Hankins (1991), pp. 40-41.
81 Hankins (1991), pp. 40-41.
82 Hankins (1990), p. 17.
83 Hankins (1990), p. 22.
84 Hankins (1990), p. 17.
85 Hankins (1990), p. 20.
86 Hankins (1991), p. 22.
87 Hankins (1991), p. 15.
88 Foley, G. (1991).
89 Kammen, D. M. and Fayemi Kammen, B. (1992).
90 Sometimes called "paraffin" in British English.
91 It has also been suggested (Singh, pp. 73-74) that Kenya invest in photovoltaics as a national security measure that will reduce its excessive dependence on petroleum imports. Again, however, this argument seems misplaced since PV is a highly imperfect substitute for oil and PV adoption will do little to reduce demand from the industrial and transportation sectors for oil.
92 Grubb, M. J. (1990).
93 Foley, G. (1991).
94 Barozzi and Guidi, p. 12.
95 Shepperd and Richards, p. 33.
96 Shepperd and Richards, p. 34.
97 Shepperd and Richards, p. 34.
98 Interview with Swaleh Imu, 27th June 1994.
99 Williams, R. H. and Terzian, G. (1994).
100 Barlow *et al.*
101 Rabah, K. V. O. (1994) Personal communication.
102 Hankins (1990), p. 34.
103 Hankins (1990), p. 34.
104 Singh, pp. 73-74.
105 Hankins (1990), p. 35.
106 For details on Solarcomm and the development of the PV market in Zimbabwe, see Hankins (1993), pp. 55-65 and Zimbabwe Ministry of Energy and Water Resources and Development, entire.
107 Hankins, personal communication, November 18, 1994.
108 Hankins, personal communication, November 18, 1994.

Tables and Figures: Acker and Kammen

- Four tables
- Forty three figures

Energy Consumption Patterns (%)

	Oil	Biomass	Hydro & Nuclear	Coal	Natural Gas
World	39	14	3	27	17
Industrialized Countries	45	1	3	28	23
Developing Countries	24	44	2	26	4
Kenya	24	74	2	0	0

Kenyan figures represent 1989 data

Table 1

Duties and Taxes for Photovoltaic Equipment -- 1993

Item	Heading/ Code	Description	Import Duty	VAT	Cumulativ e Tax
Batteries	8507.13.00*	Lead-Acid (automotive)	60%	18%	89%
	8507.20.00	Other Lead-Acid	37%	18%	62%
	8507.30.00	Ni-Cad	37%	18%	62%
Lighting Equipment	8513.10.90	Other Lamps	37%	18%	62%
	8539.31.00	Fluorescent Lamps	37%	18%	62%
Charge Controllers	8536.90.00	Electric apparatus for protecting elec. circuits	31%	18%	55%
PV Panels	8541.10.00	Diodes, transistors	31%	18%	55%
	8541.40.90	PV cells	31%	18%	55%
Pumps	8413.70.00	Other pumps	12%	5%	18%
DC Generating Sets	8502.30.20*	Unassembled	12%	5%	18%
	8502.30.30*	Assembled Solar	12%	5%	18%
	8502.30.90*	Assembled	12%	5%	18%

(* 1992 data used)

Table 2

Effects of a 12V Inverter on Fluorescent Efficacy

Fluorescent Lamp Model	Wattage	Rated Efficacy (Lumens/Watt)	Actual Efficacy with Inverter	Percent of Rated Efficacy
PL-5	5	50	32.3	64.6%
PL-7	7	57	44.6	78.2%
PL-9	9	67	55.9	83.4%
PL-13	13	69	55.1	79.9%
F4T5	4	34	18.9	55.6%
F6T5	6	49	41.0	83.7%
F8T5	8	50	41.7	83.4%
F13T5	13	63	55.3	87.8%

NB: All lamps are Philips models

Table 3

Payback Period for Battery Charging Station (25 KSh/Charge)

Dealer	Size of Panel	Cost (KSh)	Years to Recover Cost
Total Solar	50 Wp	33,200	3.64
Chintu	10Wp + 40Wp	27,800	3.05
Animatics	53 Wp	39,000	4.27
Telesales	48 Wp	30,000	3.29
ESAP	11Wp + 40Wp	34,300	3.76
Botto	47 Wp	40,000	4.38

Table 4

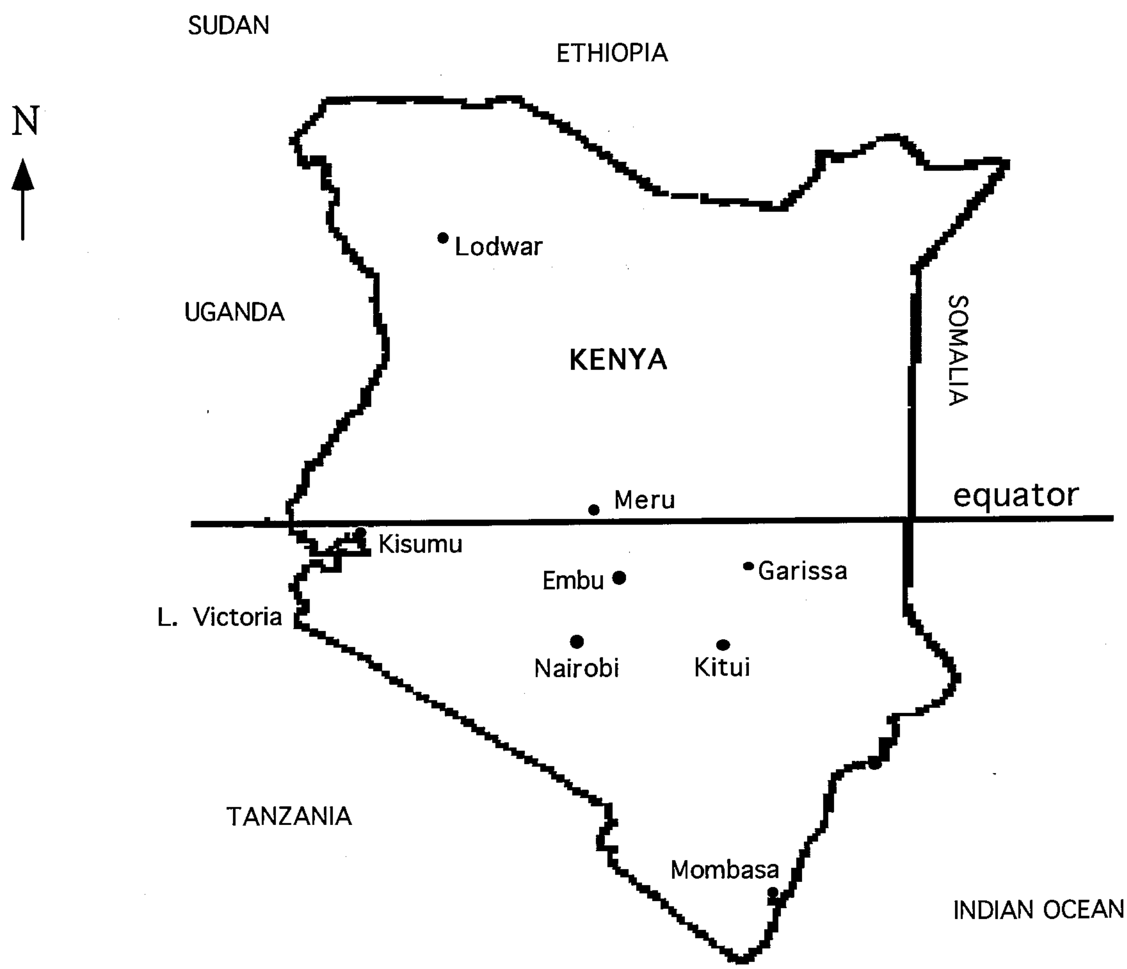
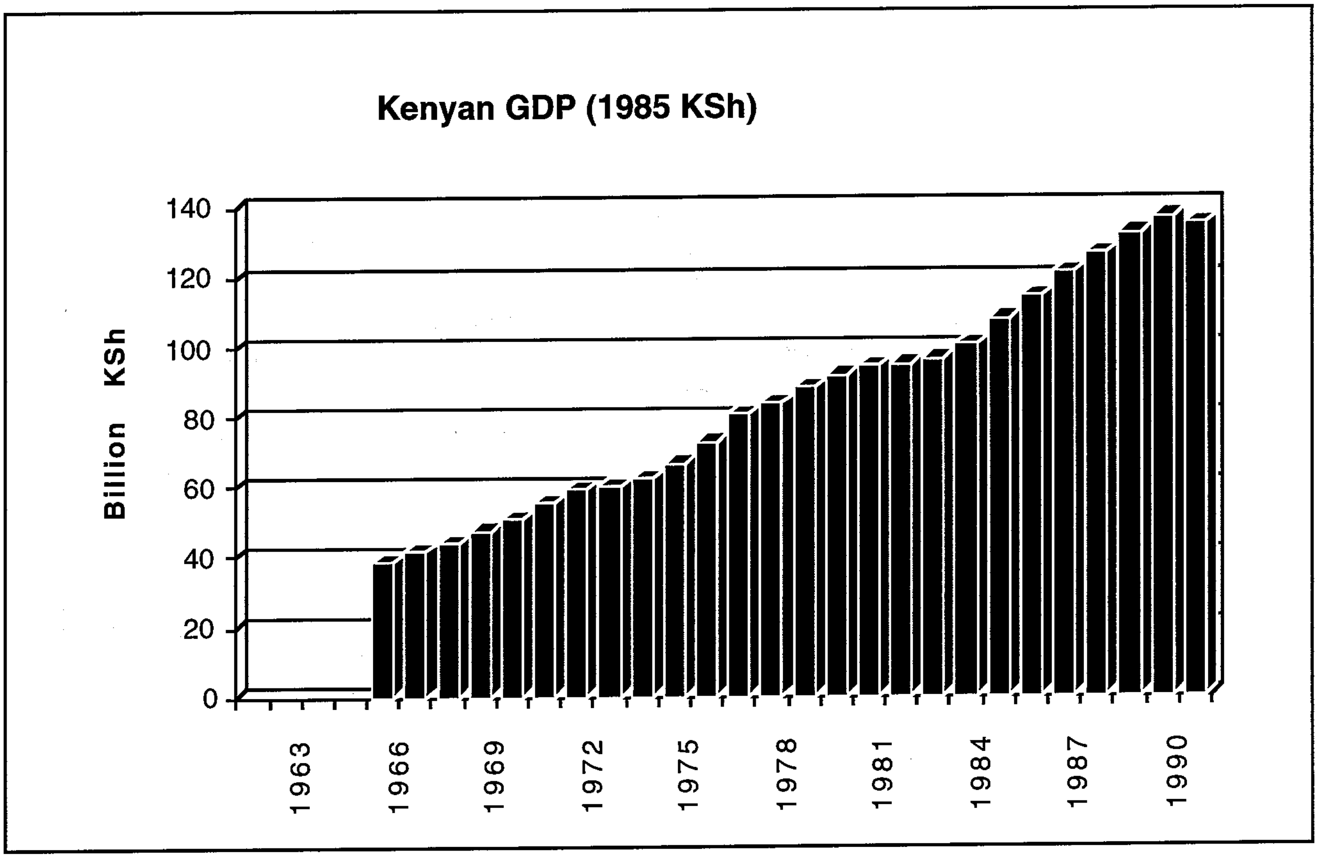


Figure 1: Kenya



Kenyan GDP (1985 KSh)
Billion KSh
140
120
100
80
60
40
20
0
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990

Figure 2

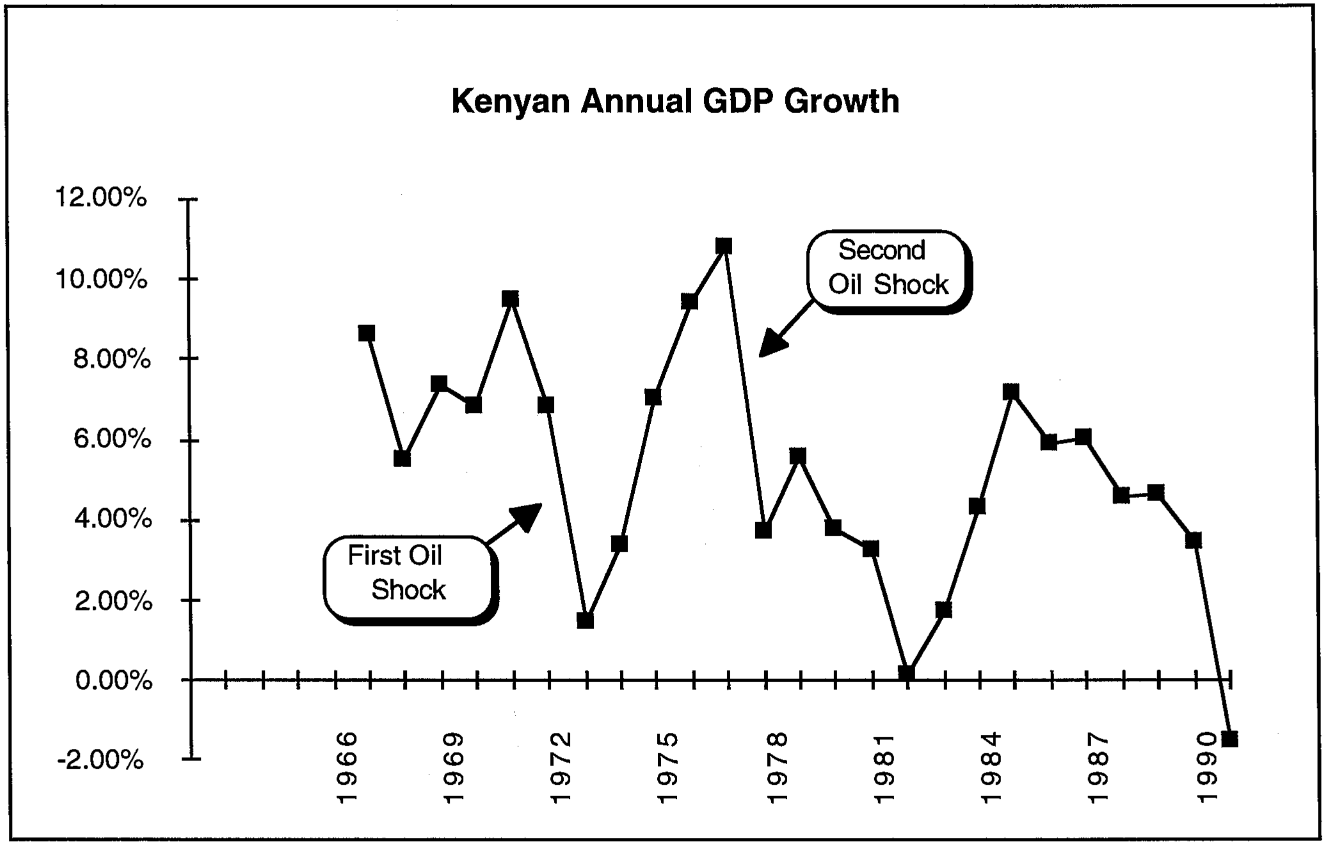

Kenyan Annual GDP Growth
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
-2.00%
1966
1969
1972
1975
1978
1981
1984
1987
1990
First Oil Shock
Second Oil Shock

Figure 3

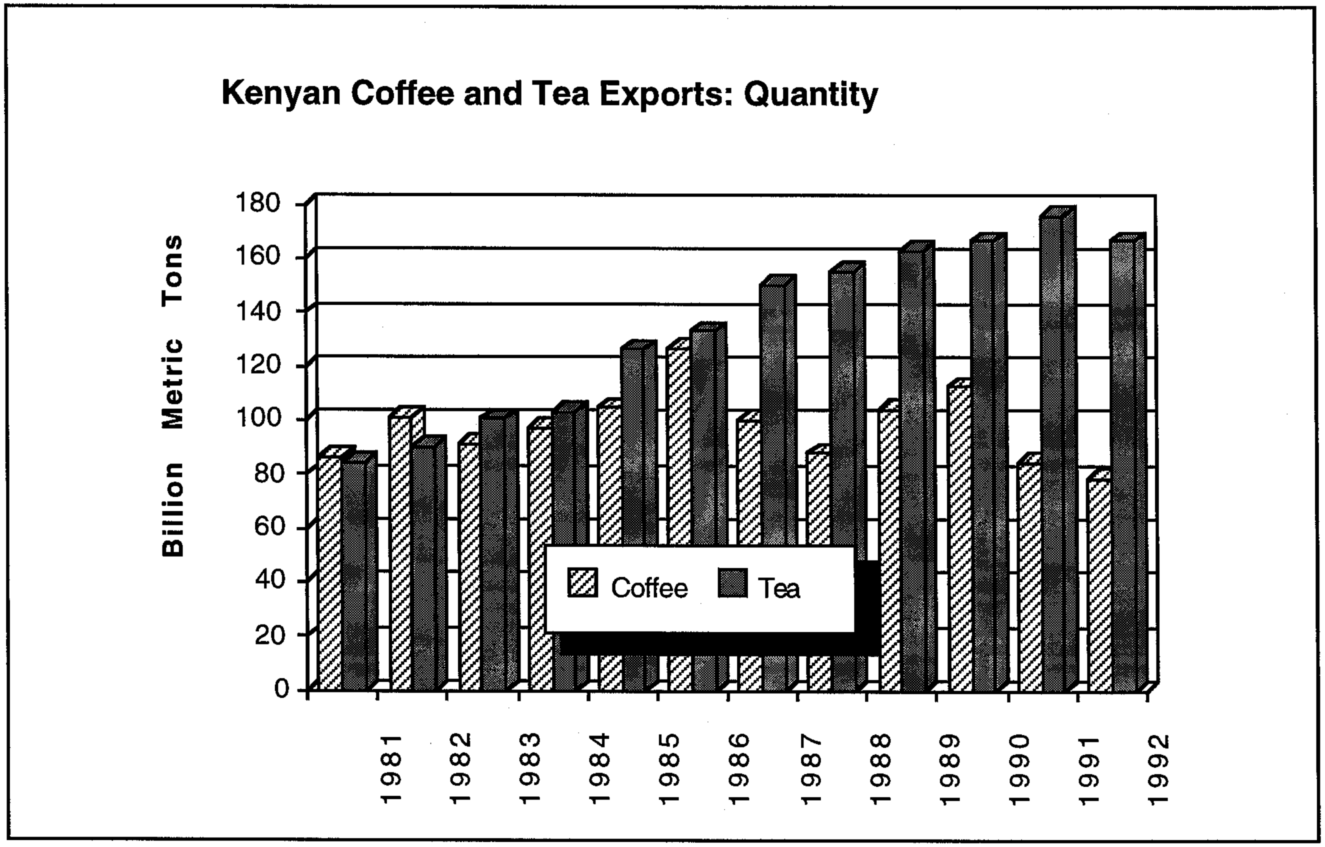

Kenyan Coffee and Tea Exports: Quantity
Billion Metric Tons
180
160
140
120
100
80
60
40
20
0
Coffee
Tea
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992

Figure 4

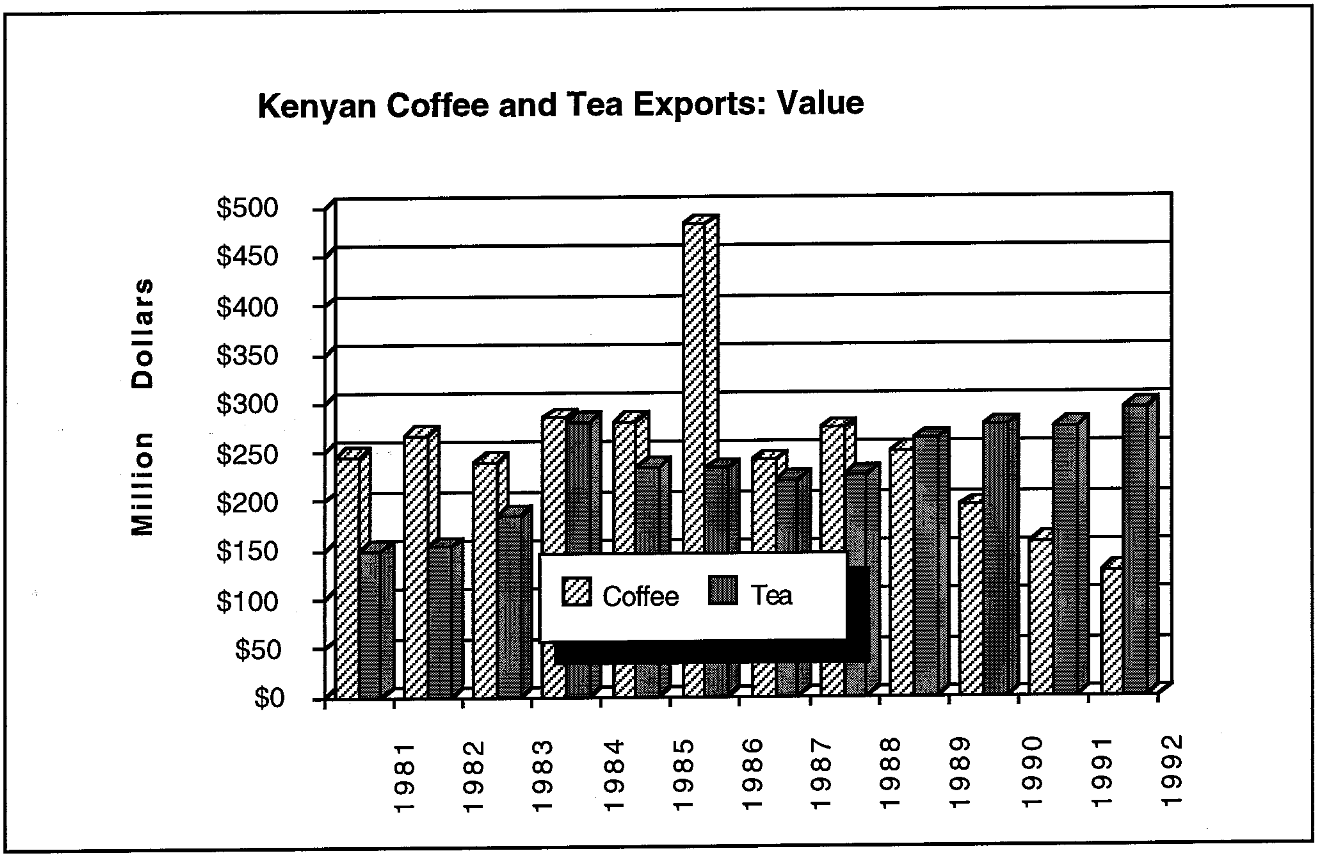

Kenyan Coffee and Tea Exports: Value
Million Dollars
$500
$450
$400
$350
$300
$250
$200
$150
$100
$50
$0
Coffee
Tea
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992

Figure 5

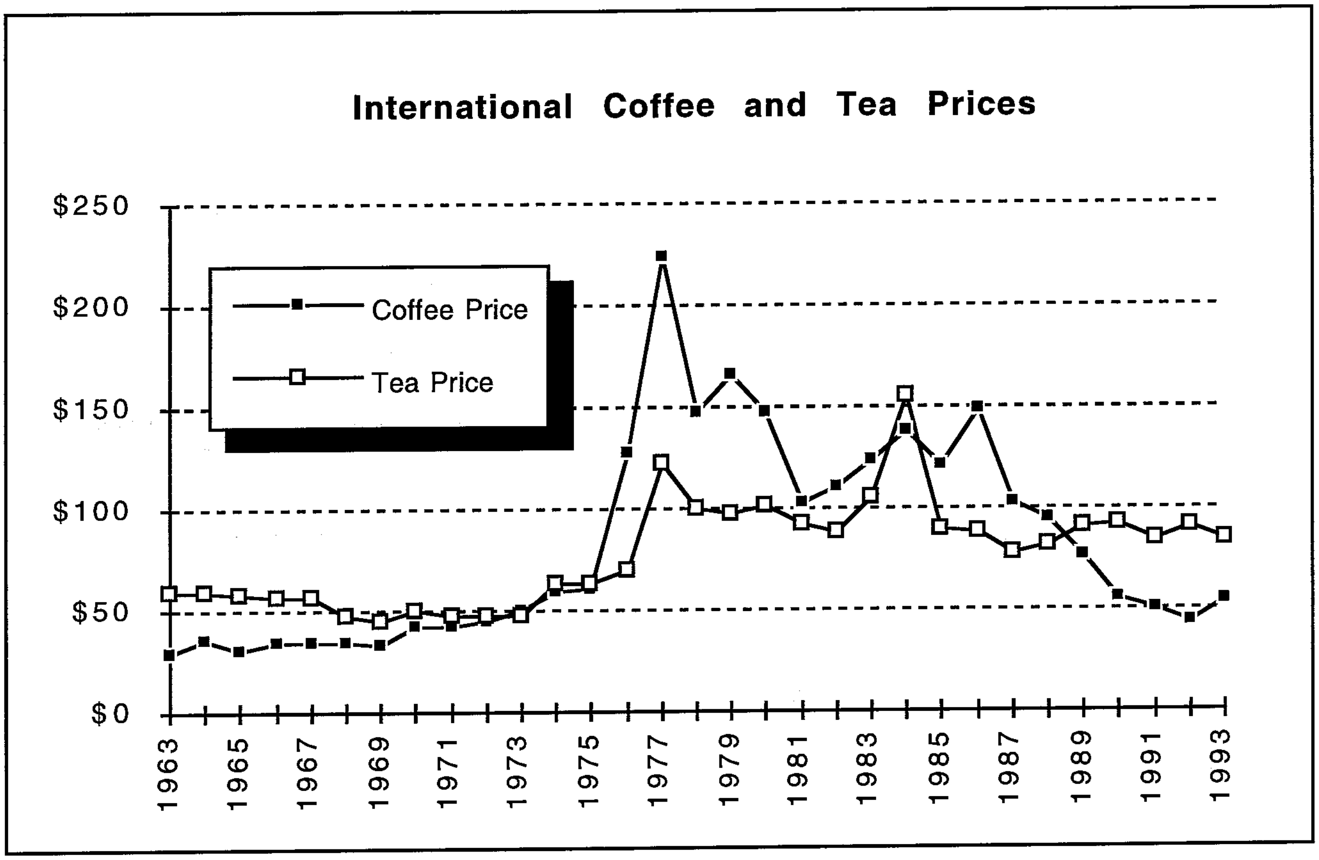

International Coffee and Tea Prices
Coffee Price
Tea Price
$250
$200
$150
$100
$50
$0
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993

Figure 6

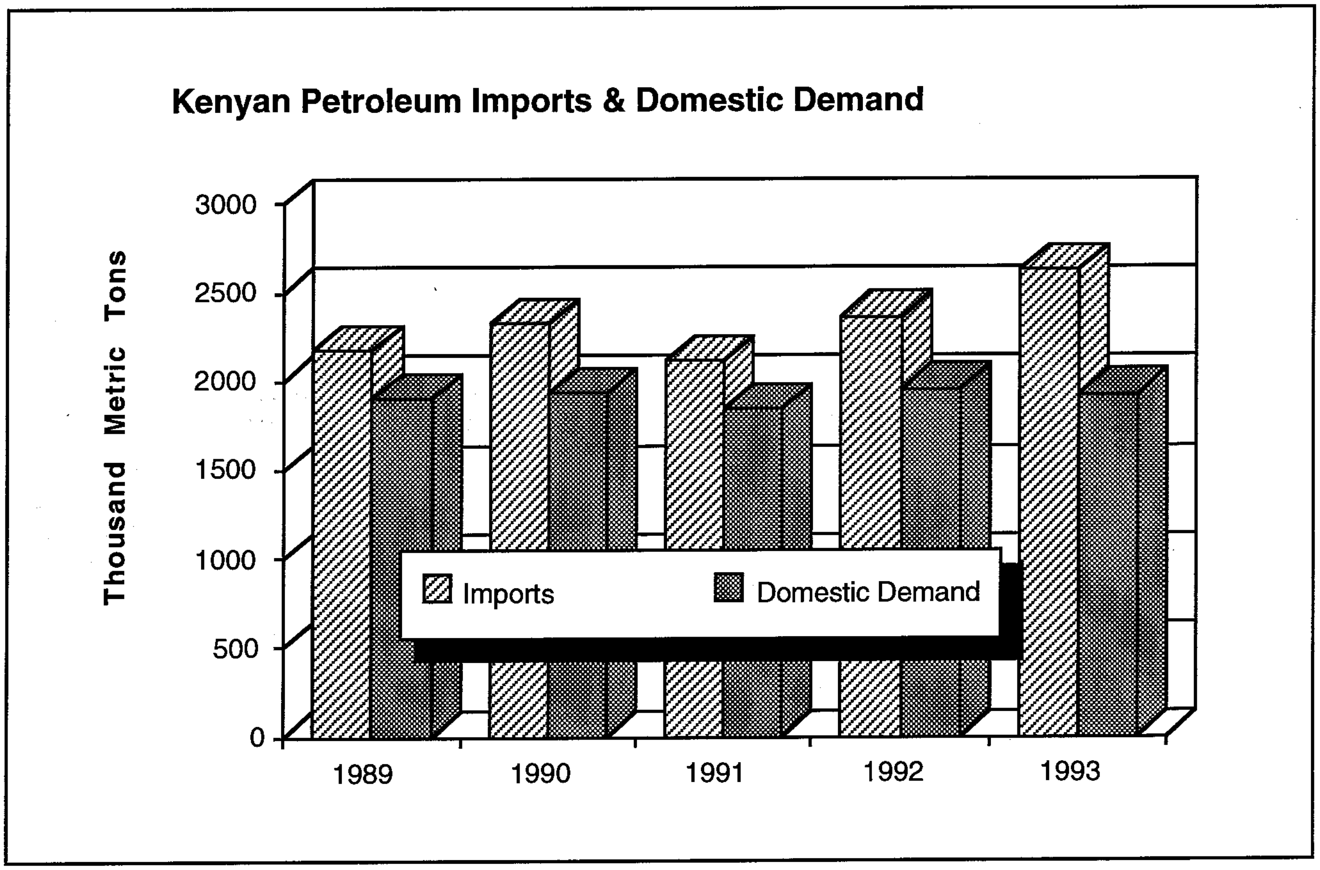
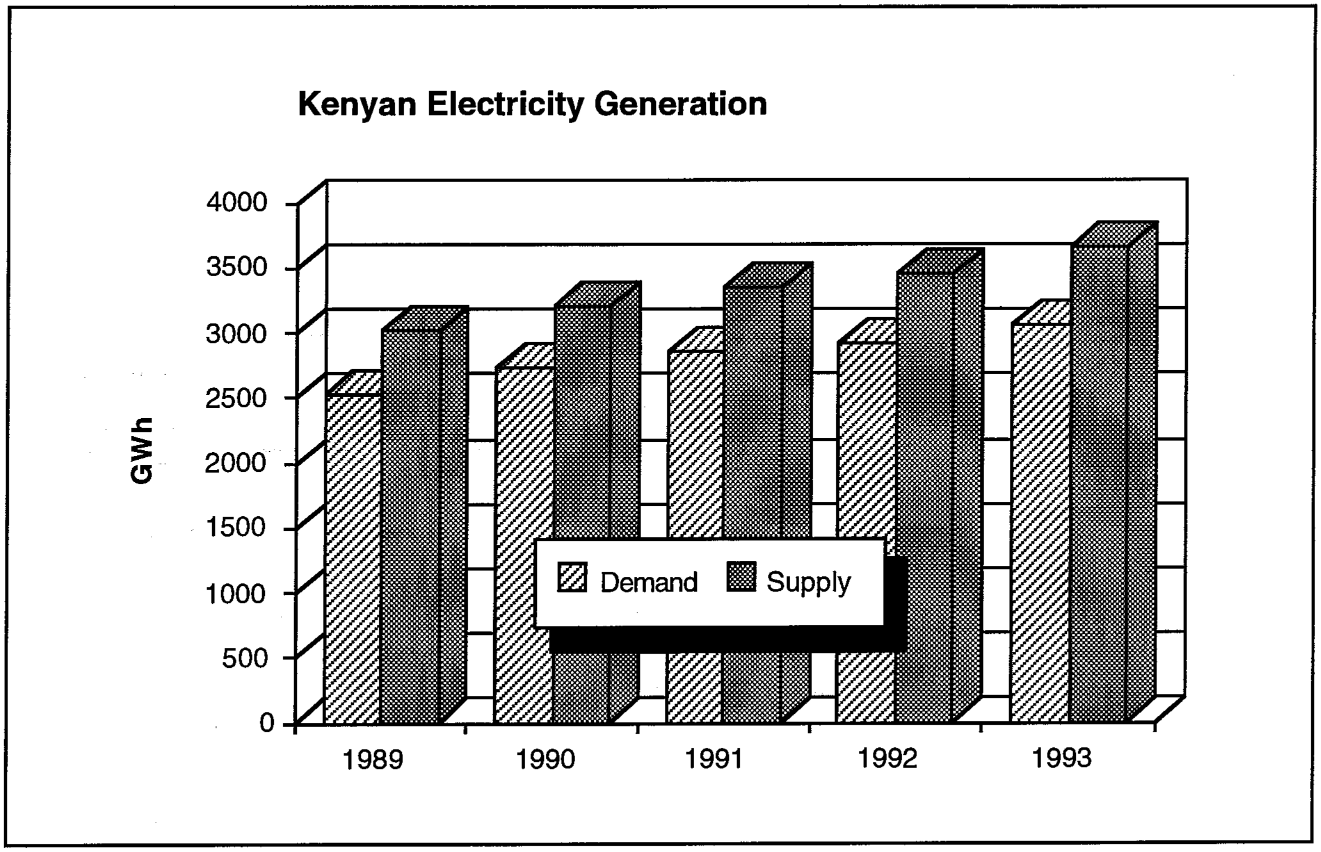

Kenyan Petroleum Imports & Domestic Demand
Thousand Metric Tons
3000
2500
2000
1500
1000
500
0
Imports
Domestic Demand
1989
1990
1991
1992
1993

Figure 7



(difference between demand and supply represents transmission losses and unallocated demand)

Figure 8

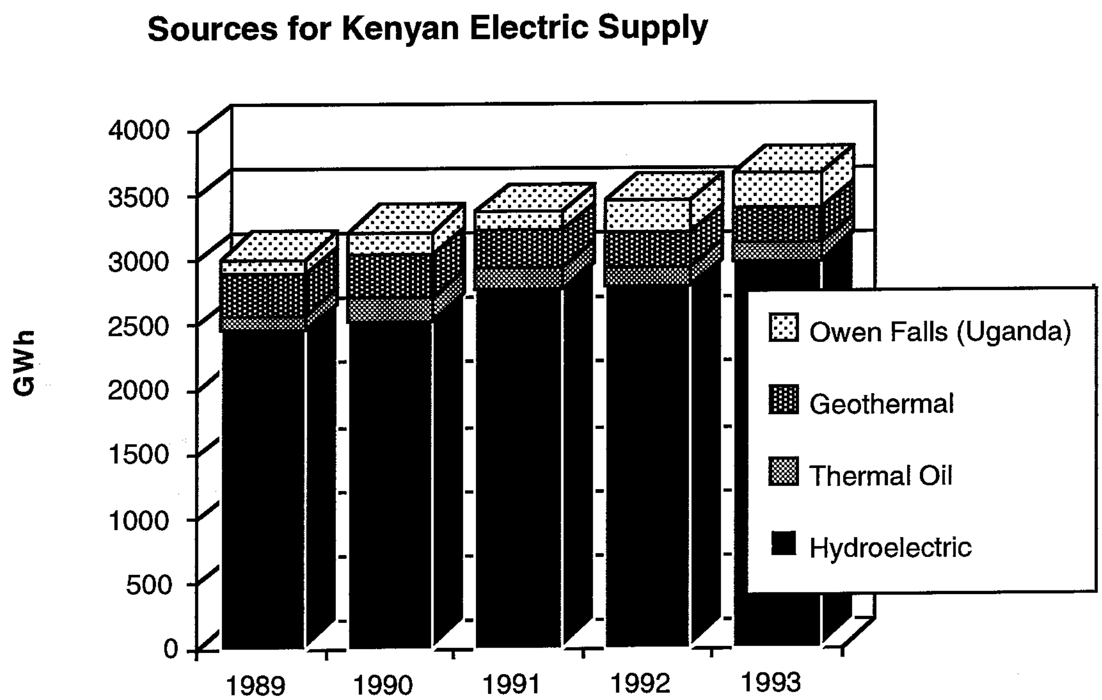

Sources for Kenyan Electric Supply
4000
3500
3000
2500
2000
1500
1000
500
0
GWh
1989
1990
1991
1992
1993
Owen Falls (Uganda)
Geothermal
Thermal Oil
Hydroelectric

Figure 9

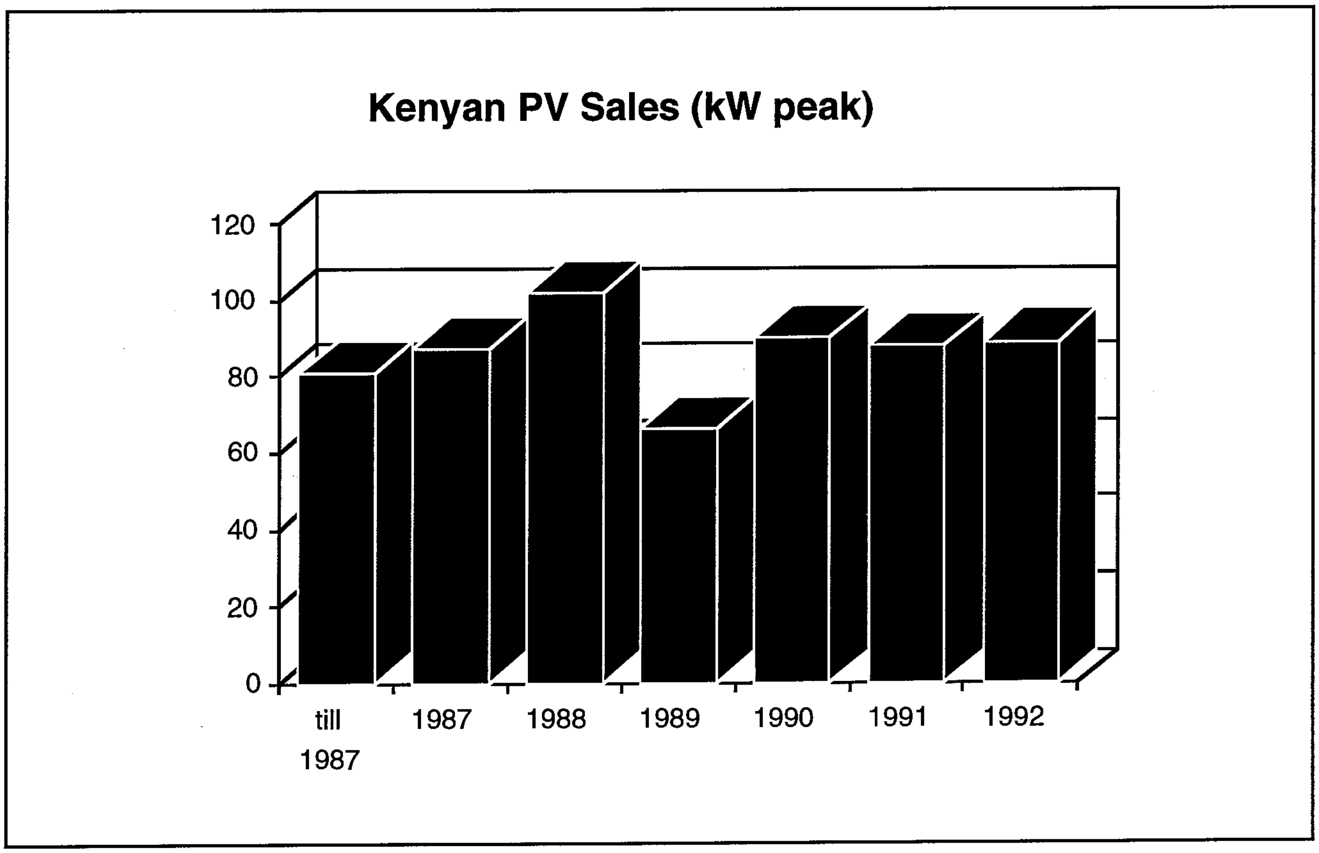

Kenyan PV Sales (kW peak)
120
100
80
60
40
20
0
till 1987
1987
1988
1989
1990
1991
1992

Figure 10

Cumulative and Annual Kenyan PV Sales (kW peak)

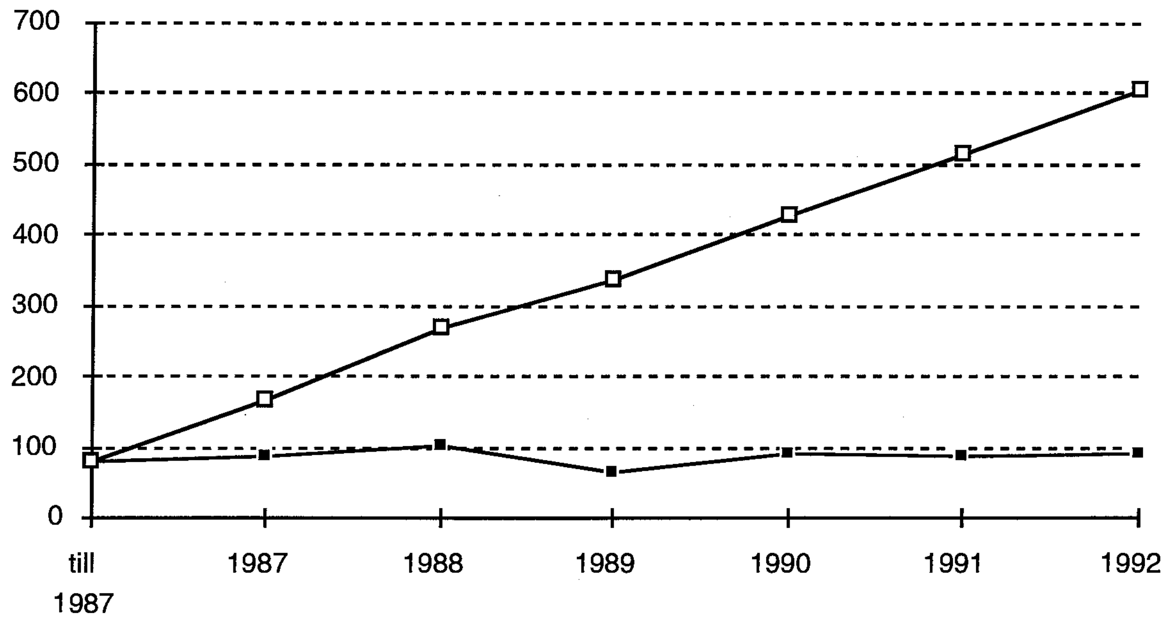
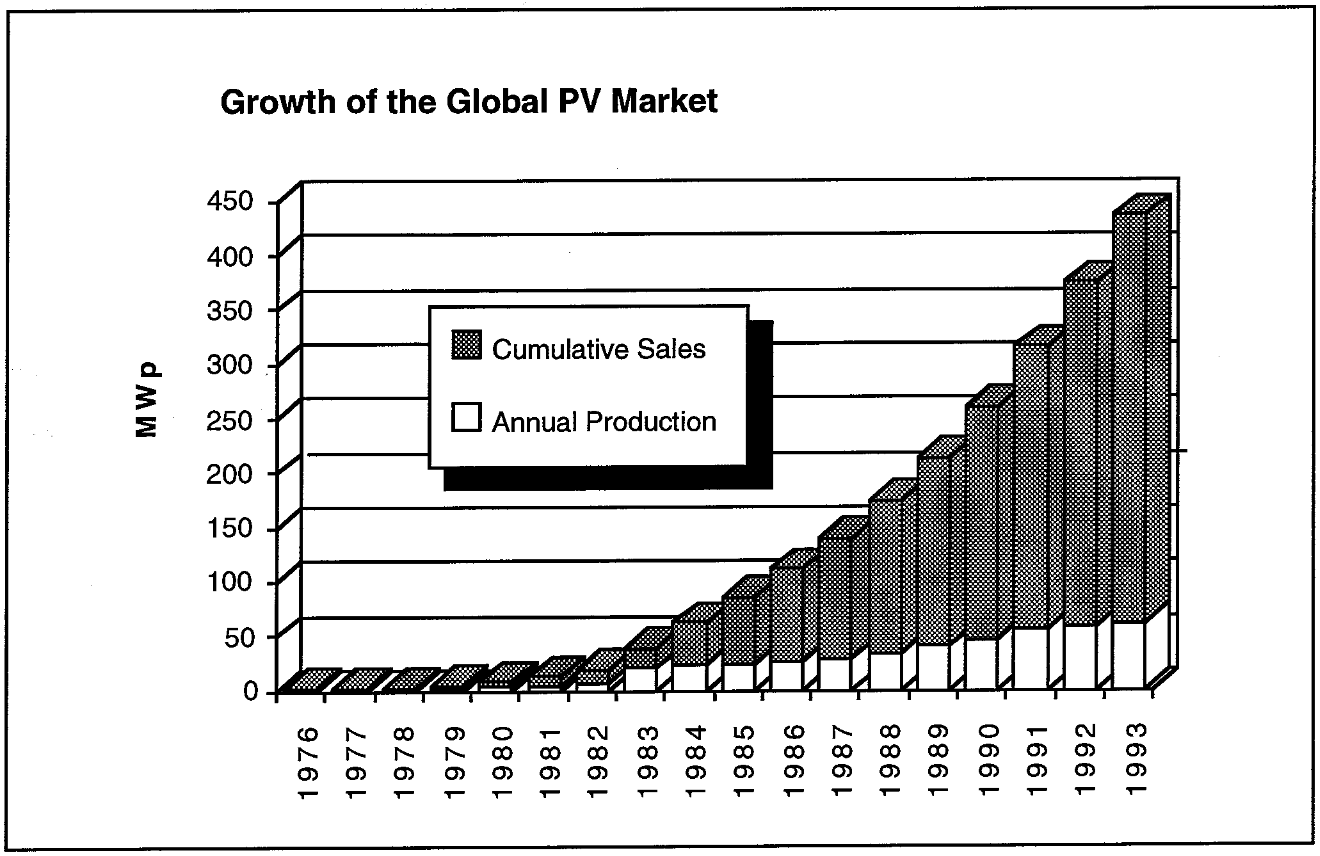


Figure 11



Growth of the Global PV Market
Cumulative Sales
Annual Production
MWp
450
400
350
300
250
200
150
100
50
0
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993

Figure 12

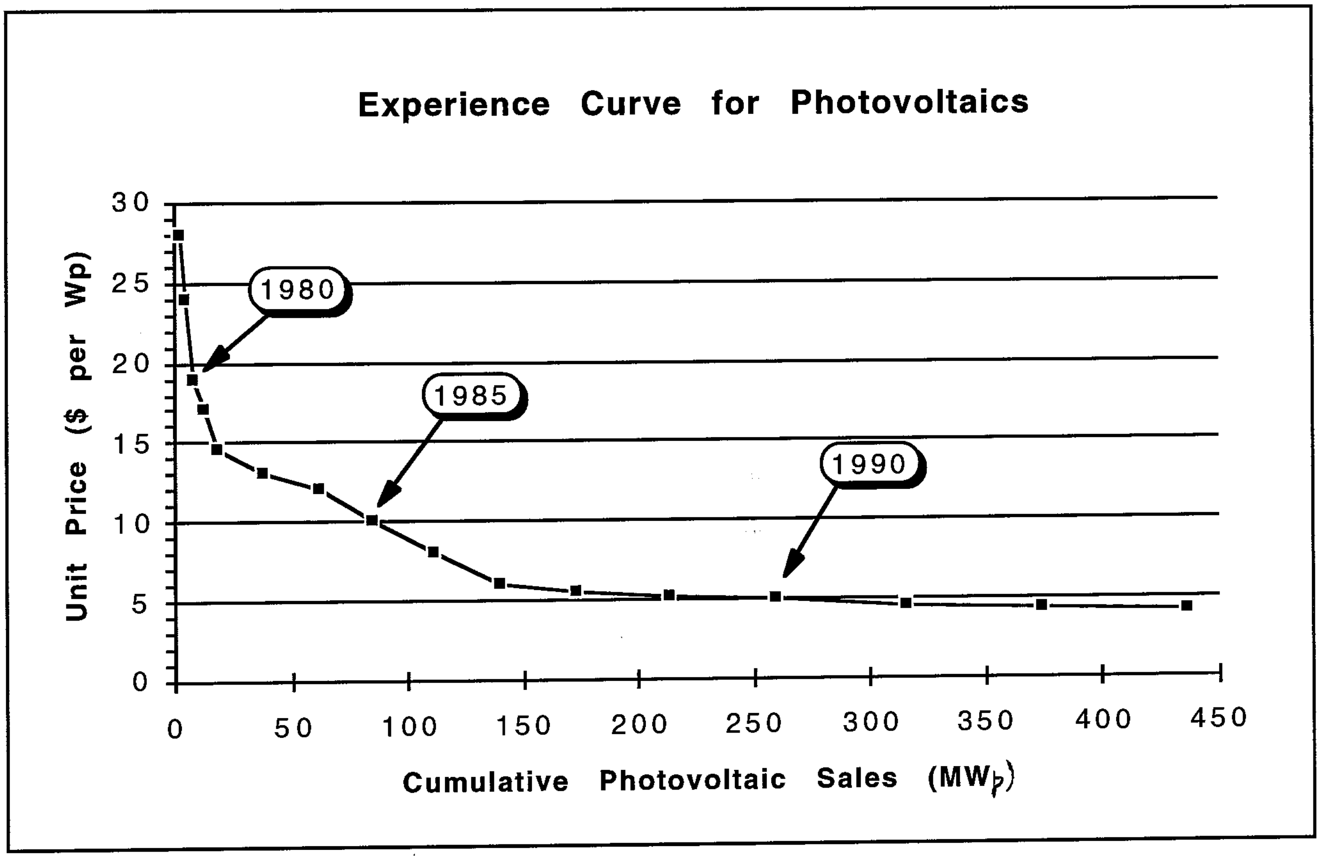
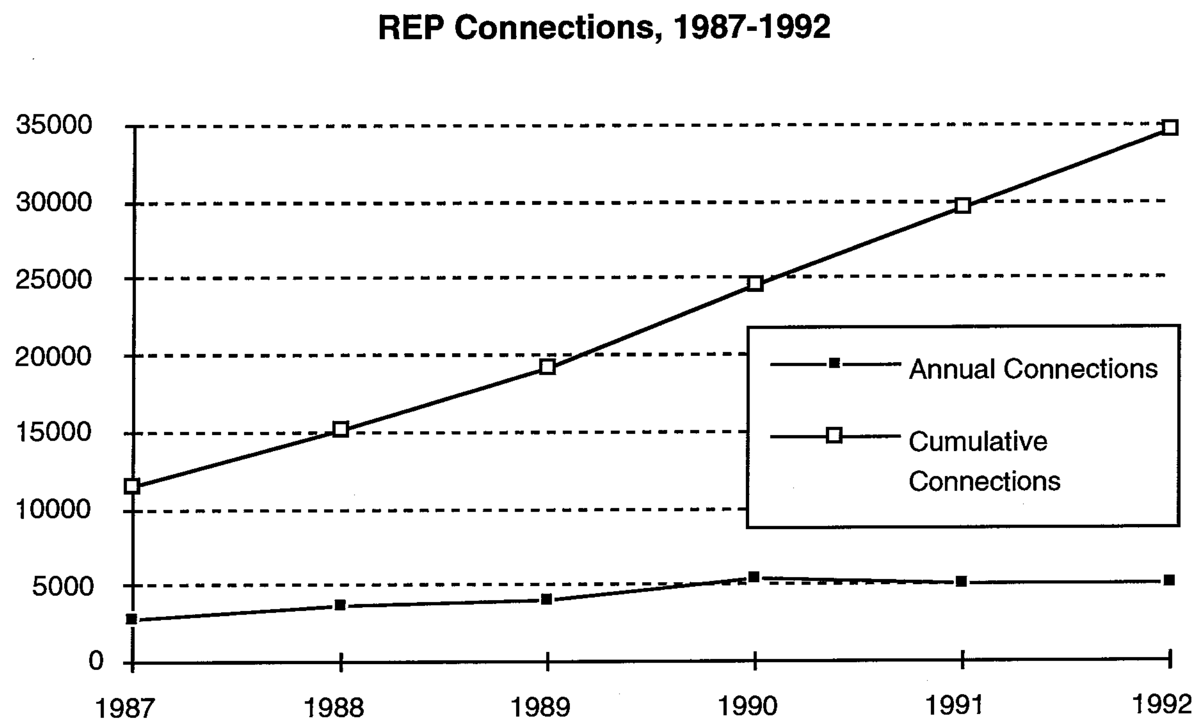

Experience Curve for Photovoltaics
Unit Price ($ per Wp)
30
25
20
15
10
5
0
1980
1985
1990
0
50
100
150
200
250
300
350
400
450
Cumulative Photovoltaic Sales (MWp)

Figure 13



REP Connections, 1987-1992
35000
30000
25000
20000
15000
10000
5000
0
1987
1988
1989
1990
1991
1992
Annual Connections
Cumulative Connections

Figure 14

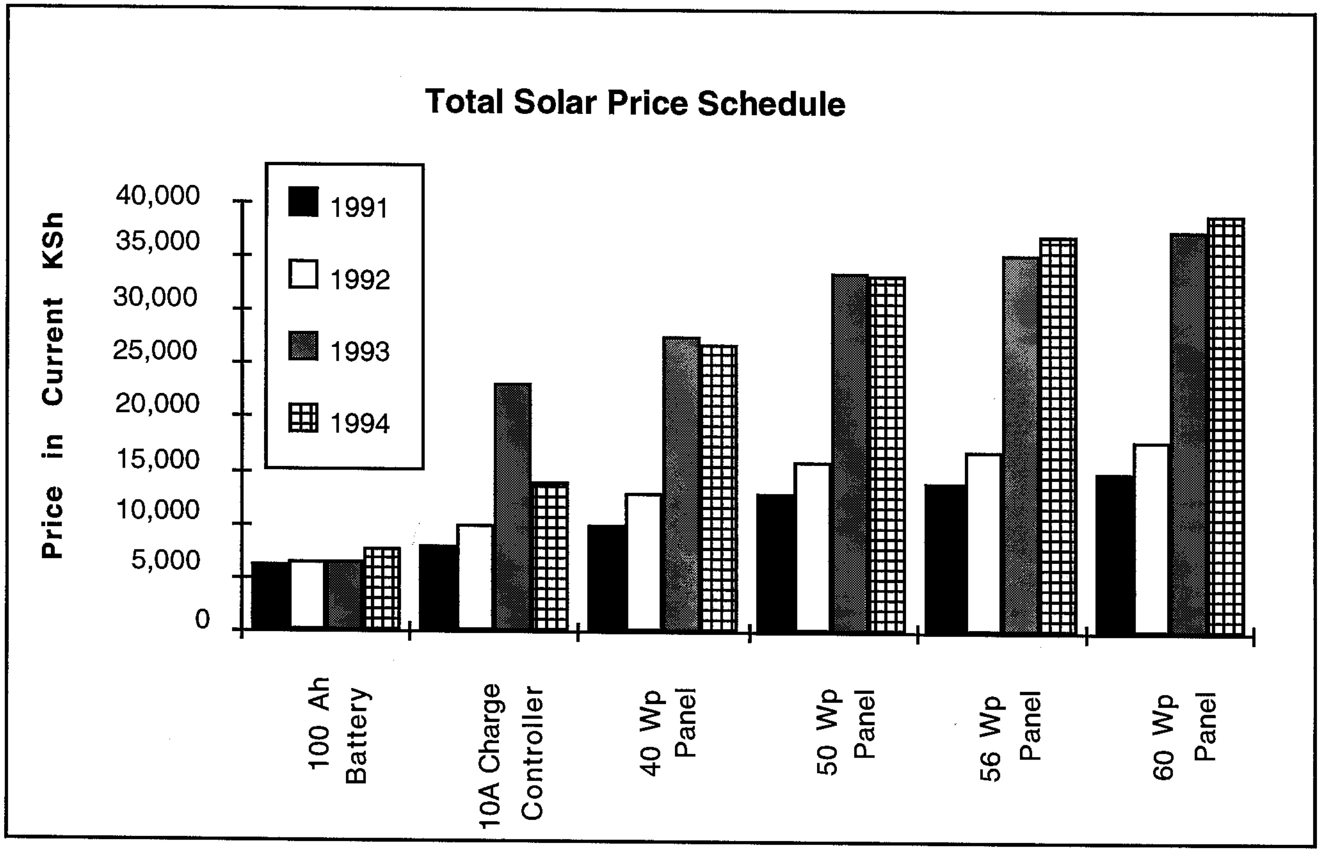

Total Solar Price Schedule
Price in Current KSh
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1991
1992
1993
1994
100 Ah Battery
10A Charge Controller
40 Wp Panel
50 Wp Panel
56 Wp Panel
60 Wp Panel

Figure 15

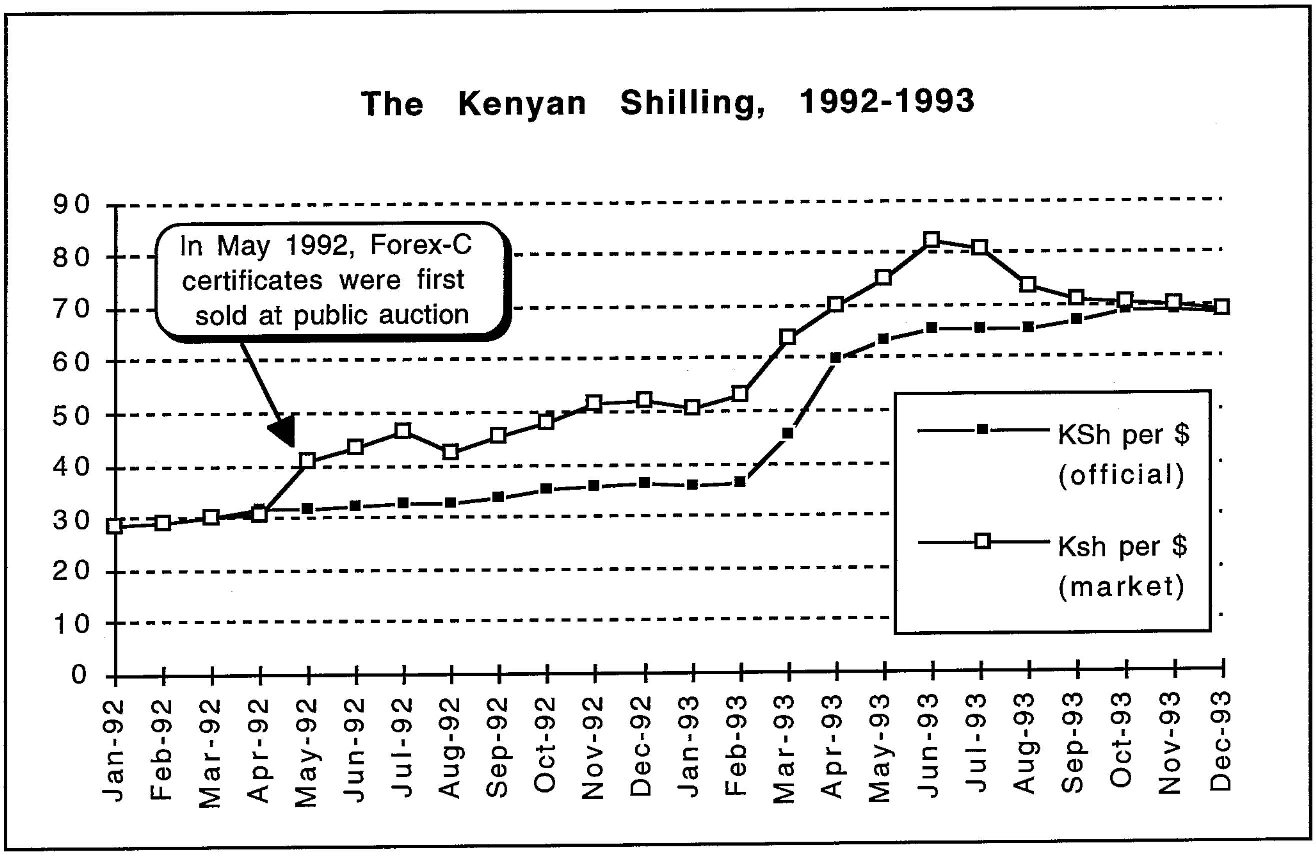
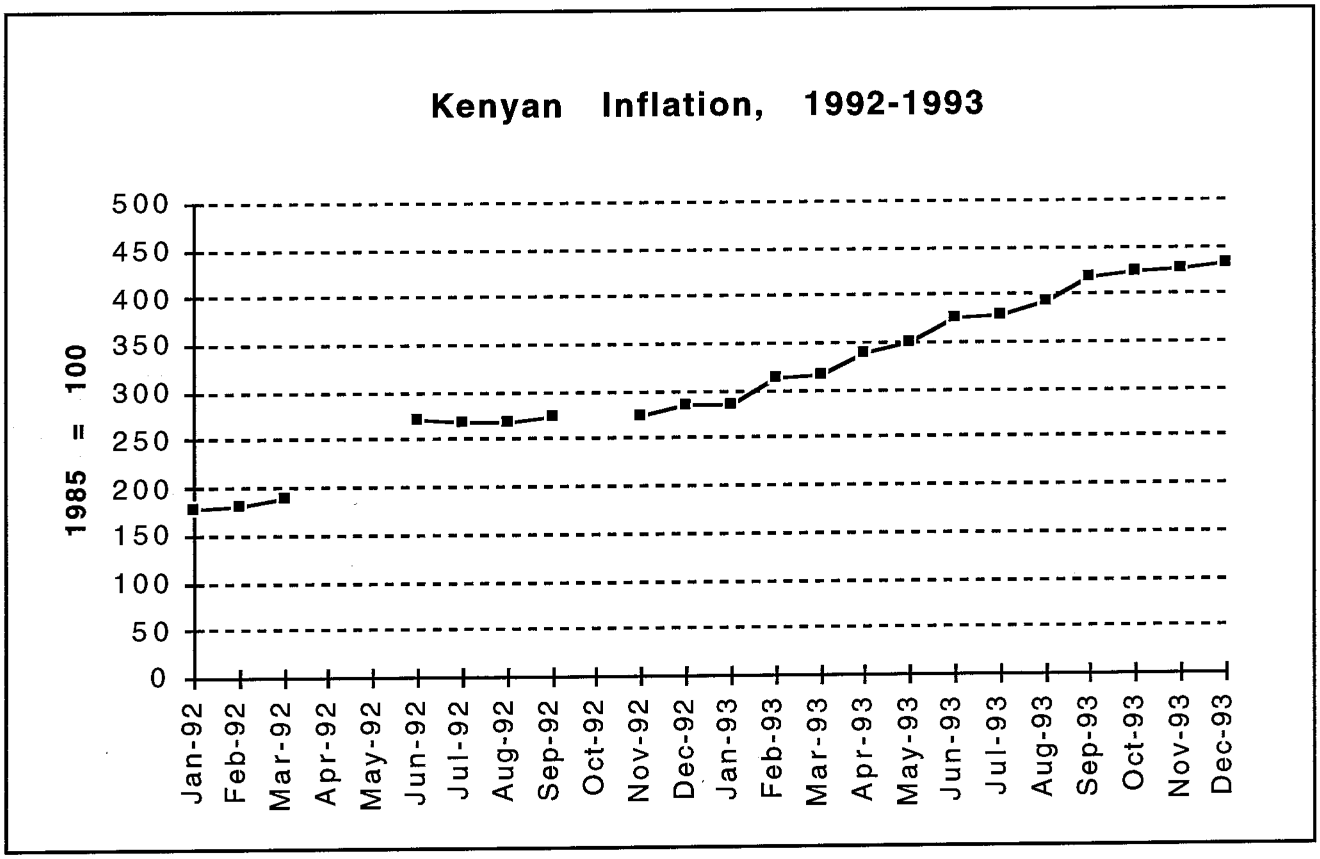
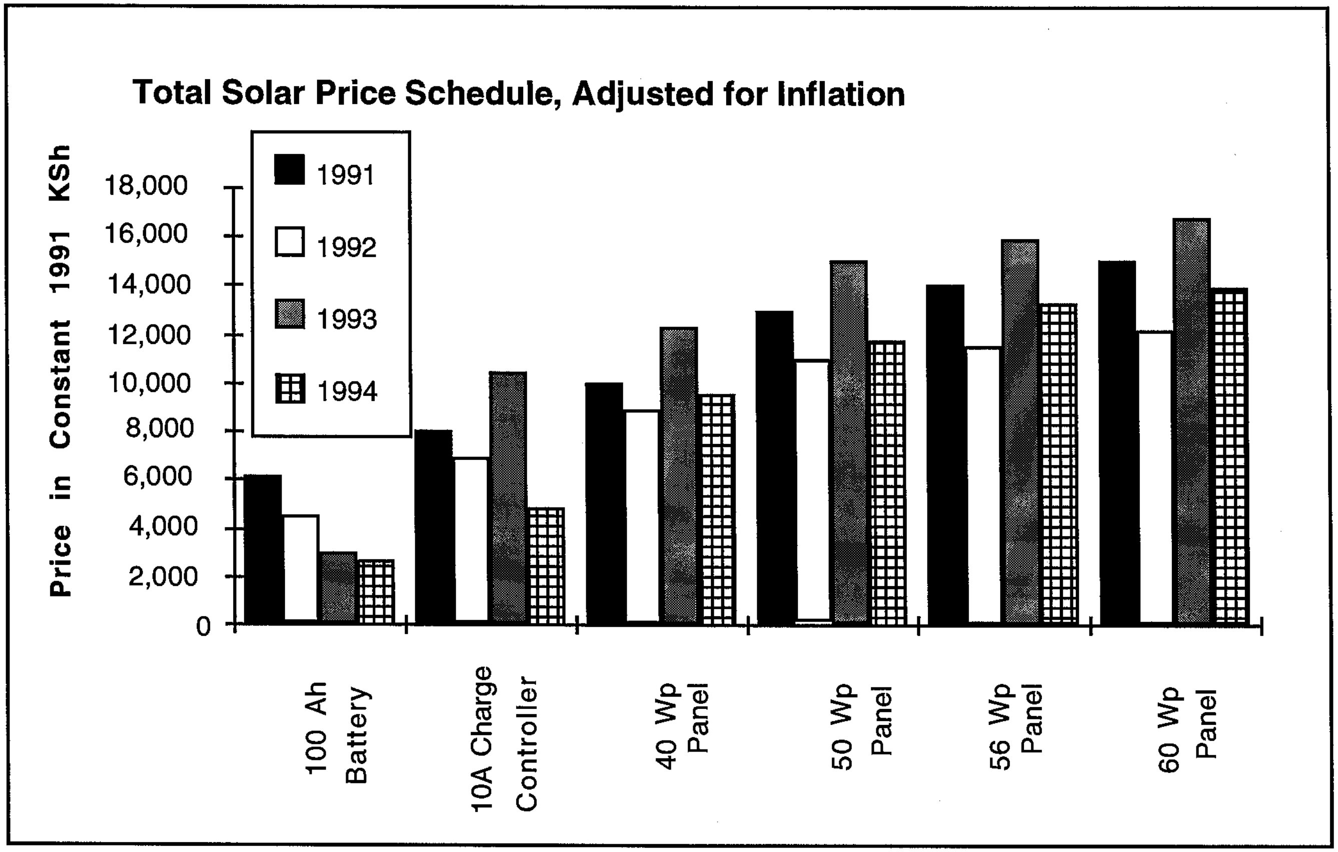

The Kenyan Shilling, 1992-1993
In May 1992, Forex-C certificates were first sold at public auction
KSh per $ (official)
Ksh per $ (market)
90
80
70
60
50
40
30
20
10
0
Jan-92
Feb-92
Mar-92
Apr-92
May-92
Jun-92
Jul-92
Aug-92
Sep-92
Oct-92
Nov-92
Dec-92
Jan-93
Feb-93
Mar-93
Apr-93
May-93
Jun-93
Jul-93
Aug-93
Sep-93
Oct-93
Nov-93
Dec-93

Figure 16



Kenyan Inflation, 1992-1993
1985 = 100
500
450
400
350
300
250
200
150
100
50
0
Jan-92
Feb-92
Mar-92
Apr-92
May-92
Jun-92
Jul-92
Aug-92
Sep-92
Oct-92
Nov-92
Dec-92
Jan-93
Feb-93
Mar-93
Apr-93
May-93
Jun-93
Jul-93
Aug-93
Sep-93
Oct-93
Nov-93
Dec-93

Figure 17



Total Solar Price Schedule, Adjusted for Inflation
Price in Constant 1991 KSh
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1991
1992
1993
1994
100 Ah Battery
10A Charge Controller
40 Wp Panel
50 Wp Panel
56 Wp Panel
60 Wp Panel

Figure 18

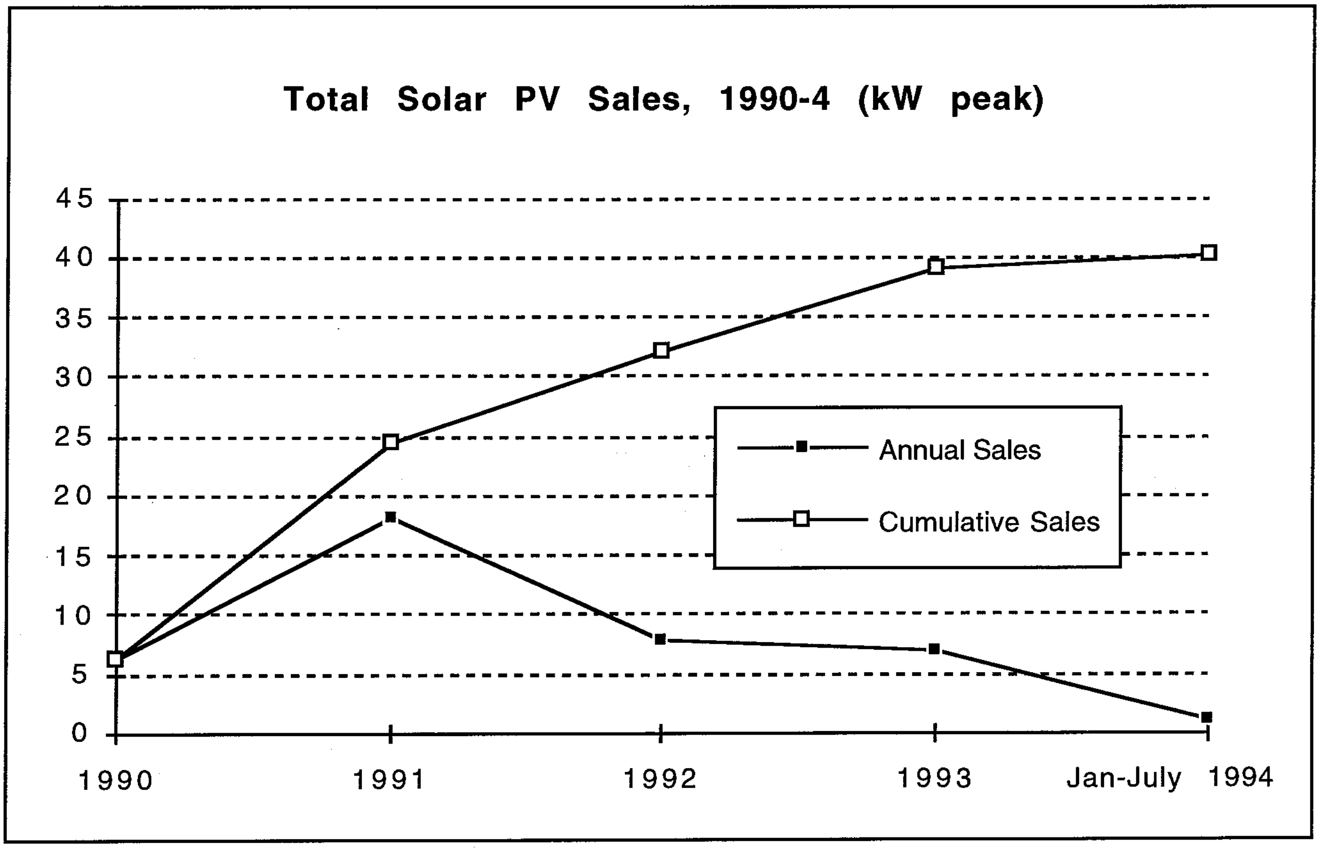

Total Solar PV Sales, 1990-4 (kW peak)
45
40
35
30
25
20
15
10
5
0
1990
1991
1992
1993
Jan-July 1994
Annual Sales
Cumulative Sales

Figure 19

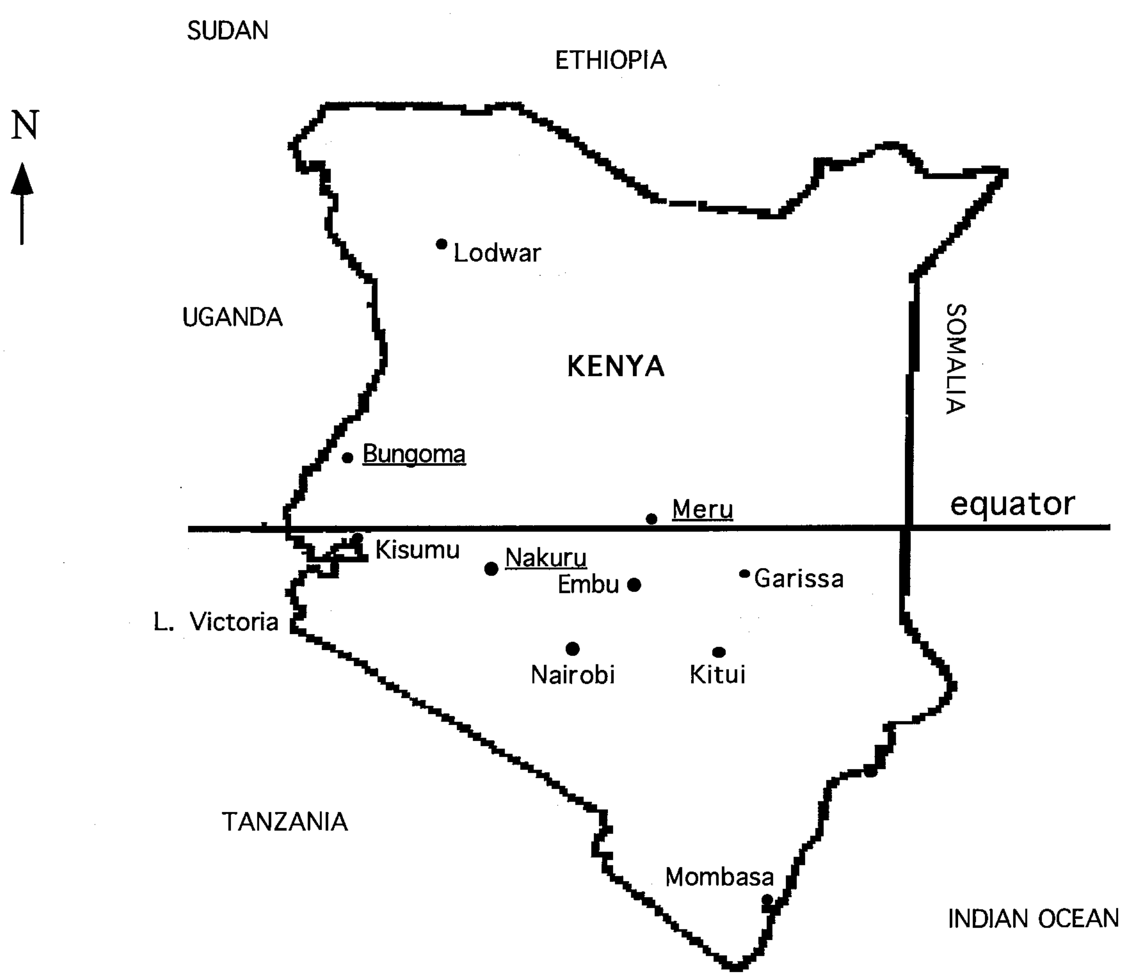


Figure 20: Map of Kenya with major towns in the PV survey regions indicated.

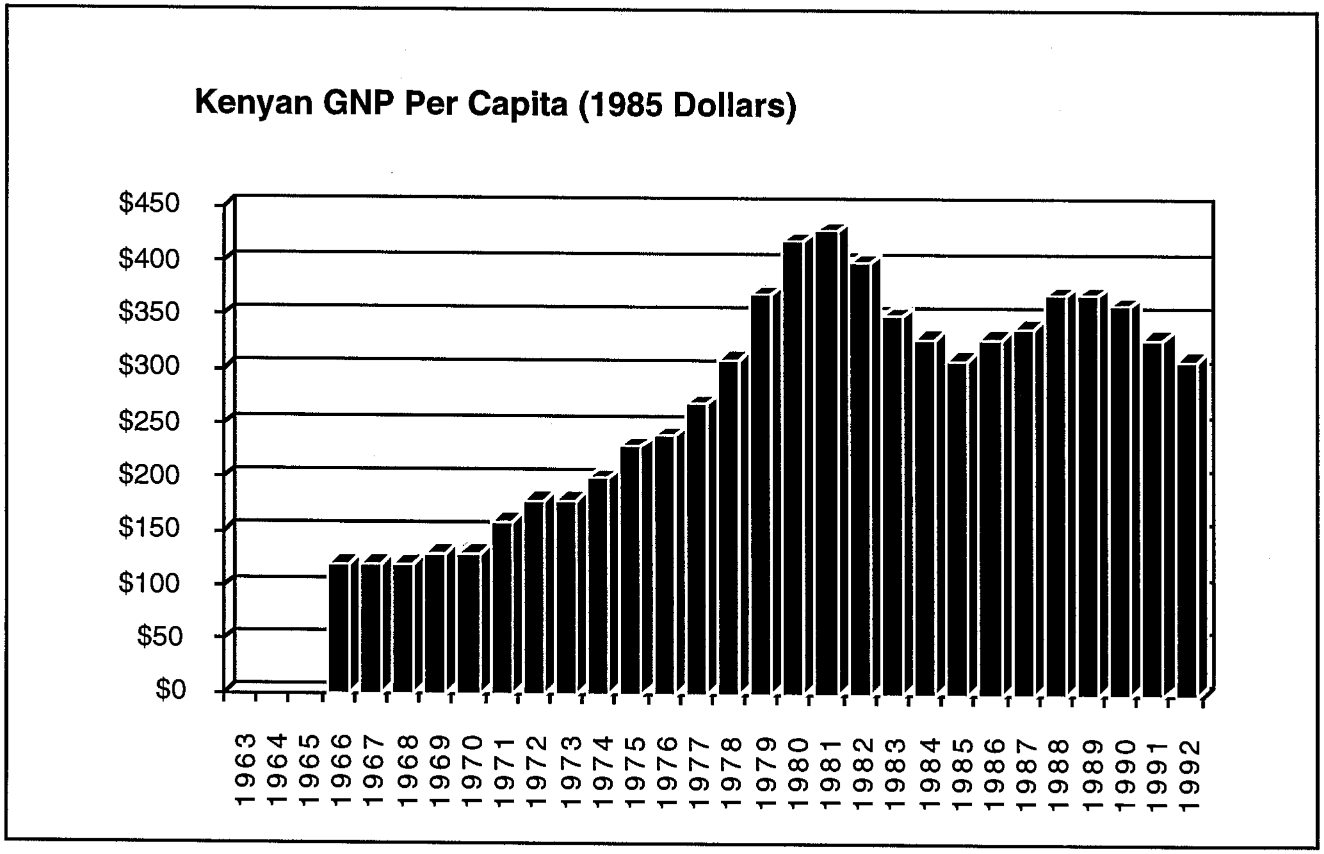

Kenyan GNP Per Capita (1985 Dollars)
$450
$400
$350
$300
$250
$200
$150
$100
$50
$0
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992

Figure 21

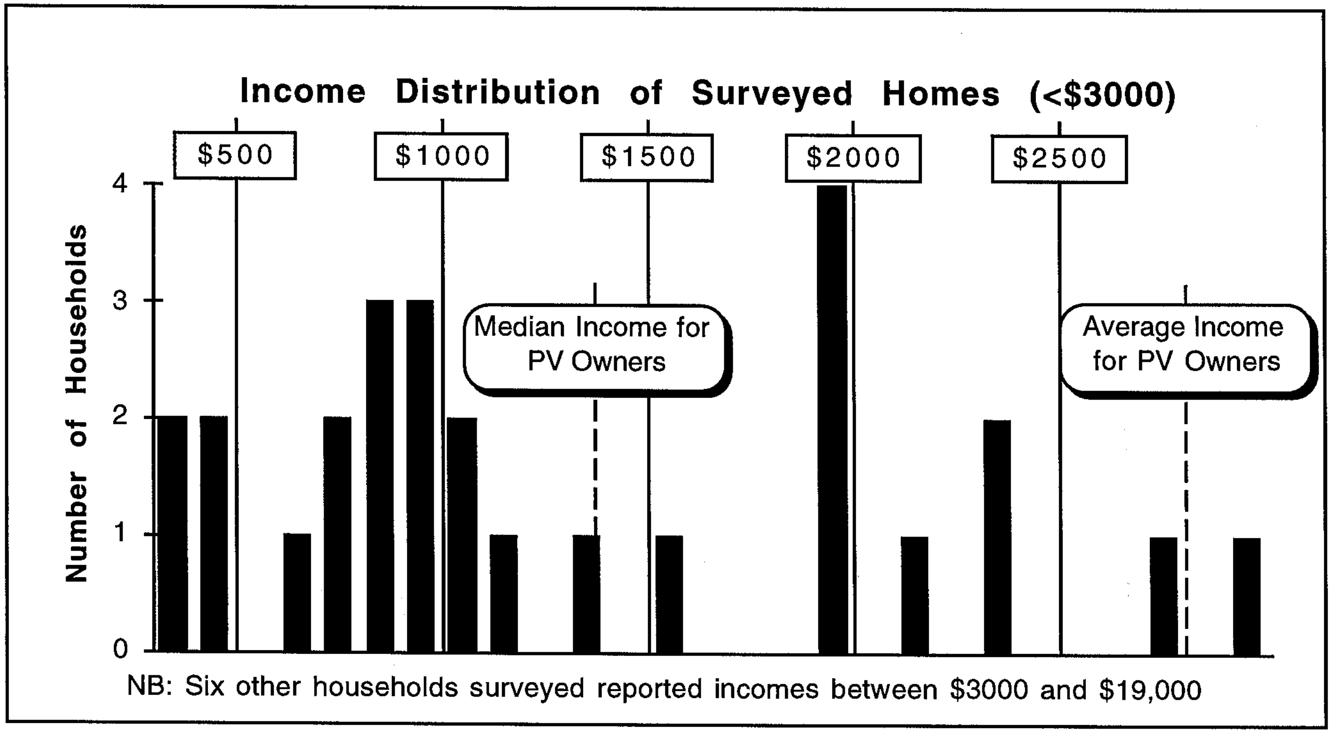

Income Distribution of Surveyed Homes (<$3000)
$500
$1000
$1500
$2000
$2500
Number of Households
0
1
2
3
4
Median Income for PV Owners
Average Income for PV Owners
NB: Six other households surveyed reported incomes between $3000 and $19,000

Figure 22

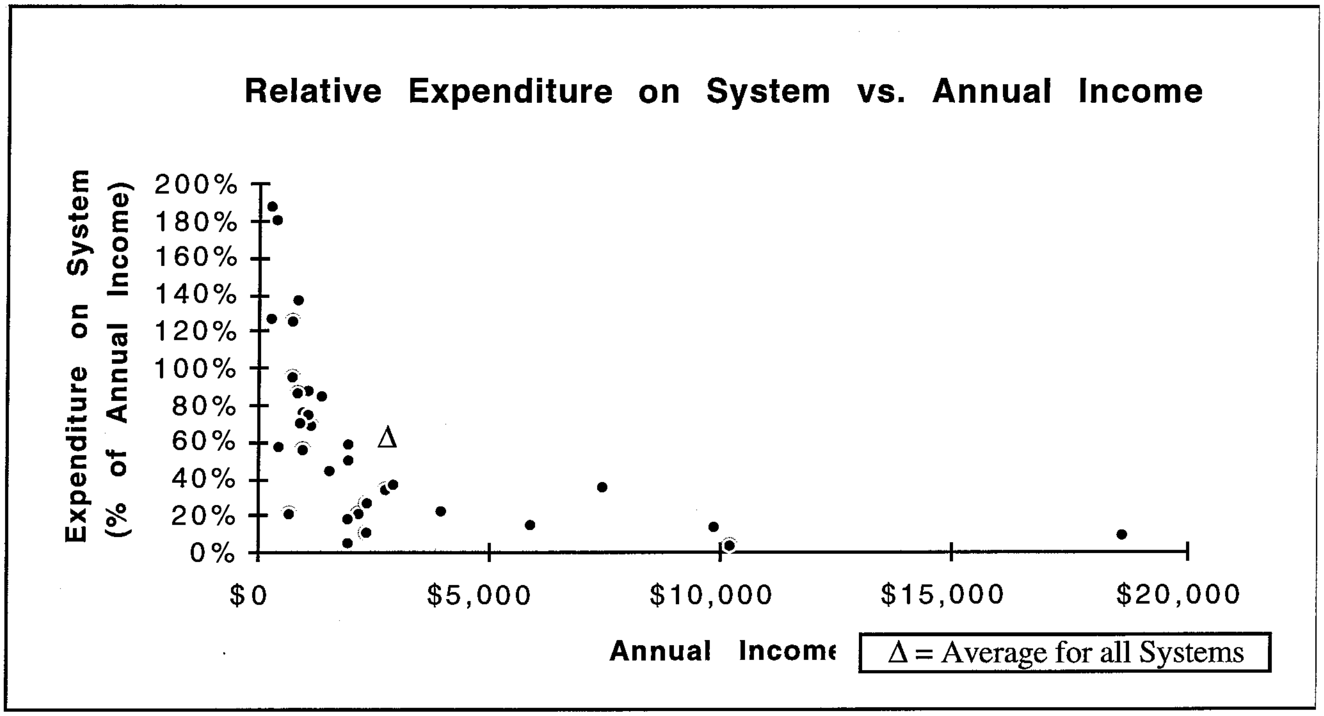

Relative Expenditure on System vs. Annual Income
Expenditure on System (% of Annual Income)
200%
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
$0
$5,000
$10,000
$15,000
$20,000
Annual Income
Δ = Average for all Systems

Figure 23

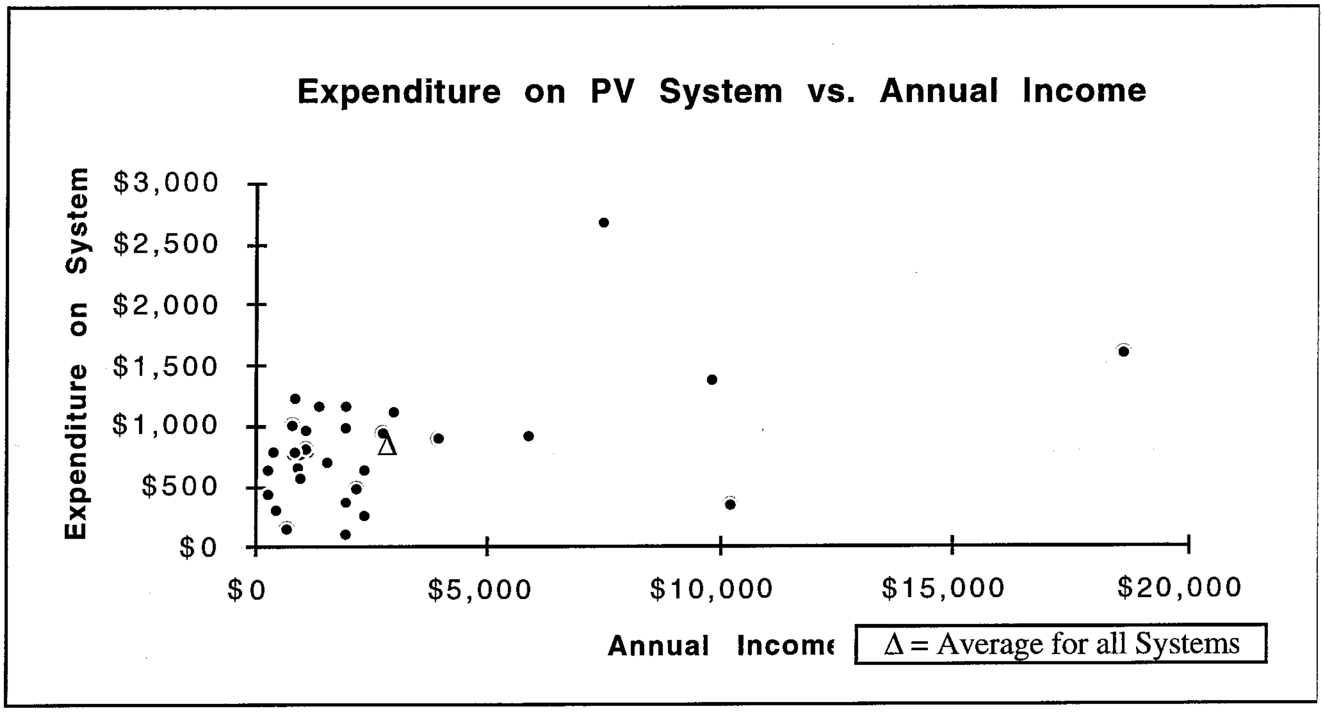

Expenditure on PV System vs. Annual Income
Expenditure on System
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
$0
$5,000
$10,000
$15,000
$20,000
Annual Income
Δ = Average for all Systems

Figure 24

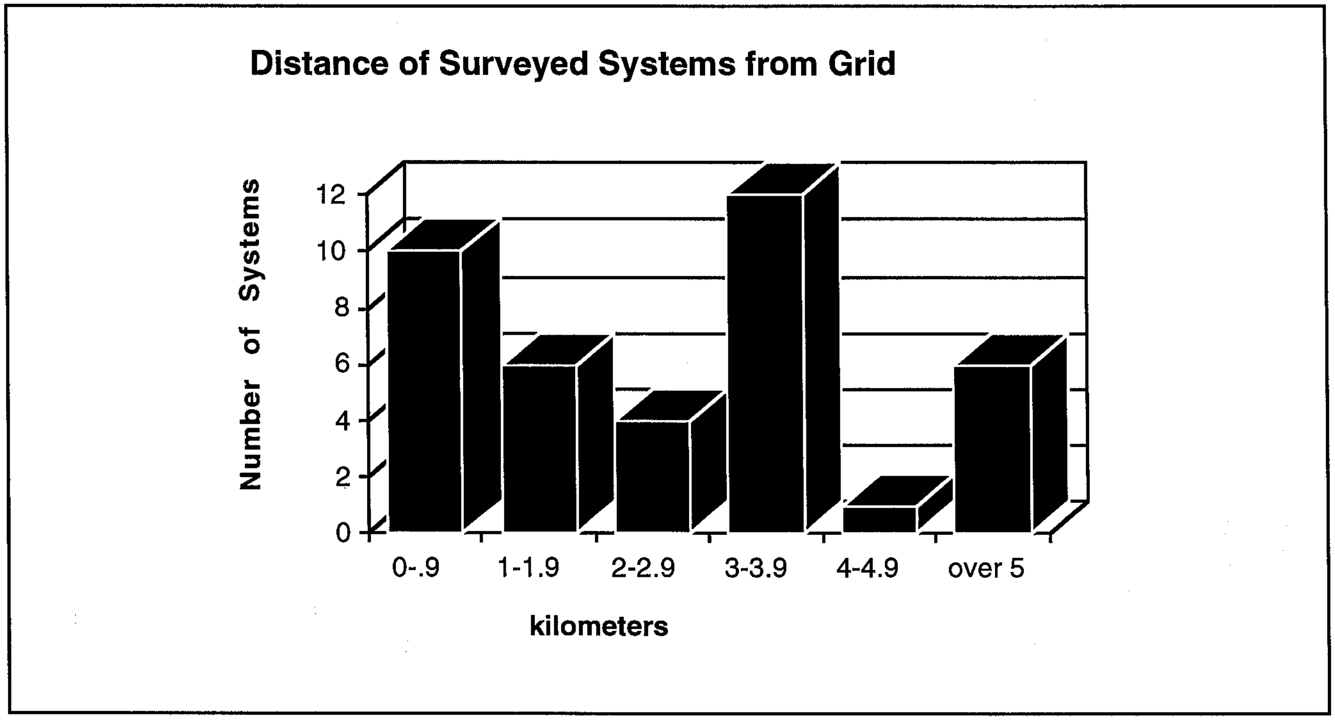
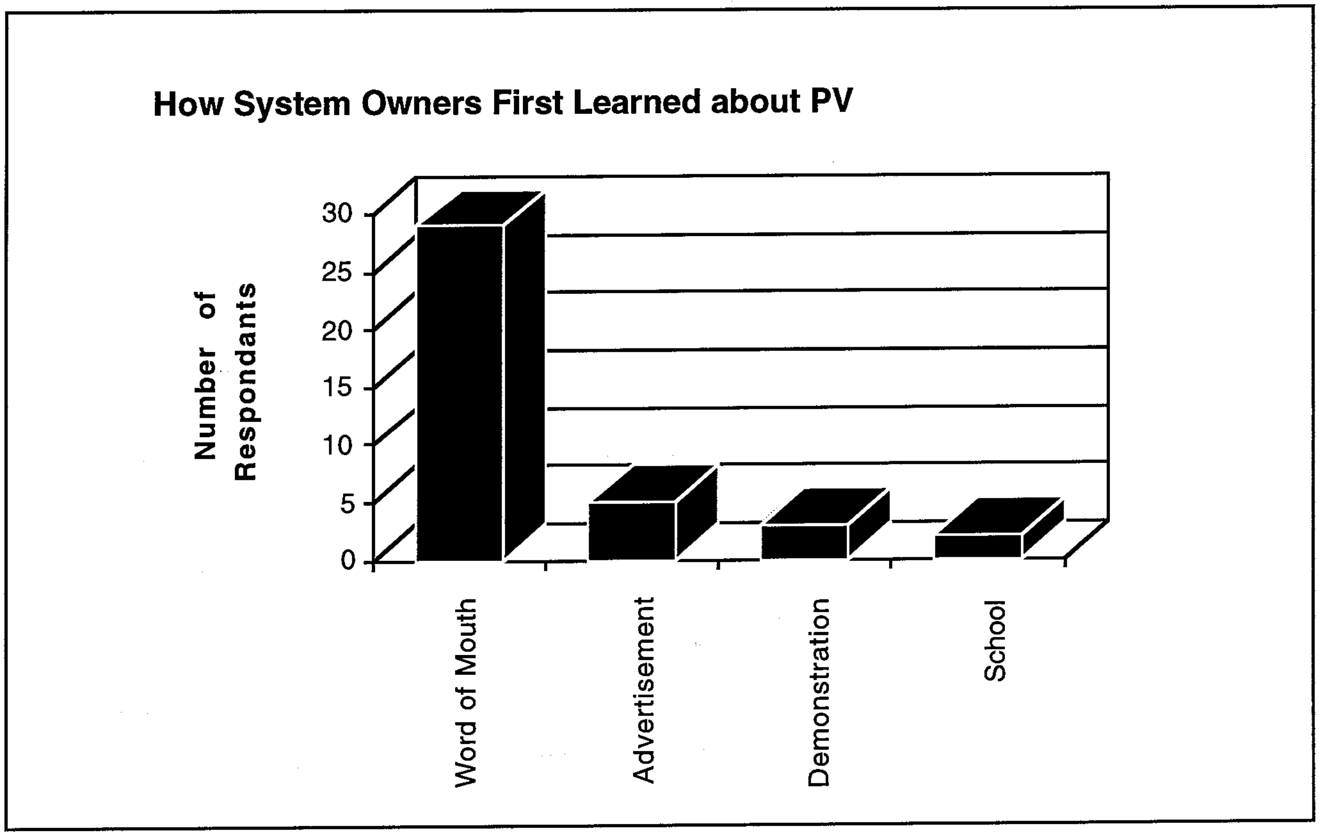

Distance of Surveyed Systems from Grid
Number of Systems
12
10
8
6
4
2
0
0-.9
1-1.9
2-2.9
3-3.9
4-4.9
over 5
kilometers

Figure 25



How System Owners First Learned about PV
Number of Respondants
30
25
20
15
10
5
0
Word of Mouth
Advertisement
Demonstration
School

Figure 26

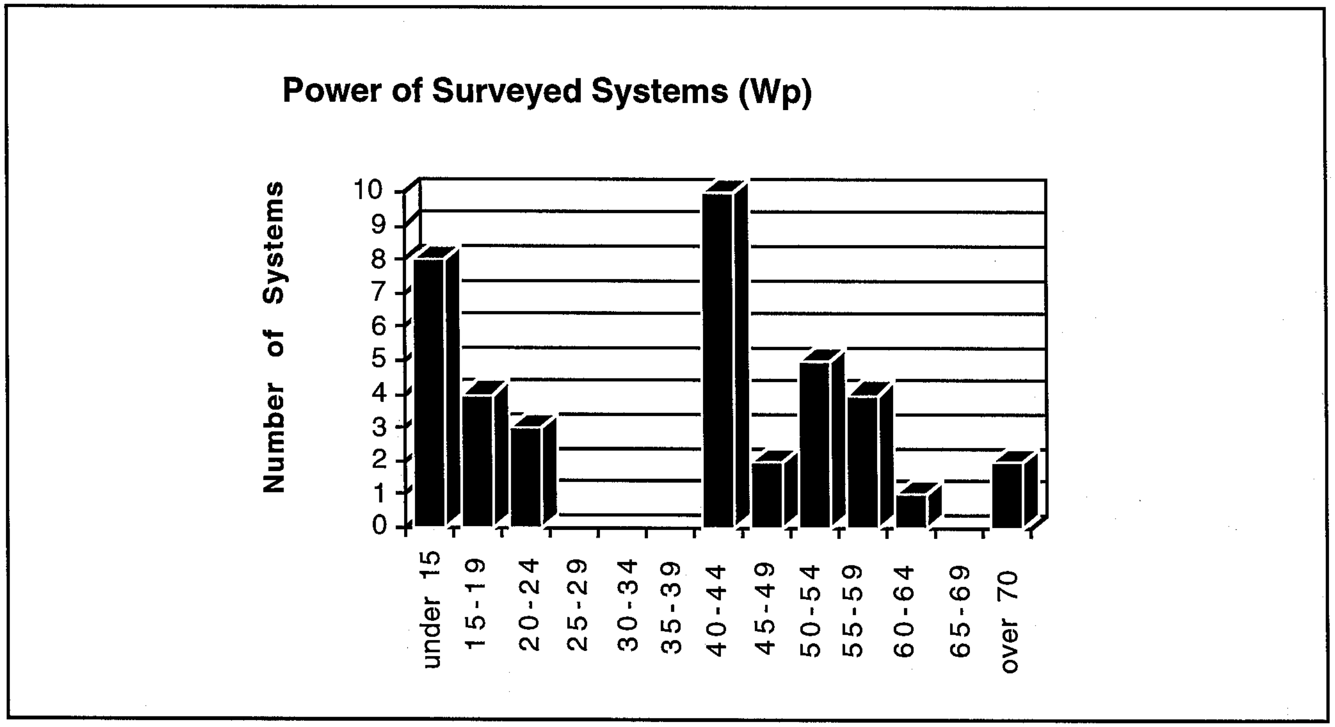

Power of Surveyed Systems (Wp)
Number of Systems
0
1
2
3
4
5
6
7
8
9
10
under 15
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
over 70

Figure 27

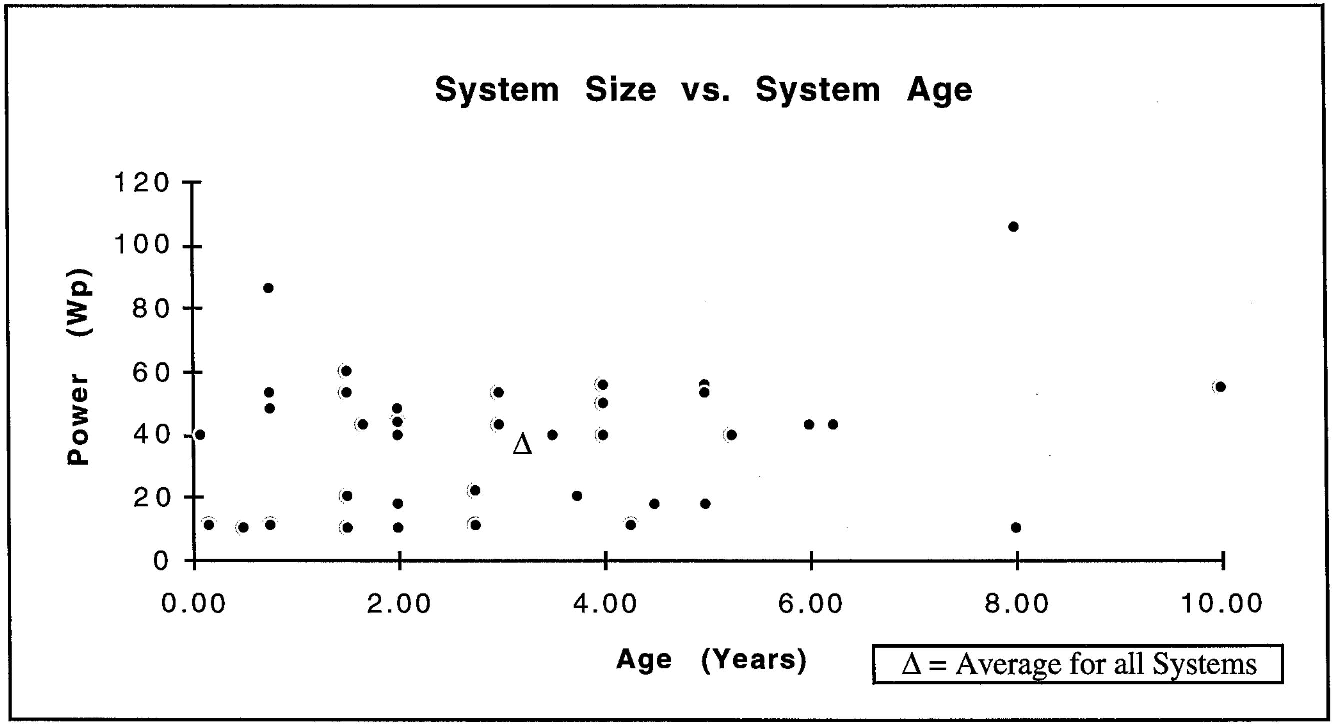

System Size vs. System Age
Power (Wp)
120
100
80
60
40
20
0
0.00
2.00
4.00
6.00
8.00
10.00
Age (Years)
Δ = Average for all Systems

Figure 28

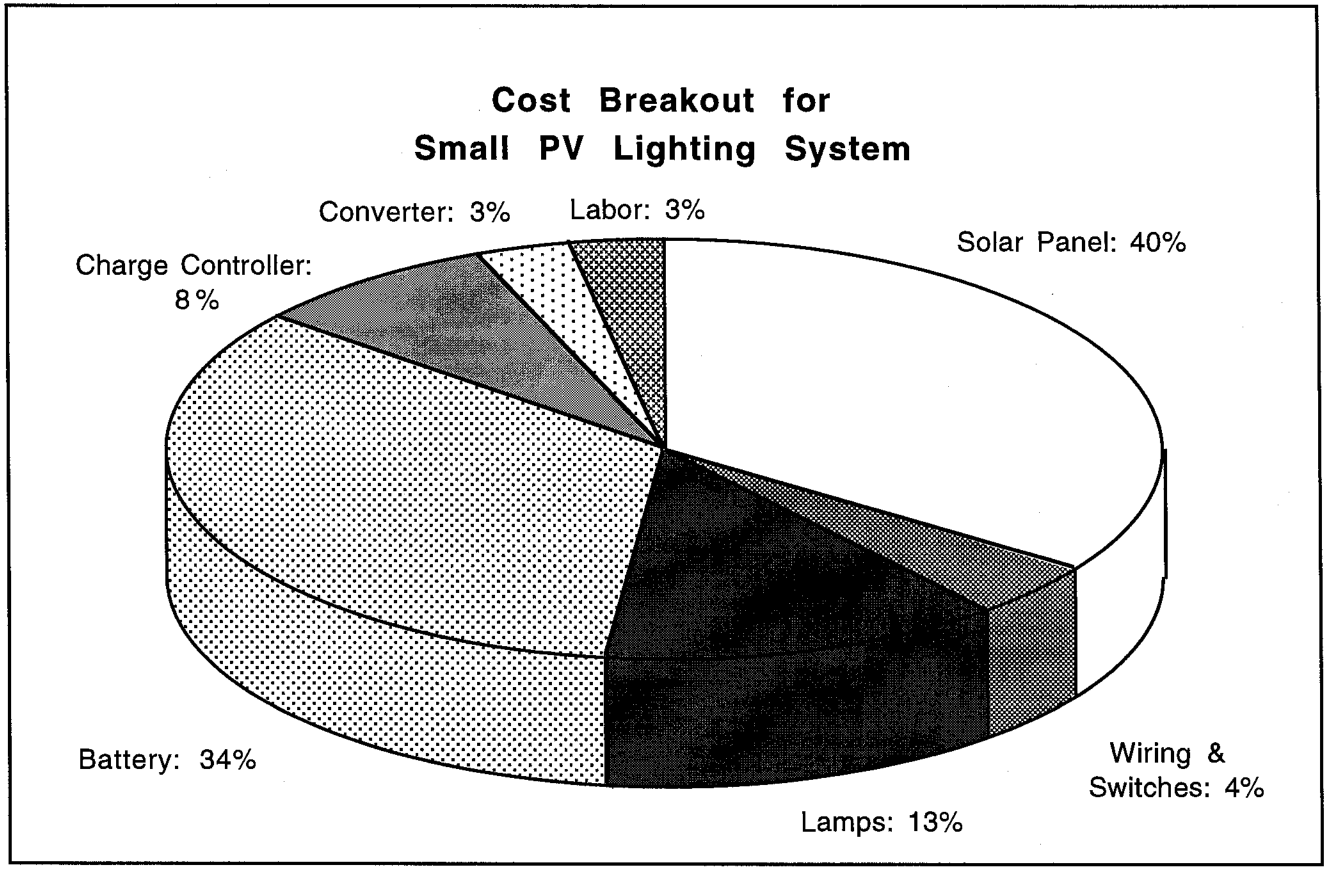

Cost Breakout for
Small PV Lighting System
Converter: 3%
Labor: 3%
Solar Panel: 40%
Charge Controller:
8%
Battery: 34%
Wiring &
Switches: 4%
Lamps: 13%

Figure 29

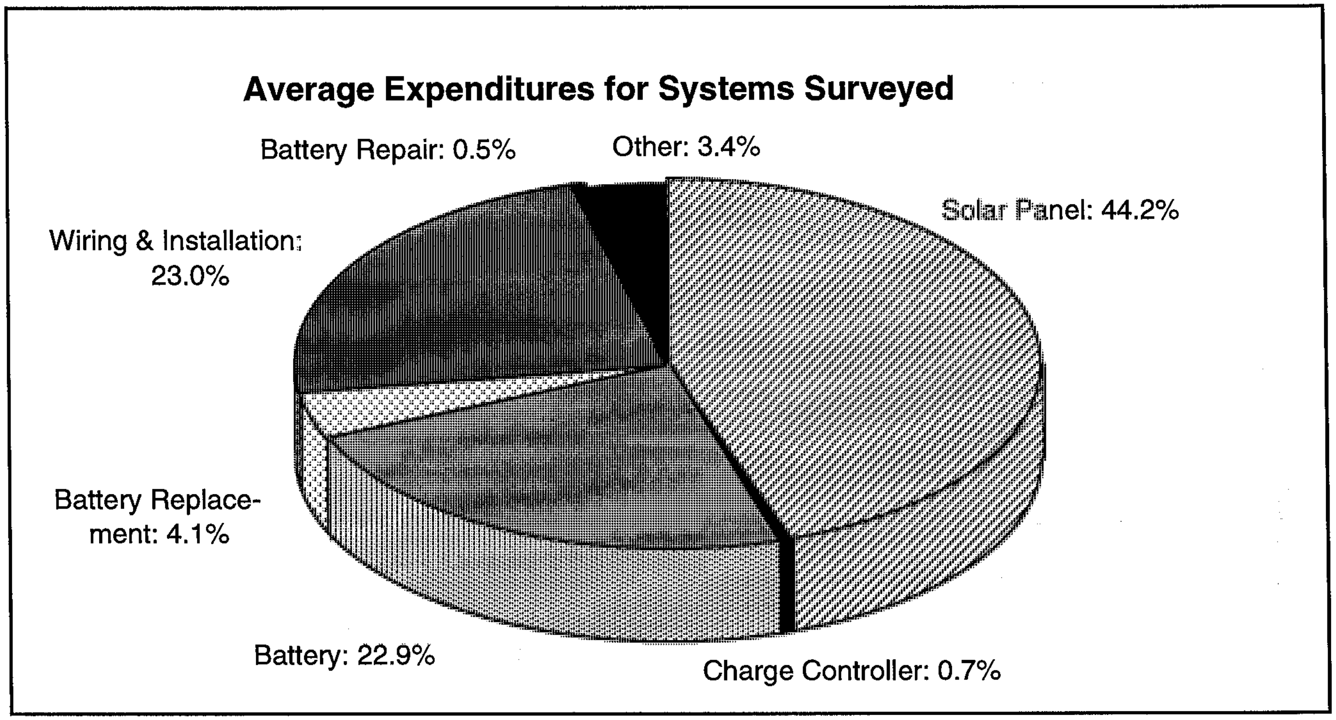

Average Expenditures for Systems Surveyed
Battery Repair: 0.5%
Other: 3.4%
Solar Panel: 44.2%
Wiring & Installation:
23.0%
Battery Replace-
ment: 4.1%
Battery: 22.9%
Charge Controller: 0.7%

Figure 30

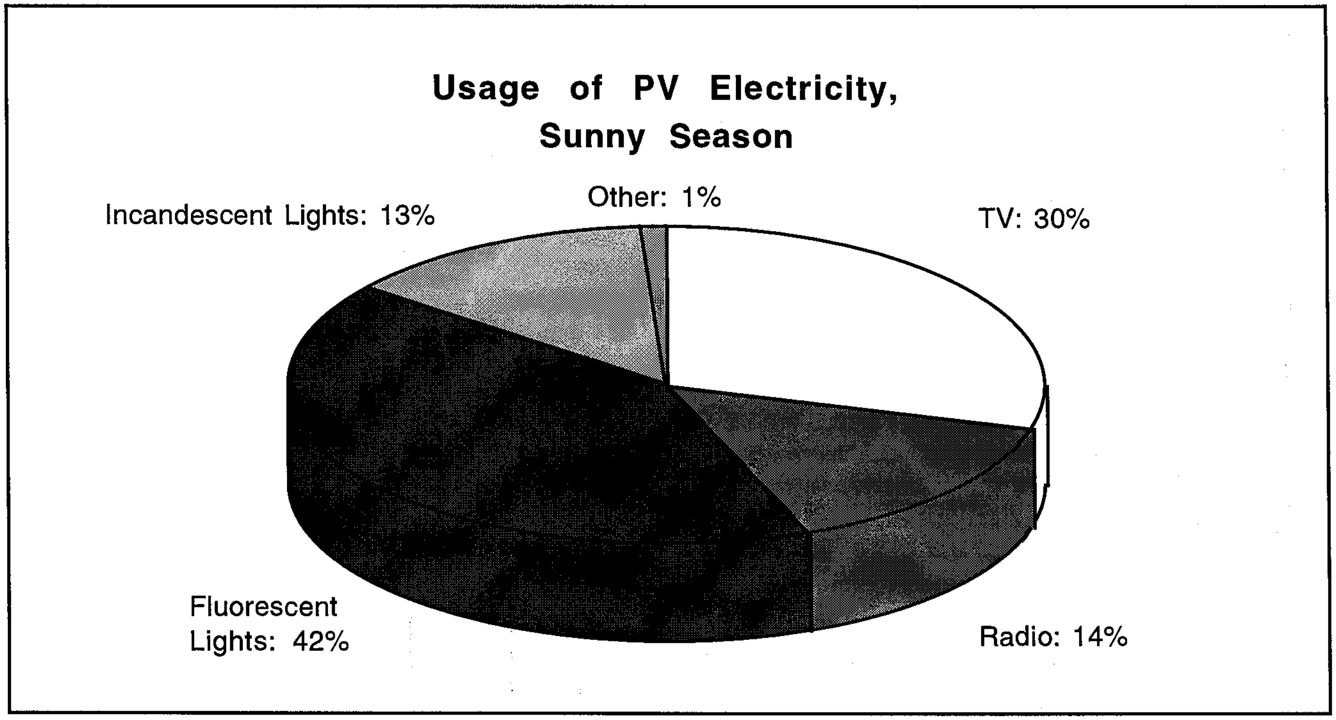
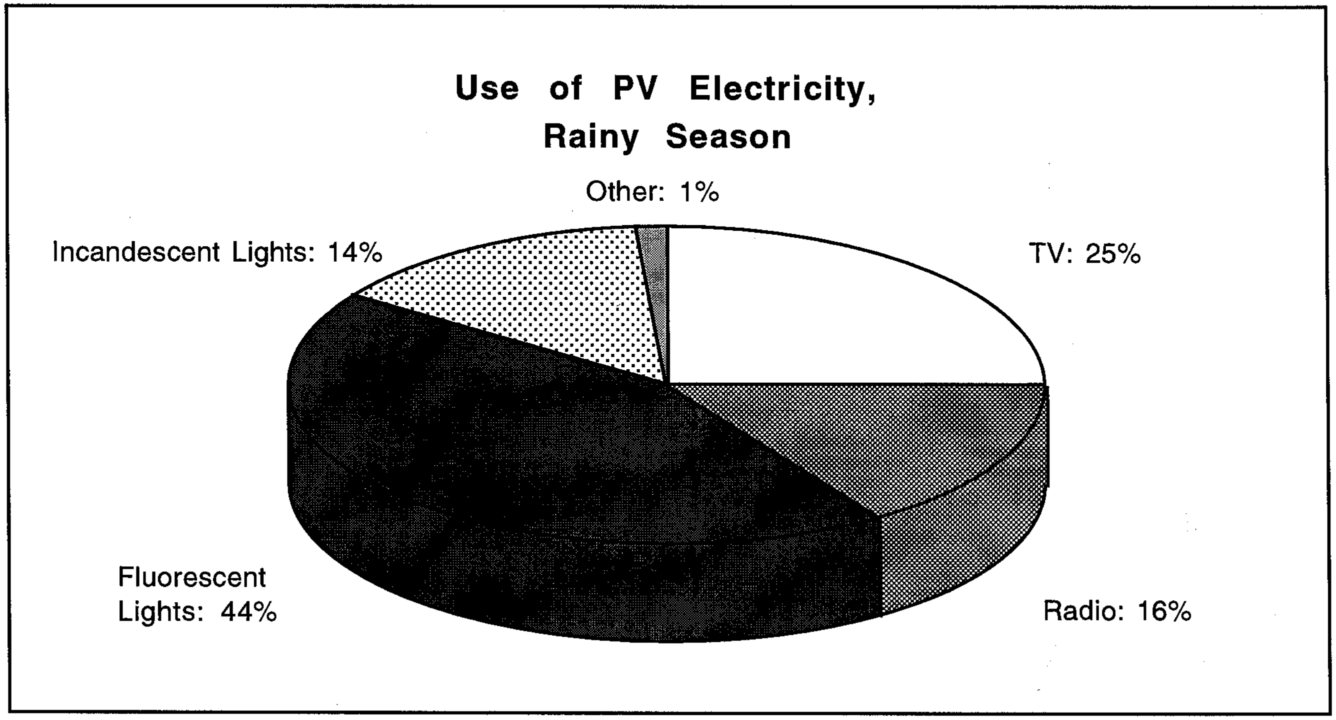
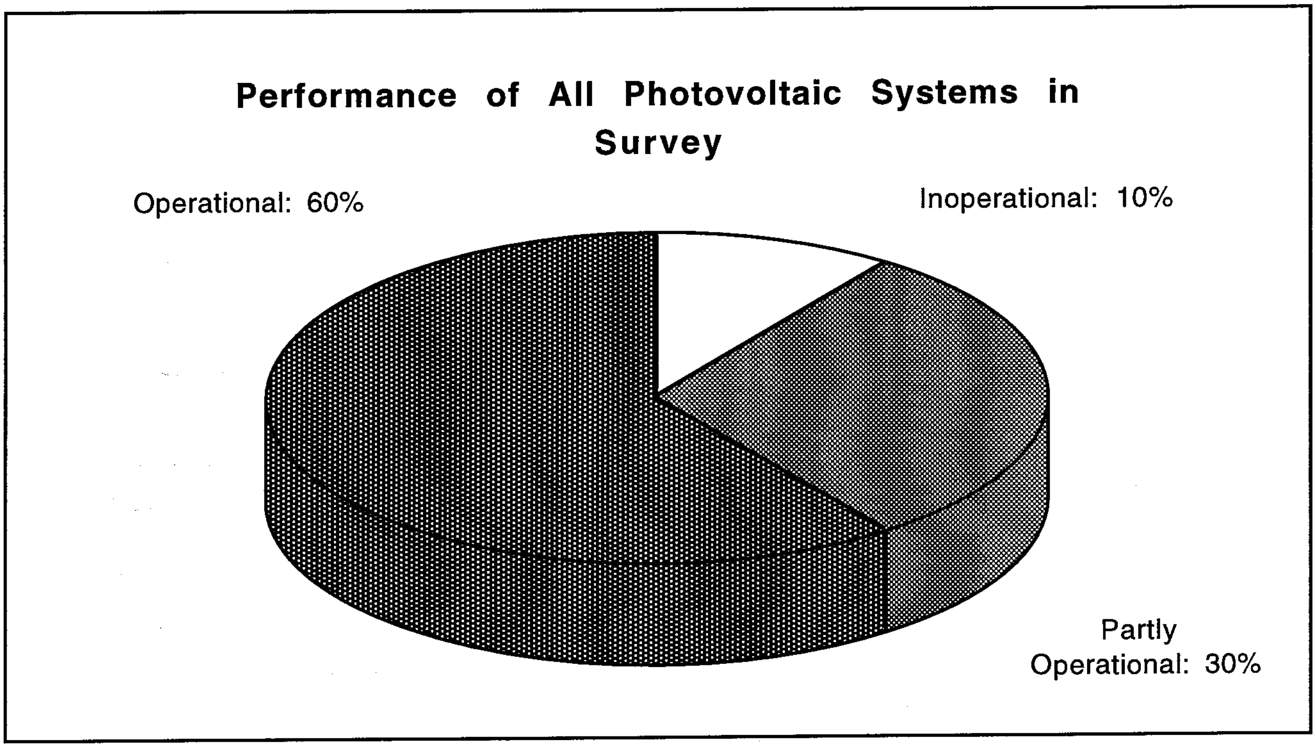

Usage of PV Electricity,
Sunny Season
Other: 1%
TV: 30%
Incandescent Lights: 13%
Fluorescent
Lights: 42%
Radio: 14%

Figure 31



Use of PV Electricity,
Rainy Season
Other: 1%
Incandescent Lights: 14%
TV: 25%
Fluorescent Lights: 44%
Radio: 16%

Figure 32



Performance of All Photovoltaic Systems in Survey
Operational: 60%
Inoperational: 10%
Partly Operational: 30%

Figure 33

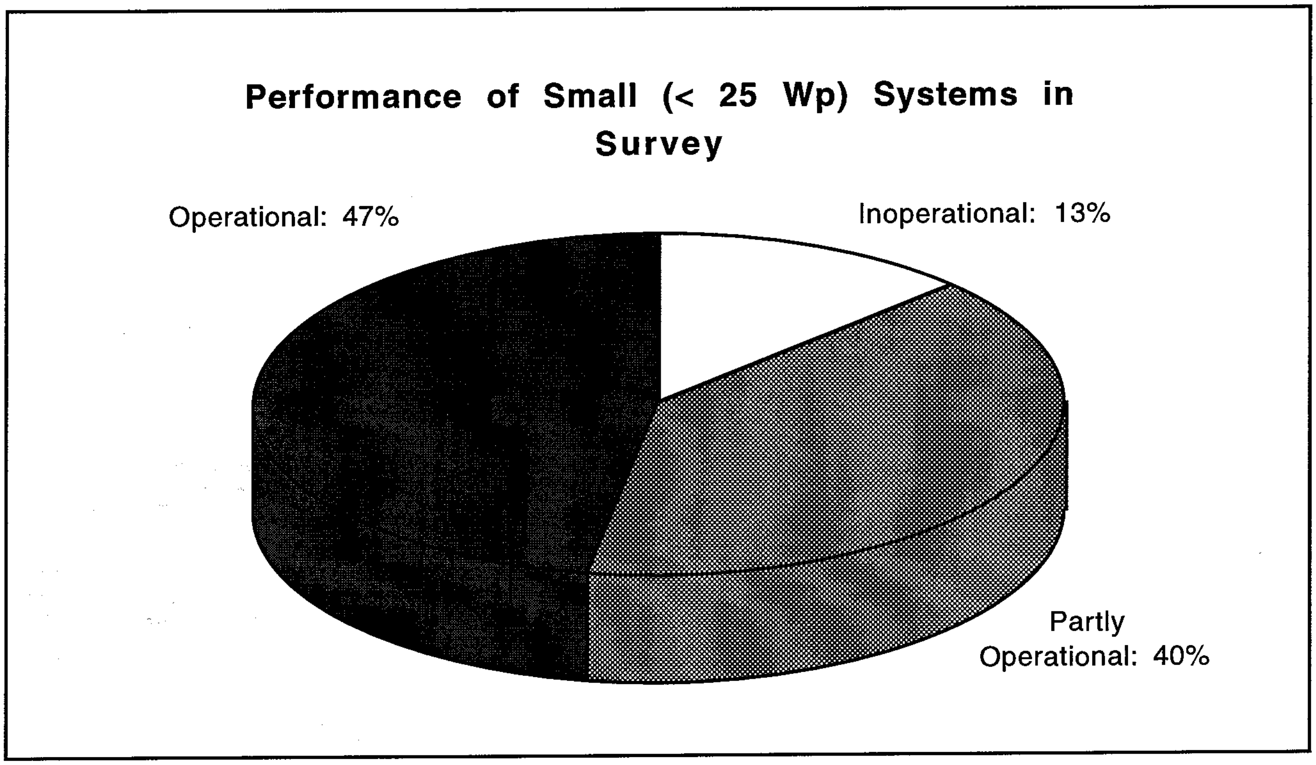

Performance of Small (< 25 Wp) Systems in Survey
Operational: 47%
Inoperational: 13%
Partly Operational: 40%

Figure 34

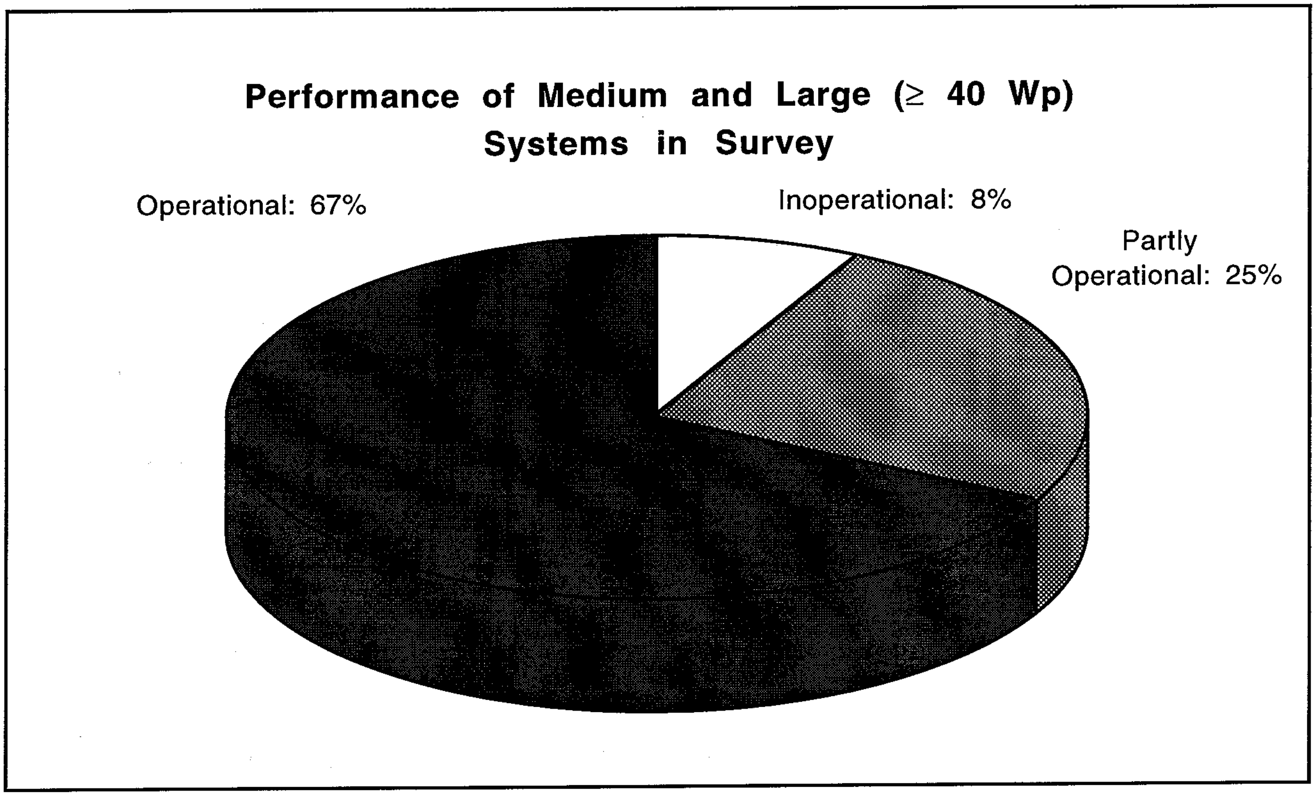

Performance of Medium and Large (≥ 40 Wp) Systems in Survey
Operational: 67%
Inoperational: 8%
Partly Operational: 25%

Figure 35

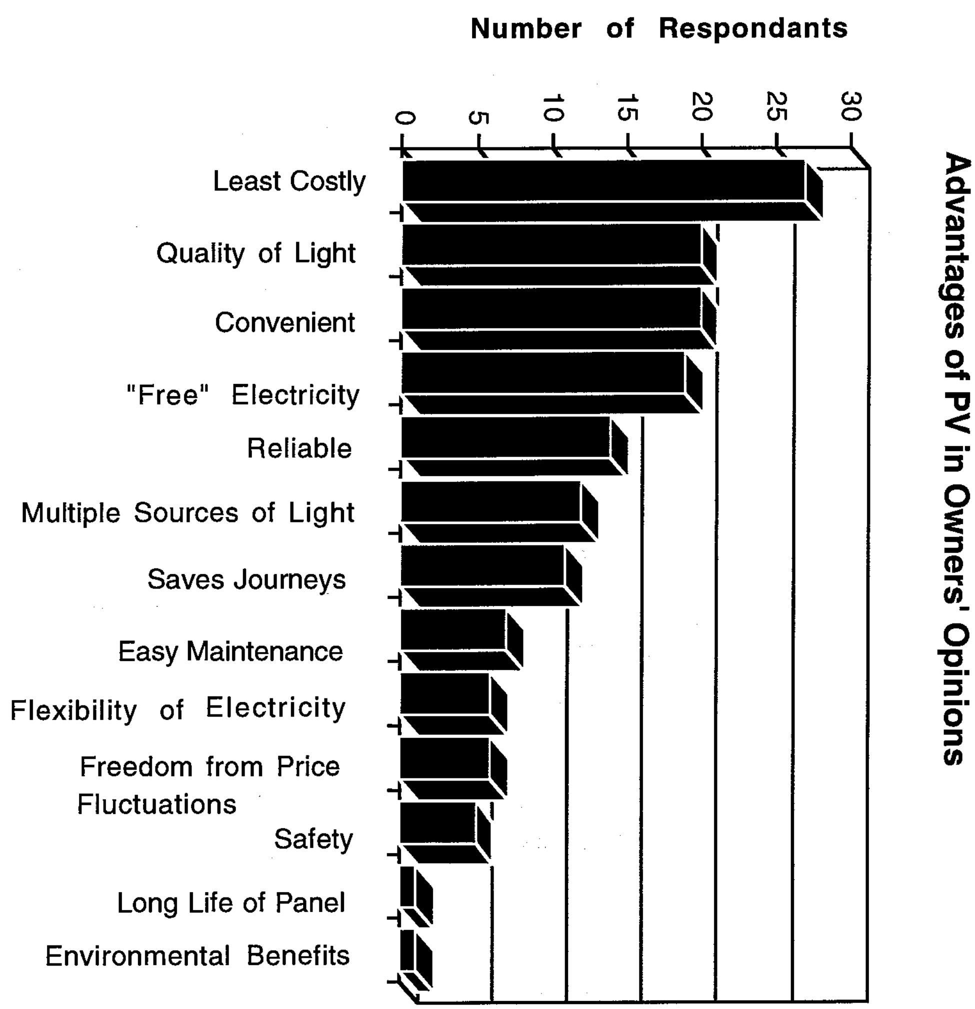

Advantages of PV in Owners' Opinions
Number of Respondants
0
5
10
15
20
25
30
Least Costly
Quality of Light
Convenient
"Free" Electricity
Reliable
Multiple Sources of Light
Saves Journeys
Easy Maintenance
Flexibility of Electricity
Freedom from Price Fluctuations
Safety
Long Life of Panel
Environmental Benefits

Figure 36

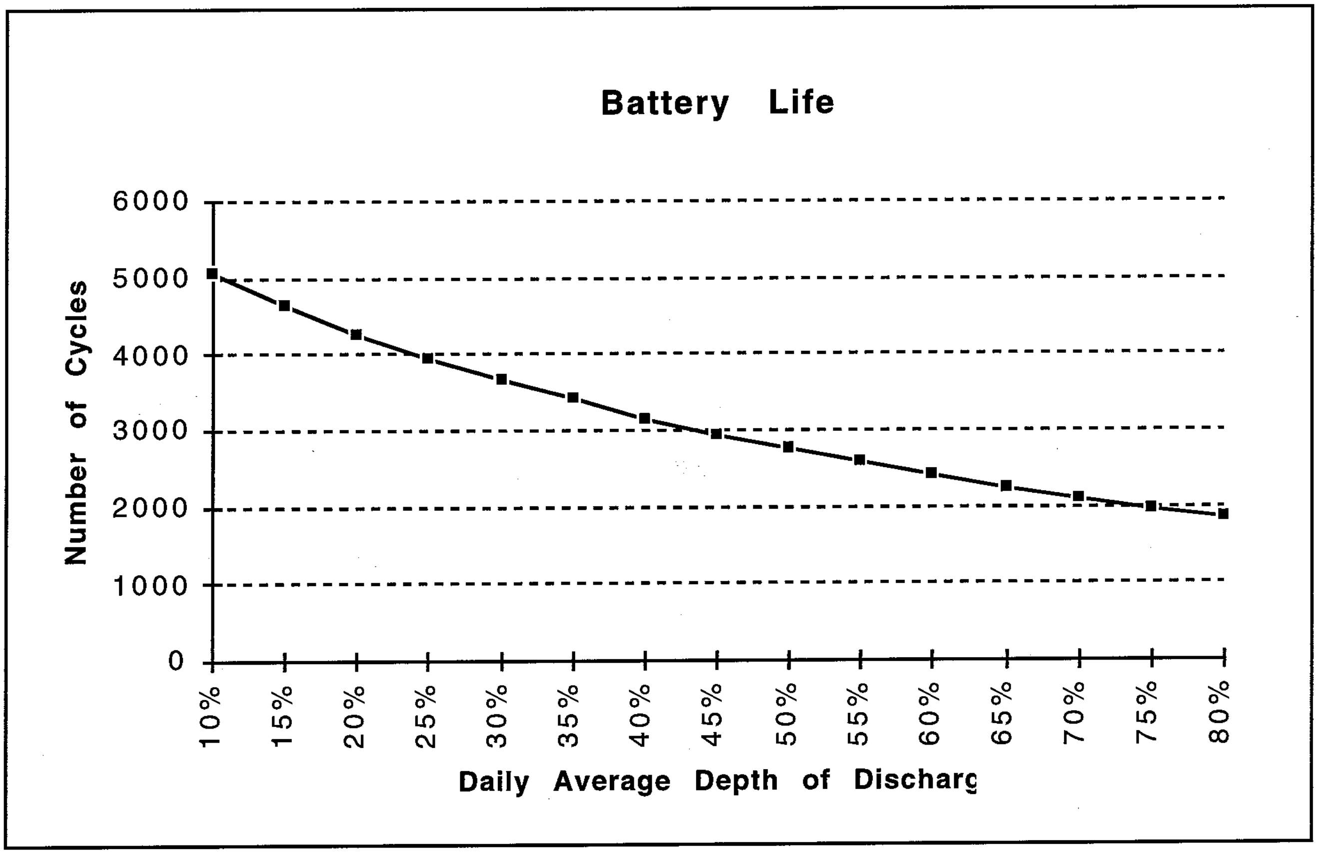

Battery Life
6000
5000
4000
3000
2000
1000
0
Number of Cycles
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
Daily Average Depth of Discharg

Figure 37

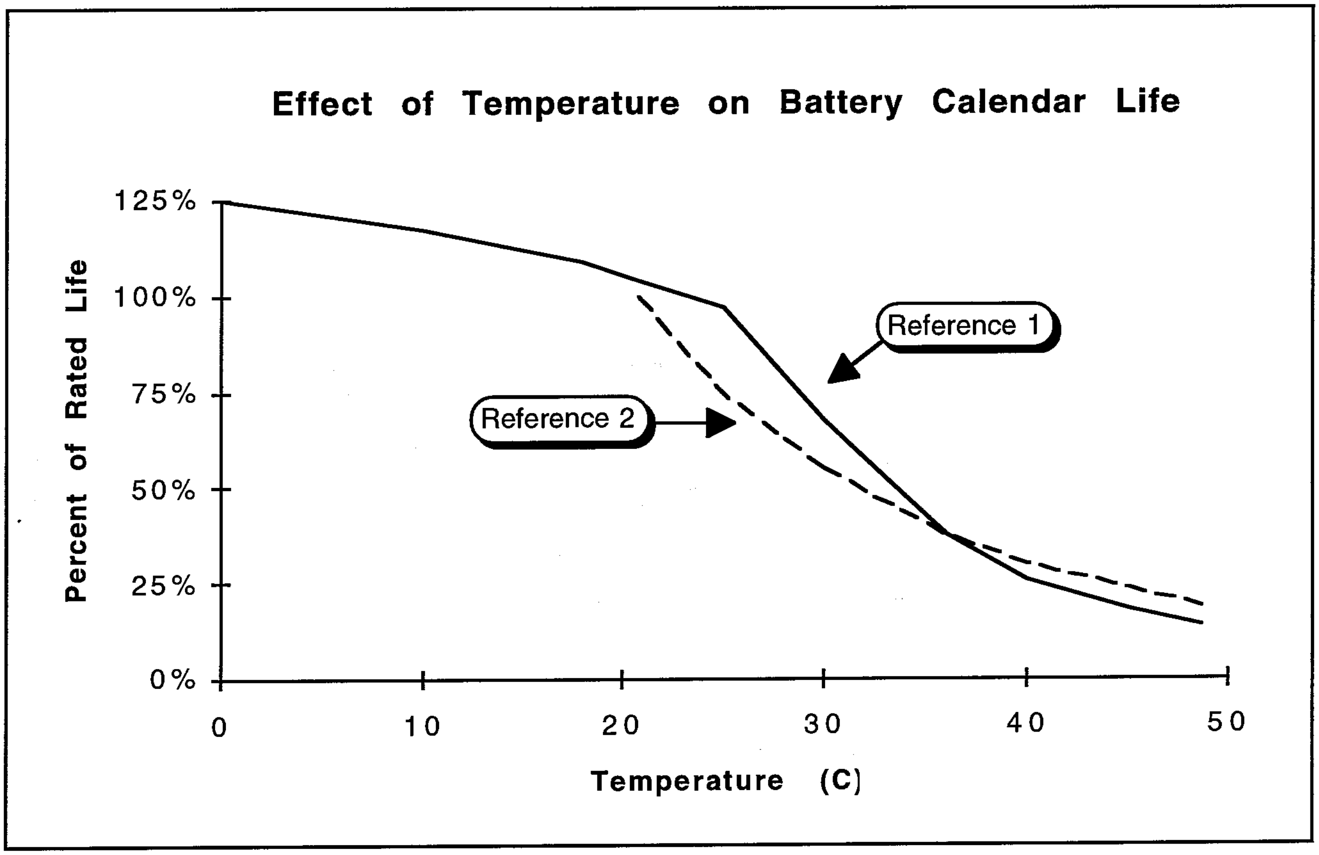

Effect of Temperature on Battery Calendar Life
Percent of Rated Life
125%
100%
75%
50%
25%
0%
0
10
20
30
40
50
Temperature (C)
Reference 1
Reference 2

Figure 38

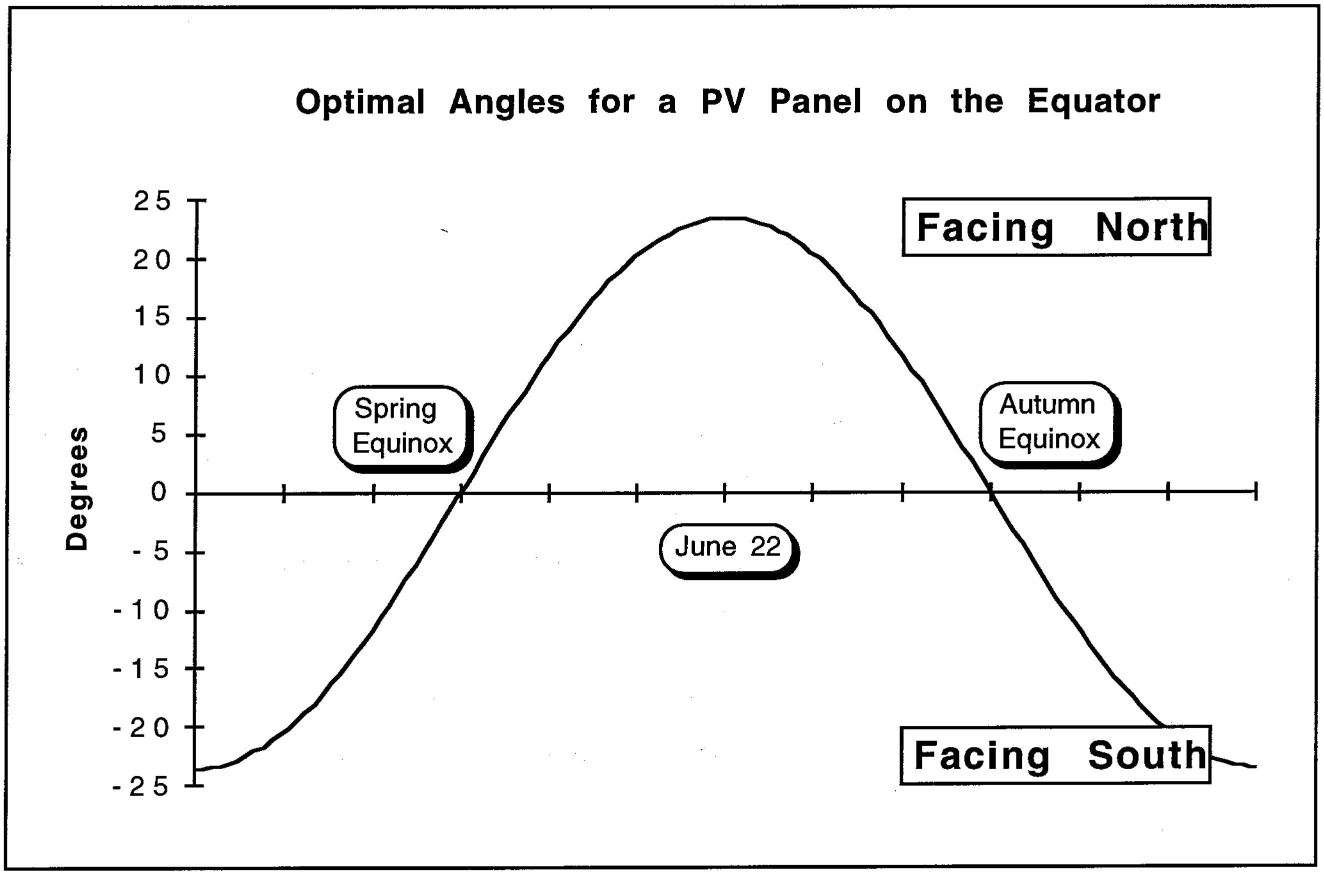

Optimal Angles for a PV Panel on the Equator
25
20
15
10
5
0
-5
-10
-15
-20
-25
Degrees
Facing North
Spring Equinox
Autumn Equinox
June 22
Facing South

Figure 39

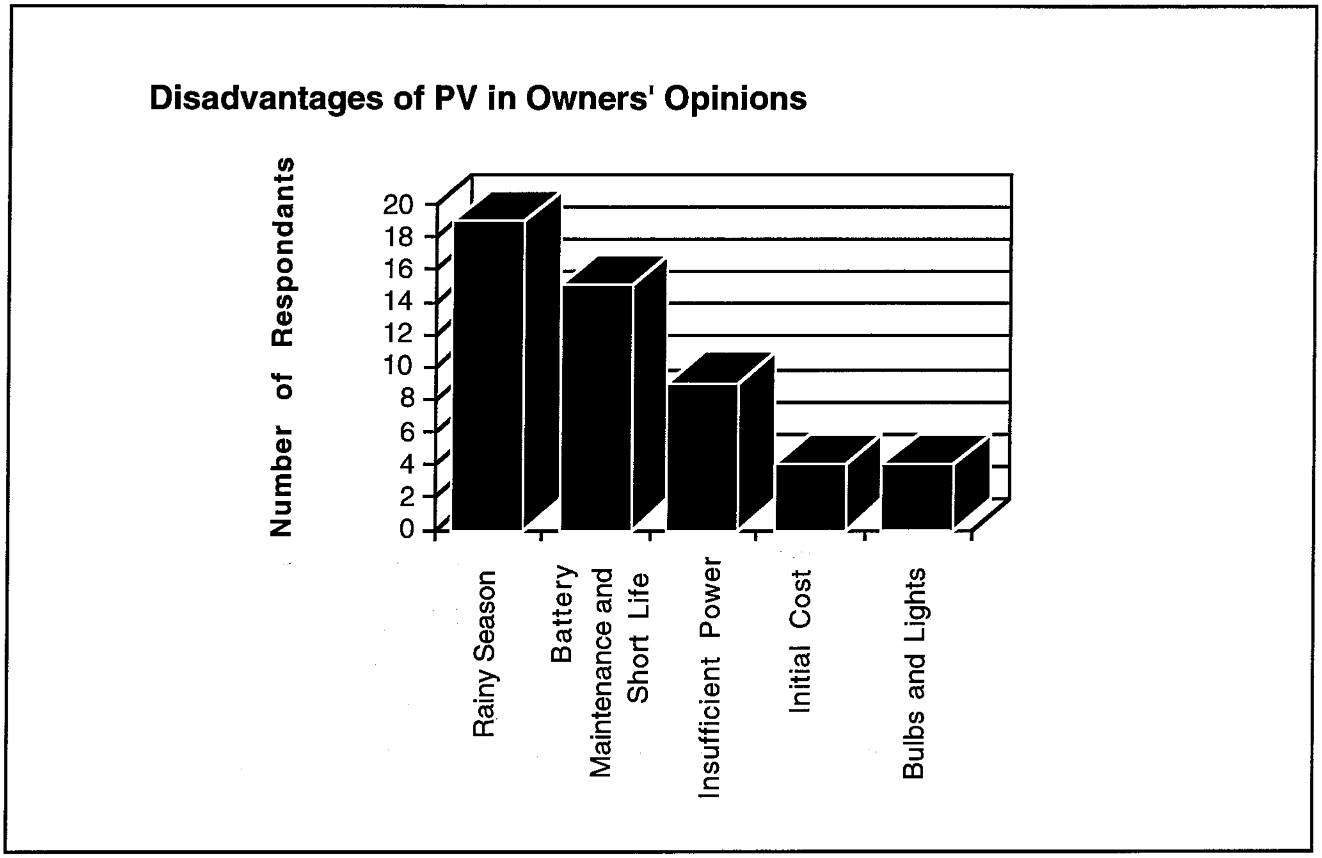

Disadvantages of PV in Owners' Opinions
Number of Respondants
20
18
16
14
12
10
8
6
4
2
0
Rainy Season
Battery Maintenance and Short Life
Insufficient Power
Initial Cost
Bulbs and Lights

Figure 40

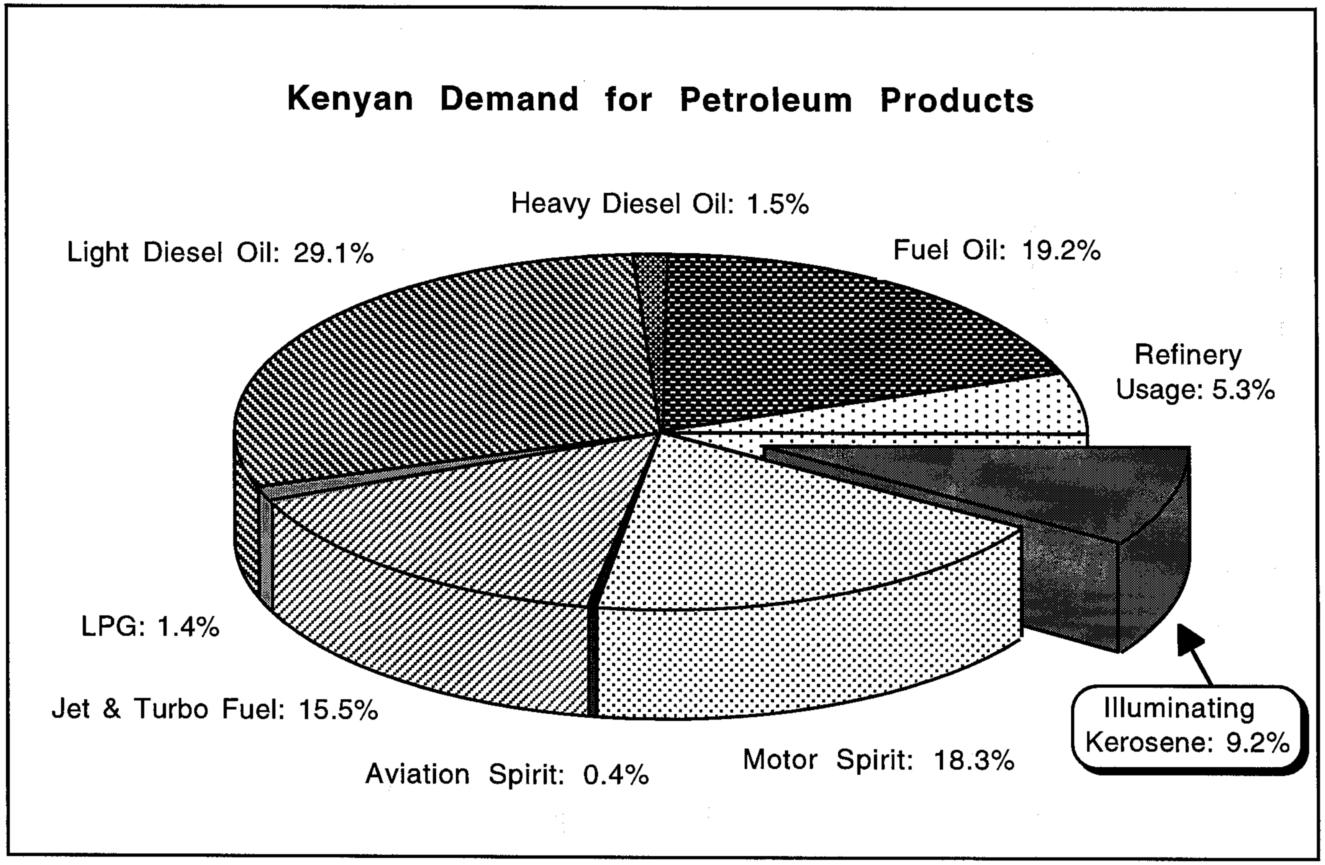

Kenyan Demand for Petroleum Products
Heavy Diesel Oil: 1.5%
Light Diesel Oil: 29.1%
Fuel Oil: 19.2%
Refinery Usage: 5.3%
LPG: 1.4%
Jet & Turbo Fuel: 15.5%
Aviation Spirit: 0.4%
Motor Spirit: 18.3%
Illuminating Kerosene: 9.2%

Figure 41

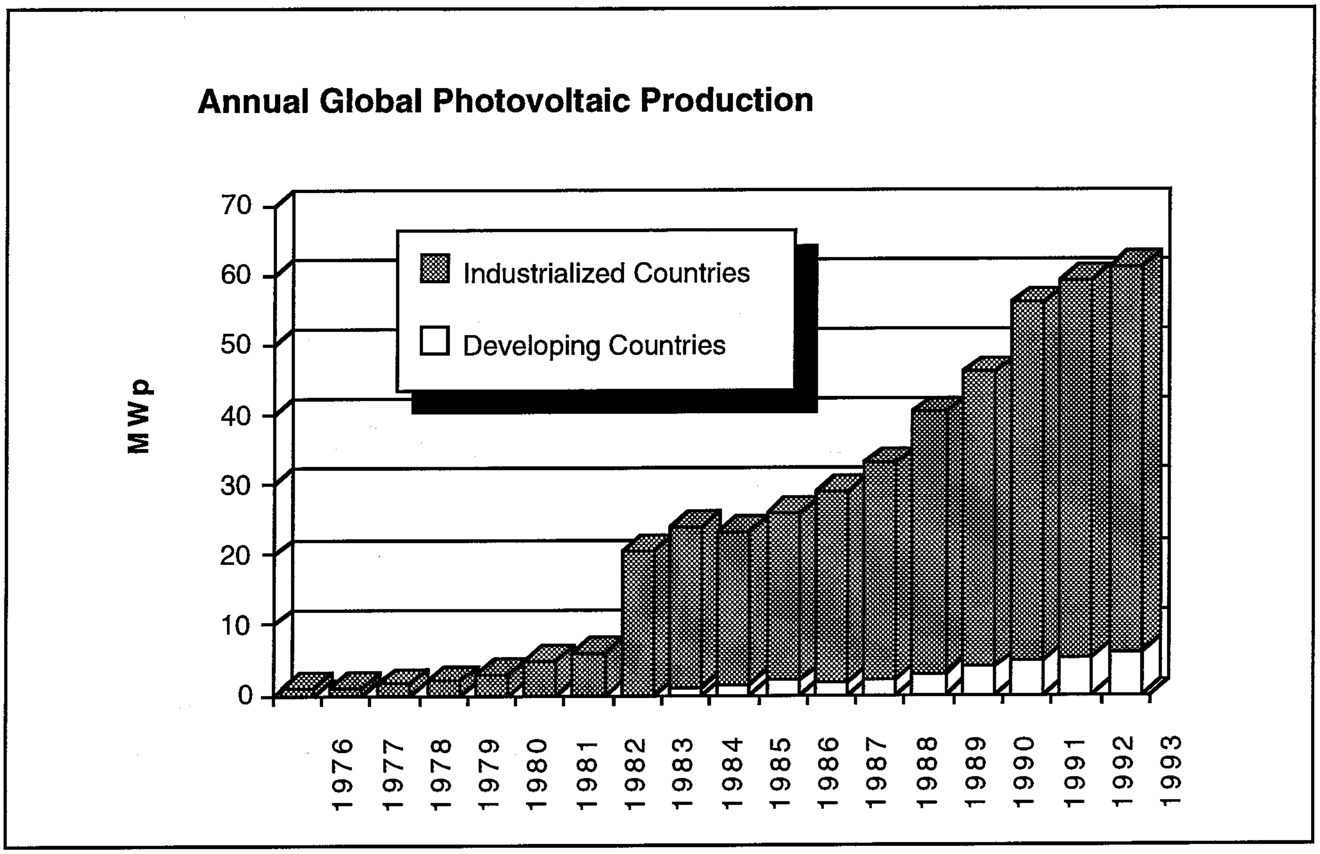

Annual Global Photovoltaic Production
MWp
70
60
50
40
30
20
10
0
Industrialized Countries
Developing Countries
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993

Figure 42

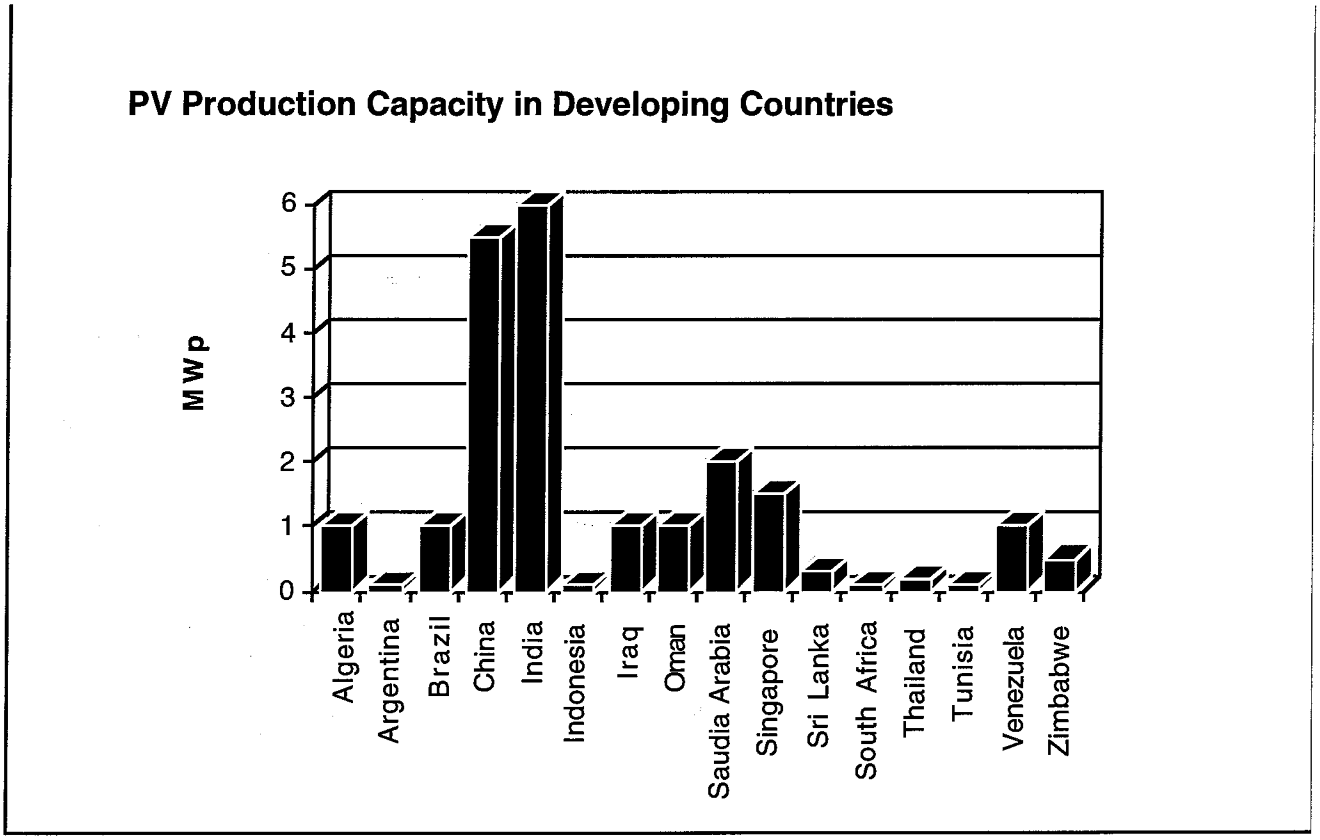

PV Production Capacity in Developing Countries
M W p
6
5
4
3
2
1
0
Algeria
Argentina
Brazil
China
India
Indonesia
Iraq
Oman
Saudia Arabia
Singapore
Sri Lanka
South Africa
Thailand
Tunisia
Venezuela
Zimbabwe

Figure 43